



CHALMERS

The Mechanical Engineer of the Future

The development of the five year Mechanical engineering
programme at Chalmers University of Technology

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Abstract

This strategy project aims to serve as the foundation for the future strategic development of the Mechanical engineering programme (Master of Engineering) at Chalmers University of Technology (Chalmers). The goal is to be one of the top Mechanical engineering programmes in Europe. The project has been led during 2014 by two students attending programme. The programme consists of a Bachelor cycle and a Master's cycle. An action research based approach has been used, and the data collection has included both quantitative and qualitative methods. Data collection aimed to gather the different stakeholders' views of the future of Mechanical engineering education, and to learn from other programmes and universities. The stakeholders have been defined as: Academia (universities in general, and Chalmers in particular), students and alumni from the five year Mechanical engineering programme, industry, and society. The global outlook has focused on universities within Europe and the USA, and has included site visits. Data has been analysed continuously and summarised into five challenges. The challenges for the mechanical engineering programme have been identified as: recruitment, arenas for meetings between industry-university-student, skills of the engineer, internationalisation, and uncertainty. These have been further discussed and evolved into recommendations for the Mechanical engineering programme.

The first recommendation, connected to the challenge 'uncertainty' is vital for a holistic long term development of the programme, and it states that *The Mechanical engineering programme has to agree on what should characterise a Master of Science in Mechanical engineering, i.e. the combined Bachelor and Master's cycles, at Chalmers.* Without this foundation it will be exceedingly difficult to organise further developments. Other general recommendations for the programme include mapping and defining what is already being done in the programme, developing it and then improving the way that the strengths of the programme are exhibited both internally and externally.

Table of Content

- Abstract..... ii
- 1 Introduction 2
 - 1.1 Context - Mechanical engineering at Chalmers 2
 - 1.2 Background..... 3
 - 1.3 Aim..... 4
 - 1.4 Limitations and Scope 4
- 2 Method 4
 - 2.1 The stakeholders..... 5
 - 2.1.1 Chalmers..... 5
 - 2.1.2 Students, and alumni..... 6
 - 2.1.3 Industry 6
 - 2.1.4 Society 7
 - 2.2 Global outlook 7
 - 2.3 The analysis 9
- 3 Summary of data collection 9
 - 3.1 The study 9
 - 3.2 Related studies 13
- 4 Challenges 15
 - 4.1 Recruitment..... 15
 - 4.2 Arenas for meetings between industry-university-student..... 15
 - 4.3 Skills of the engineer 15
 - 4.4 Internationalisation 16
 - 4.5 Uncertainty..... 16
 - 4.5.1 Mismatch..... 16
 - 4.5.2 Different needs/interests 16
 - 4.5.3 Marketing 17
 - 4.5.4 Past-Present-Future 17
- 5 Discussion..... 17
- 6 Recommendations 21
 - 6.1 Overall..... 21
 - 6.2 The five year programme 21

| | | |
|-------|-------------------------------|----|
| 6.3 | The Bachelor cycle..... | 24 |
| 6.4 | The Master's programmes..... | 24 |
| 6.5 | The courses | 25 |
| 6.6 | Action plan | 25 |
| 6.6.1 | Overall..... | 25 |
| 6.6.2 | The five year programme | 25 |
| 6.6.3 | The Bachelor cycle..... | 25 |
| 6.6.4 | The Master's programmes..... | 26 |
| 6.6.5 | The teachers | 26 |
| 7 | Impact of the project..... | 26 |
| 8 | Literature references | 27 |

1 Introduction

This strategy project, the Mechanical engineer of the Future, aims to serve as the foundation for the future strategic development of the Mechanical engineering programme at Chalmers University of Technology (Chalmers). This project has been lead by two students at the Mechanical engineering programme at Chalmers in 2014. The students have experience in both operative and strategic levels, in educational questions at Chalmers in general and at the Mechanical engineering programme in particular.

The report starts with an introduction to the project and the current Mechanical engineering programme, and the aim and scope of the project. This is followed up by the method for the project and a summary of the data collection. The data is then summarised in five key challenges for the programme, these are discussed, and followed by the recommendations. For those interested, an appendix will be released where the data is summarised per stakeholder and university, please see <https://chalmersuniversity.box.com/s/il7zosl369yc5d0o9eyl> for further information.

1.1 Context - Mechanical engineering at Chalmers

The Master of Science in mechanical engineering programme is a five year programme divided into two cycles. The first cycle consists of three years of full time studies corresponding to 180 ECTS and ends with the degree of Bachelor of Science. The second cycle is a two years (120 ECTS) Master's programme. After completing both cycles the student is awarded the Swedish degree "Civilingenjör" as well as the degree of Master of Science. This structure is the result of the Bologna process, which included comparable B.Sc and M.Sc degree system (European University Association, u.d.) between 29 countries within Europe. The B.Sc and the M.Sc are academic degrees, while the combined Bachelor and Master's programme is an engineering degree, i.e. Master of Science in Engineering. Chalmers has structured their courses around programmes which means that it is not possible to just apply for and take one course at the university. The academic year at Chalmers consists of two semesters, autumn and spring, which are divided into two study periods of eight weeks and one exam week, nine weeks in total. The academic year of 2014/2015 is the first year to have a study period of nine weeks, before this it was usually eight weeks, and to have examinations after Christmas for study period two. The courses consist mainly of 7.5 ECTS, and there are usually two courses in parallel per study period. Each year of the Bachelor cycle contains a project course, devised according to the CDIO-methodology that stretches over one semester. The Master's programmes mostly have courses of 7.5 or 15 ECTS to facilitate the scheduling for the students and to make it easier to choose courses from other programmes.

All students at the Mechanical engineering programme apply to the five year programme in Mechanical engineering, and after finishing the first cycle they have the possibility to choose between more than 15 Master's programmes within Chalmers. The students also have the possibility to do their Master's programme at another university in Sweden. The Mechanical Engineering programme is responsible for eight of the Master's programmes at Chalmers, and

the other Master's programmes belong to other five year engineering programmes. The fact that Mechanical Engineering students can choose Master's programmes owned by other programmes also means that students from other programmes are allowed to attend the Master's programmes belonging to the Mechanical engineering programme. There is also a possibility for the students to choose a Master's programme that will not give them the national Master of Science within Mechanical engineering degree, but only a B.Sc degree and M.Sc degree; however, very few students do this. The students are then able to select any Master's programme at Chalmers, providing that they have the right prerequisites.

The director of the five year Mechanical engineering programme is responsible for the programme, and works together with the programme team consisting of the director of studies and the student guidance counsellor for the Mechanical Engineering programme. Each Master's programme has a director that reports to the director of the Mechanical engineering programme. In addition to this, the programme has an advisory board which consists of representatives from faculty, the PhD students, the students, and industry (mostly large companies). The programme is organised in an educational area together with Industrial design, Automation and Mechatronics and the Marine and Naval programmes, with a Dean of education as the leader. Chalmers has a buy/sell organisation for their programmes and departments, which means that the Mechanical engineering programme orders the courses from the different departments. The programme is responsible for the aims, content, sequence, and quality of the courses and the study environment, while the departments are responsible for the teachers. All courses are evaluated by the programme management on a yearly basis together with the teacher/s and the students.

The university has created Areas of Advance, which are clusters for research considered to be of special importance to the university.

1.2 Background

The five year Mechanical engineering programme at Chalmers has received national recognition on several occasions due to its high quality. In 2008 the programme received an award for an excellent educational environment by Swedish Higher Education Authority, UKÄ, which also awarded the programme the grade "very high quality", the highest distinction possible, in a national assessment in 2013. The programme was the only five year Mechanical engineering programme to receive this distinction. However it was only the five year programme and the Master's degree that were awarded the highest grade, the B.Sc degree was awarded "high quality". Additionally, the programme received the best engineering education award from the industrial employer's organisation Teknikföretagen in 2012, which highlighted the collaboration with industry partners and the philosophy of continuous improvement within the program.

In 2009 a workshop was held at Chalmers with the theme "Shaping the Future of Mechanical engineering Education at Chalmers" aiming to find what was required of Chalmers to educate the Mechanical engineers of tomorrow. Some milestones for benchmarking were created, with the future goal to be the best and most recognised Mechanical engineering programme in Europe. Following this conference a visiting committee was appointed, with members from industry and academia from all over the world. The purpose of the committee was for the programme to receive continuous outside assessment on how it was doing in terms of its aim of becoming the best. The

committee met up at Chalmers in 2011 for their first visit and the result was a set of ideas on how to improve the programme further. One suggestion was to formulate a strategy to use as a guideline when it came to the continuous improvement. The next meeting for the committee was conducted in December 2013. Many improvements had been made since the previous visit, including the creation of 40 new project rooms for students to work in. The committee was impressed with the development of the programme, but still asked for a strategy. The motivation now being that most “quick fixes” and small problems had been rectified, but that bigger changes, the sort that would raise awareness of the programme in Europe and world-wide, would be more difficult and would benefit from being coordinated by a strategy. By not having a clear strategy the programme would risk sub-optimisation of their work because different improvement projects may work against each other.

1.3 Aim

On the back of the awards and the with the continued encouragement of the visiting committee, this project was started as a means to create a strategy for the further long and short-term development of the program, aiming to improve the reputation in Europe and world-wide as one of the top Mechanical engineering programmes. This would mean updating the vision and goals as well as a plan of action for how the programme can continue to improve, become more visible internationally and benchmark against other universities.

1.4 Limitations and Scope

The time frame given was that the project should be conducted during maximum one year, but that the data collection should neither collide with the project team’s term-time nor the universities’ holiday period. Therefore, the work was concentrated around the summer months, with the start-up in the spring and the finishing touches being done in the autumn.

This study has focused on the five year programme in Mechanical engineering, Master of Science in engineering (M.Sc engineering). The study has not considered the students that only study towards their Master’s degree within a programme associated with the Mechanical engineering programme specifically, but has focused on getting a cohesive five year programme. To define which qualities are needed for a future mechanical engineer, a more general approach of “the engineer of the future” has been used to get input from a wider field.

2 Method

The project was initiated in January of 2014, and was mostly performed during the summer of 2014. The focus was on gathering the different stakeholders’ views of the Mechanical engineering programme, and its future, and to learn from other programmes and universities, how they work and what they think about “the engineer of the future”. An action based research method has been used, where data has been collected and analysed iteratively. To maximise the time available for the project the work has been performed in parallel, with regular discussions between the participants. This has made it possible to adjust the project over time, but also means that the processes have been affected by in which order, and when in time, the stakeholders and

universities have been involved. However, the final analysis has taken this into consideration, to make sure it does not affect the conclusion and recommendations.

2.1 The stakeholders

The project started by defining the stakeholders for the Mechanical engineering programme, and how their views and opinions should be collected. The stakeholders are listed in Table 1.

Table 1: The stakeholders to the Mechanical engineering programme

- Universities in general, and Chalmers in particular
- Students and alumni from the five year Mechanical engineering programme
- Industry
- Society

Data collection was performed using both quantitative and qualitative studies. The quantitative studies were used to get input from a wide range of people, and to include several aspects and views within one category of stakeholders. The qualitative studies were used to get more thorough and detailed answers from the stakeholders, and to get input from specific parts within one stakeholder, e.g. input from the different Master's programmes. Before the summer surveys, workshops and interviews were carried out with students, alumni, Master's programme directors and industry representatives.

2.1.1 Chalmers

The Master's programmes involved in this study are those that are most popular among the students, have a strong connection to Mechanical engineering and/or programmes that involve specific elements of importance and non-traditional thinking, see Table 2. Input from these Master's programmes was gathered through interviews with the director of the Master's programme, or a person in a similar position. To get a more holistic view some interviews were performed with PhD students from some of the departments involved. The PhD students were recommended by the directors of the Master's programmes and could also give their views of the Mechanical engineering programme as alumni.

Table 2: Master's programmes that have been involved in this study

| | |
|---|------------------------------------|
| Applied Mechanics, | Product Development, |
| Automotive Engineering, | Production Engineering, |
| Industrial Ecology, | Quality and Operations Management, |
| Learning and Leadership ¹ , | Supply Chain Management, |
| Management and Economics of Innovation, | Sustainable Energy Systems, and |
| Materials Engineering, | Systems, Control and Mechatronics |
| Naval Architecture and Ocean Engineering, | |

Further information was gathered from meetings with people around the university, not necessarily connected to Mechanical engineering, including people connected to Challenge Lab, MOOCs, programmes using tracks during their Bachelor cycle and programmes using alternatives methods of

¹ A master degree taught in Swedish, which is both an M.Sc degree and a teaching degree. The programme is called Lärande och Ledarskap in Swedish

admittance. Input from Chalmers centrally has been collected from policy documents for their vision and mission and Chalmers' rules for a Chalmers degree, to be able to connect this project to the overall strategy for Chalmers.

2.1.2 Students, and alumni

To include students from all five years of the Mechanical engineering programme a survey was performed, in class for the Bachelor cycle and online for the Master's programmes. The aim with a live survey for the Bachelor students was to get as many responses as possible, the drawback being that the students did not have much time to think their answers through. As the Mechanical engineering Master's students are spread out over more than 15 Master's programmes it was more convenient to perform an online survey to get diversity among the respondents, this method also gave the students time to think about their answers before submitting them. Responses were gathered from 14 different Master's programmes. The survey included questions about what the students thought the programme should focus on, what the students think is lacking in the programme today and which qualities they think a future employer will value. Surveys were complemented with workshops with student representatives from the Bachelor cycle and the most common Master's programmes for the Mechanical engineering students. The goal with these workshops was to get a qualitative view on the questions, and to discuss different opinions and to get more developed answers.

A smaller survey was sent out to alumni for them to give their views on the programme. Secondary data from Chalmers' own surveys to alumni has also been used, in an effort not to overwhelm alumni with questionnaires. In addition to this, data from a Chalmers survey to the first year students was used to gain insight into why students choose to attend the programme.

2.1.3 Industry

A survey was sent to the industry, and respondents were selected from a catalogue sent out during the Chalmers student union's career fair, where companies had indicated that they were interested in recruiting Mechanical engineering students. The same survey was handed out during a workshop about simulation in education held in the Mechanical engineering building and co-hosted by the programme. Unfortunately, the total number of responses was low, and angled towards engineering analysts in a way that does not correspond with future careers of Mechanical engineering students; due to the large number of answers from the workshop. This was taken into consideration in the analysis. To get quantitative information from the industry interviews and workshops were conducted with the advisory board of Mechanical engineering, which includes industry representatives. Some additional interviews have also been conducted with industry representatives selected by the project team because of a special connection to engineering in general or Mechanical engineering in particular

2.1.4 Society

Society's view of a Mechanical engineering degree has been collected through the national criteria for the degree in B.Sc, M.Sc, and the national five years degree M.Sc Engineering, and the national assessment in 2013.

2.2 Global outlook

The investigation of other universities and their thoughts on the (Mechanical) engineer of the future was performed nationally and internationally. The universities that were included in the study were selected together with the director of the Mechanical engineering programme. This list was continuously updated, aspiring to have diversity among the universities, both geographically and in their views of education with a connection to Mechanical engineering. The main objective was to study universities in Europe as one goal for the programme is to be the leader in Europe. Owing to beneficial circumstances, and interesting concepts at universities within the US, the project could also include site visits to American universities. Some of the universities were already connected to the programme, while others were new connections. To get the most honest and holistic view from the different universities, site visits were performed at the majority of the universities included in this project. The context and the circumstances in which the university operates affect the way the education is performed and the results, which has been an important consideration during the project. Three things that have been identified to affect the outcome are: resources, number of students, and culture.

Contact was established with the universities during the spring and some site visits were performed to get early input to the study. An interview guide was designed, and developed during the project as more knowledge about the subject was gathered. It was adapted slightly to the specific university and interviewee. Most site visits included both a tour around the facility/facilities and one to several interviews. The site visits were performed by one person from the project team, which made it possible to do more visits than if they would have been conducted by the entire project team. One drawback of using this system is that the impressions from the visits can become biased.

Table 3 shows the universities that have given their input to the project, and which role the interviewee/s had.

Table 3: List of which universities that have been included in the study

| University | Interviewee | Nation | How |
|---|---|----------------|---------------------------|
| Delft University of Technology (Delft) | Director of B.Sc and M.Sc Aerospace Engineering | Netherlands | Study visit and interview |
| Design Factory (DF) at Aalto University (Aalto) | Director of DF and a student of Mechanical engineering | Finland | Study visit and interview |
| ETH Zürich (Zürich) | Coordinator of Studies, Department of Mechanical and Process Engineering | Switzerland | Email |
| Imperial College London (Imperial) | Director of courses, faculty of Engineering, department of Mechanical engineering | United Kingdom | Study visit and interview |
| Linköping University (Linköping) | Student representative Mechanical engineering | Sweden | Email |
| Massachusetts Institute of Technology (MIT) | Member of the visiting committee and professor of Mechanical engineering | USA | Study visit and interview |
| Olin College of Engineering (Olin) | Professor within Mechanical engineering, and a student | USA | Study visit and interview |
| Pennsylvania State University (Penn State) | Aerospace Engineering, Mechanical engineering, Director of the Learning Factory | USA | Study visit and interview |
| Royal Institute of Technology (KTH) | Student representative Mechanical engineering | Sweden | Phone interview |
| RWTH Aachen University (Aachen) | Student representative Mechanical engineering | Germany | Skype interview |
| Stanford University (Stanford) | Leader of Stanford Designing Education Lab (DEL) | USA | Study visit and interview |
| Technical University of Denmark (DTU) | Director of B.Sc Mechanical engineering and director of M.Sc Applied Mechanics | Denmark | Study visit and interview |

2.3 The analysis

Data collected from the stakeholders and the universities has been analysed iteratively through multiple discussions within the project group, and feedback sessions with the director of the Mechanical engineering programme. To complement this study information has also been collected from scientific articles and other articles within the subject of *the engineer of the future*. The two main reports that have been taken into consideration were written by The American Society of Mechanical Engineering (ASME) and by MIT respectively, investigating the future of (Mechanical) Engineering education.

During the autumn, after the last data had been collected, the analysis was summarised into challenges for the five year Mechanical engineering programme, which were emailed to the visiting committee for feedback. Their feedback was included in the updated challenges, which were transformed into recommendations for the programme. Challenges and recommendations were also discussed with student representatives. The study was then presented to faculty at the faculty conference of the programme. Faculty had the opportunity to give feedback during the session, and afterwards by email. The recommendations were then updated, to include the feedback obtained during the faculty conference and discussions within the project team, and an action plan for the recommendations was developed. The study has also been presented for the educational area that the five year Mechanical engineering programme belongs to, and the advisory board.

3 Summary of data collection

The first part of the summary consists of the stakeholders' views of the future of the Mechanical engineering programme at Chalmers, and an analysis of the context. The summary ends with a review connected to this study on other projects within the same field. The extended data collection will be released as a separate appendix, please see <https://chalmersuniversity.box.com/s/il7zosl369yc5d0o9eyl>.

3.1 The study

Chalmers has an aspiration to achieve “global attraction through excellence in education” .One of the foundations for this is to have innovative and creative learning processes and to work interdisciplinary, another is to develop sustainable technology for man kind. These goals include collaboration with industry, and society, recruiting the most motivated students, movability during education, and development of the individual. (Chalmers University of Technology, 2010)

Chalmers also has some criteria for their degrees involving courses within sustainability, and the relationship between human, technology, and society. These two general Chalmers criteria are areas where the five year programme needs to be strengthened according to the national board for university education, UKÄ. Several of the teachers agreed that the students need to strengthen their ability to handle multiple perspectives, scientific theory, and their understanding of technology's role in society. The industry said that knowledge within sustainable development will increase in importance.

Most students thought that the ability to work in a group and communication skills were important and something they wanted more practice in, but some students thought that there was too much focus on these skills today, and not enough on the technical skills. Some of the directors of Master's programmes had a similar concern, that the students now have weaker technical skills than before. They also thought that the students need to understand the importance of being able to work independently, even in a group, which the industry agreed upon. Industry demanded good technical understanding, rather than specific software, as theory will be the same but the applications and tools will change. However, the importance of soft skills was emphasized at many of the studied universities. Both the students and the teachers saw the usefulness and the need to work with open problems, and some teachers said that students need know how to handle information efficiently. This includes finding the right information, sorting large amounts of information and knowing when there is enough, or not enough, information.

The discussions at the university visits about what qualities a future engineer should possess have been summarised in Table 4.

Table 4: Skills of a future engineer

- Creative innovators that will solve the global challenges of the future
- Develop the skill for independent learning for life
- Have a broad base but be really good at “something”
- Communication and the ability to co-operate.
- The ability to think analytically and critically
- System thinking and being able to see the whole picture
- Interdisciplinary
- Ethics and morale
- Commitment

The students wanted to have more collaboration with industry, and some of the first year students said that they did not want to wait until the end of the Bachelor cycle to get it, but rather have it right from the start. However, the following years' students seemed to be more satisfied with the amount of industry interaction. In general, the Master's programmes focus more on a future career in industry, than in academics. However, some of the Master's programme directors said they wanted to educate the students for the future, not for current roles in industry. One classification of future roles for Mechanical engineering students that was discussed with a member of the advisory board was: specialist, “systems manager”, innovator, leader and researcher.

It has been identified that it is tougher for the international Master's students to get a thesis in industry, due to lack of personal connections, cultural differences and a wish from the industry to get Swedish speaking students to do their theses. Industry representatives mentioned that they appreciate when students have experience of real projects, but added it could be other things than work experience such as experience from societies at university or “life experience” in general.

The students, and also the teachers, had different ideas on how to collaborate with the industry. Some students wanted to have the opportunity to do an internship, but they did not like the idea

of getting ECTS for it. Internships are common in the Netherlands, Germany, and Switzerland. There are both internships at shop floor level and as an engineer, and they could be from 6 weeks up to 6 months. The Bachelor of Engineering programme (BEng, 180 ECTS) at DTU also had internships. In the United Kingdom the students are required to work for a while after acquiring their degree to get certified as engineers. Some of the universities studied have companies that they collaborate regularly with, and in the US is it common to have a capstone project in the final year, where the students perform a project for a company. It is also quite common that industry representatives act as a jury during the students' presentations, and give awards. Penn State saw this collaboration with industry as win-win-win for the students, the faculty, and the industry.

The Mechanical engineering Bachelor cycle at Chalmers has in general more mandatory courses than other B.Sc degree programmes within Mechanical engineering. At Aalto, Delft and DTU part of the elective credits should be used towards a minor. It is common that the students take a minor in Engineering economics and management, as their mandatory courses are more closely related to Mechanical engineering, basic science, and engineering skills such as projects skills. To handle the greater amount of elective courses it is common that the students have mentors, who are faculty members, and an individual study plan. The students and the directors of the Master's programmes at Chalmers are generally satisfied with the Bachelor cycle, and that it touches upon a wide variety of subjects. Some students think Mechanical engineering should be broad, and that this requires a lot of mandatory courses in the Bachelor cycle, while others thought there should be a possibility to focus earlier or to be able to try different subjects. There was a concern among some students that the course quality could decrease if there were more elective courses, and that students would choose the "easy way out". It was also highlighted that many students chose the five year Mechanical engineering programme because it is broad and that they would have access to many Master's programmes. Master's programmes often consist of more than one year of elective courses, including the thesis, which most thought was enough. One of the teachers thought that too many credits of the elective Master's courses could be Bachelor level courses, which count towards the Master's degree.

The directors of the Master's programmes want students from different Bachelor cycles to get diversity among the students, but mentioned that it can be hard to get the right level of the courses when the students start the programmes with different levels of knowledge. Some Master's programmes have lowered their prerequisites for the Master's programme, or are thinking about doing so, to make it possible for students from more Bachelor cycles to choose the programme. Industry had a divided view of the amount of elective courses the students should have. Some representatives thought that the students should follow their passion to be motivated, while others said it was hard to compare candidates if they had a lot of different courses, and they did not know what the different courses meant. Industry also had difficulties differentiating between the three degrees: B.Sc, M.Sc and the Master of Science in engineering degree.

Some universities abroad, and the visiting committee, highlighted the importance of having diversity among the faculty members and the students, both in terms of gender and nationality. This creates an international environment which has been credited as something that increases the quality of the education.

The students would like to have better integration between the courses, and to have even more types of examination methods than today, and that those could affect the student's final grade. Today it is common to have projects, labs, quizzes and hand-ins during the course, but the grade is most often decided by a written exam. Some students also said they lacked time for reflection. Teachers also talked about different types of examination and learning activities. Olin focuses on projects, teaching mathematics and mechanics within those courses, instead of specific mathematics courses. To support these types of courses the classrooms are designed for team work. That the facilities support the learning of the students has been observed in many of the universities, with some examples listed in Table 5.

Table 5: Examples of facilities

| | |
|------------------------|---|
| Delft | Had projects over a long period of time, and the groups get dedicated study places |
| Design Factory (Aalto) | Focus on multi- and interdisciplinary, and had therefore flexible surfaces |
| DTU | Had redesigned the classrooms to benefit discussions in the classrooms, i.e. flipped classrooms |
| Olin | Students work a lot in problem solving teams and have lab equipment in classrooms |
| Penn State | Had a learning factory (workshop) to support their capstone projects |

As mentioned in the beginning of this chapter, Chalmers highlights movability, and several of the students take this opportunity, but most often for only half a year. One of the teachers felt that the 3+2 system is not used to the extent that it could be; for instance, only a few students change university within Sweden between their Bachelor and Master's degree. Most students that have started the Bachelor cycle at Chalmers stay at Chalmers during their Master's as well. However, some of the Master's programmes at Chalmers offer the possibility to do a double degree together with international partner universities. In the US it is more common that the student changes university if they choose to study a Master's. At Olin all students apply to one common entrance and then choose a major after a couple of terms. KTH has introduced a programme in Mechanical engineering where the students can study abroad during their Bachelor in France, Spain or Germany. Another way to encourage mobility and learning from different cultures is to have global project teams, which Penn State has done during their Capstone project.

Some ideas that have been discussed and things that other universities do are summarised in Table 6.

Table 6: Ideas from universities and faculty members

| Ideas | Reference for the idea |
|---|--|
| Interviews with the students when they graduate, so called exit interviews, | MIT |
| Large screens around the department showing the occupancy in computer and project rooms. | Imperial |
| Boot-camp for course development. The teachers get the opportunity to test their course on colleagues prior to the live session with students, and also get feedback along the way. | Stanford |
| Idea for project courses: Introduction project where the students should build shooting device and compete with the other student teams. | Linköping University |
| Idea for project courses: The students should design a toy, and work with real customers, e.g. fourth grades that will evaluate the toy in the end of the course. | Olin |
| Collect the Bachelor theses in a yearbook to give to the students, the book can also be used by the faculty in public relation affairs. | Delft |
| Develop own course literature and have an organisation that facilitate this, so individual teachers' work can be used in more courses and by more teachers. | Mechanical engineering faculty conference (Chalmers) |
| "Band-aid courses" for the Master's programmes that should the help students to develop their skills to preferred level to support the possibilities to have diversity among the students" backgrounds. | Mechanical engineering faculty conference (Chalmers) |

3.2 Related studies

The two reports studied, one from The American Society of Mechanical engineering (ASME) and the other from MIT, were investigating the future of mechanical engineering education and the future of engineering education. The ASME report, published in 2011, highlights the importance of an increase in curricular flexibility and offering a curriculum that encourages innovation and creativity. Moreover, developing the students' professional-skills to a higher degree, increasing the amount of project-based learning and creating strategies for attracting a more diverse student body are recommended. A suggestion for the increased flexibility of the curriculum was that a programme identifies a series of core Mechanical Engineering courses and then let students choose a concentration area or minor to make up the rest of their degree. This idea has been

adapted in many of the universities studied in this project, for example Stanford, MIT, Delft and Aalto.

The professional skills identified in the ASME report were as follows; complex system-level perspective, inter-disciplinary teamwork, leadership, entrepreneurship, innovation, and project management. It was suggested that these skills could easily be implemented in design-build-test courses, preferably with multi-disciplinary teams, and would at the same time also increase the practical experience given to students. The Mechanical engineering programme at Chalmers has included ethics and communication (written, verbal and visual) in their current definition of professional skills, and these are taught primarily in the term-long design-build-test projects conducted each year. There is also a requirement from Chalmers that the students study the equivalent of 7.5 ECTS of sustainability and human-technology-society.

Another way of giving students a more practical experience is to make sure that professors have experience from industry and not only academic experience. This is suggested by the report to give the professors more credibility if they can show real world practical applications of what they are teaching. However, the recruitment of faculty is handled centrally by Chalmers, and therefore this is not anything that can be decided upon by the Mechanical engineering programme.

During the course of the project, MIT released a report on the improvement of their Engineering education. The MIT task force identified 16 recommendations. These recommendations concern bringing more innovation and flexibility into the curriculum through the use of new and different learning models and a re-examination of the current core requirements and through better collaborations across the university. There is also a suggestion for these innovations to be made accessible for a wider audience than previously, so that more people can be a part of MIT, both in residence and across the globe.

The report discusses the importance of using new methods of teaching and examination to make sure that students' skills are developed in the most efficient way, this includes the new model of game-based learning and project based learning. MIT benefits from extensive online resources, something that the task force feels should be further developed and better integrated in the curriculum in the form of blended learning. One recommendation concerns appointing a group of different stakeholders to create new learning spaces across campus, this would enhance the educational experience for students and also enable creative discussion and innovation within the education.

The general view of the MIT report is that there is much that is great with MIT but that the fear of losing something that is good should not hinder experimentation with new models and new ways of teaching a broader audience. This could be true for the Mechanical engineering programme at Chalmers as well, as it is possible that there is a fear of losing the things that have made the programme successful by changing the way the curriculum looks.

4 Challenges

From the analysis, the challenges were summarised into five areas seen below. The challenge that should be given priority is the “uncertainty”, without a firm and clear identity it will be difficult to develop the programme strategically.

4.1 Recruitment

The current system for accepting students into the programme is based on some form of scoring; either grade scores or test scores. The grades taken into account are either the high school grades (gymnasiebetyg) or grades from the foundation year at Chalmers. The test scores come from the national entrance exam to university studies, which tests basic Swedish, English and mathematical skills. There is a national regulation that one third of the places in the programme should be given to the applicants with the highest national entrance exam score, one third to applicants with the highest high school grades and the rest is for the university to decide. Chalmers has decided to divide the remaining third between the three scores, test, high school grades and grades from the foundation year. During the course of this project it has been questioned whether this system fulfils the general Chalmers goal of only accepting the most motivated students. Is it certain that grades and test scores indicate who will become the best engineer or the most motivated student?

4.2 Arenas for meetings between industry-university-student

The programme offers diverse career paths but it is difficult to get input from all the different possible paths, both in curriculum development but also in student interaction. Students have indicated that they would like even more connection and collaboration with industry. They also want it in slightly different forms than what is available today. Moreover, this challenge connects to how the students learn about what is going on around the different departments at Chalmers and in the Areas of Advance. Exciting opportunities for students to work on research projects and help out around departments would be made easier if there was a simple way of connecting to departments. Therefore, one of the challenges identified is to find arenas for new ways of interacting between these three stakeholders.

4.3 Skills of the engineer

When asked, students rated working in a team as one of the most important skills for getting a job, but when employers were asked the same question they rated being able to work independently as important, as the ability to work independently is also important within a team. How can the programme teach both at the same time, and how can they introduce research methodologies, ethics and communication as efficiently as possible? When interviewed, both students and faculty have mentioned a lacking ability to write scientific reports. The overall level of communication has improved over the last couple of years, but more can still be done.

4.4 Internationalisation

Internationalisation was put forward in Chalmers' list of goals for 2020, yet most exchanges take place during the Master's programme, and even then it can be tricky to match up courses. Few projects run together with students from other schools. Indications from industry and Master's programme directors say that it is more difficult for international students to get industry-led Master thesis projects, many end up doing their thesis within a department as that is where they get accepted. This does not really match up with Chalmers' international profile.

4.5 Uncertainty

The biggest challenge the programme is facing is uncertainty. There is a general uncertainty when it comes to the image and role of Mechanical engineers. Prospective students do not know what future careers they will have if they enrol in the program. Master's programme directors do not always trust that the students from the Bachelor cycle have the skills/knowledge that the course objectives of prior courses say that they should, even if they have passed courses with good grades. Human Resources departments (HR) and recruiters find it difficult to keep track of what different courses entail and what skills the applicants have when they supply a list of courses. One HR-representative from a recruitment business mentioned in a survey that: "We have limited our recruiting of Mechanical engineering students because we don't know what all the electives mean". There is also an uncertainty among employers where there are examples of diagnostic tests for future employees, which could be interpreted as that they do not trust the students' grades.

4.5.1 Mismatch

There is a system of recommended or prerequisite courses, where students need to have passed or at least been registered to certain courses to gain entry to certain Master's programmes. These requirements have gradually decreased to allow programmes to accept students of more diverse backgrounds and in doing so get more applicants. This change means that even if an "optimal" Bachelor cycle is designed, the bar would need to be raised in the Master's programmes, and then the bar might be too high for students from other programmes.

It is also evident from interviews with directors of Master's programmes that there is a mismatch between what students choose to study and what society needs. A Master's programme with several tracks might encourage students to choose the track where there is a strong need for engineers, but in many cases the students choose the other tracks. This leads to the question of which the main stakeholder of the programme is, the students or the society where they will work.

4.5.2 Different needs/interests

Because of the broad nature of the programme, and the fact that it is possible for students to choose 15+ Master's programmes there are discrepancies in what subjects are considered "core subjects" or "basic knowledge". Some Master's programmes require more theory whereas others require more applied knowledge, they also require different levels of certain subjects, and in some cases certain subjects might even be considered superfluous. Because the Bachelor cycle is large (150 students per year) there are also different needs and preferences among the students, such as different preferred learning styles, some require participative exercises whereas others just want to study and write their exams. How to handle these different needs and interest is the

challenge, should they be balanced or should there be different tracks for different needs and preferences? This challenge is also connected to what skills are required by industry, is it reasonable for students to learn to study for an exam or does there need to be continuous examination for the students to really digest the material?

4.5.3 Marketing

The programme offers an almost endless supply of possible career paths, which makes it difficult to market. What do the students actually become and how is that marketed in the most efficient way? This uncertainty is tricky to work with because opportunities for the specific marketing of the programme are limited today, as there is a general plan for marketing of the entire university. However, there are certain freedoms given to programmes, so it is still an important challenge to work with.

4.5.4 Past-Present-Future

What is the programme educating for, the present situation or the future? Is it important to teach students about the past so that they can better understand the future? Interviews with older students have indicated that too much focus might be put on the future so that students, sometimes, aren't well enough equipped for the current working situation. Other students do not understand what they should learn about the history within the field.

5 Discussion

The visiting committee, when consulted regarding the challenges, agreed with what had been identified. There were some specific suggestions regarding how the challenges should be approached, for example that it was important not to make too drastic a change too quickly to swing in the direction of either stakeholder. It was also suggested by one member of the committee that some uncertainty is good, as too much detail and micro-managing can stifle creativity and flexibility, and also that there is an inherent risk of mismatch with the 3+2 Bologna process.

One big issue with identifying recommendations and challenges has been how to use the views of the identified stakeholders. Students have a right to have some say in their education, they are also the only ones that experience the whole programme and not individual courses like the teachers, and the university needs to educate the researchers of tomorrow. Likewise, industry, both local and global, needs engineers with certain skills, and society needs engineers to solve the problems of tomorrow. Included in the stakeholder 'Society' is also the local community, meaning how Chalmers should contribute to the improvement of the local area and attract the engineers of the future by encouraging youths to study science and technology.

There has been a continuous discussion as to how to weight these four stakeholders in how much say they should have, especially when their views are conflicting. It becomes quite problematic when some stakeholders are at opposite ends of a spectrum in certain questions, but also poses a challenge when the stakeholders all agree, as in the case with what subjects to include in the curriculum. There are many ideas on what other courses to include, or what the stakeholders

would like more of, but few or none of what should be removed. It would be beneficial if there was a unified plan detailing how to handle stakeholders in matters like these, as that would speed up the process. During the study it has been difficult to get in contact with all different stakeholders, particularly to get response from a diverse group of companies and alumni. This introduces ideas about establishing networks with industry and alumni; today the contact is primarily on a personal level between teachers and employees of companies, and students/teachers/Master's programme directors and alumni.

During the course of the project it has come to light that the students in the programme belong to a rather homogeneous group. Most are male (usually between 20-25 % of the students are female) and start university straight after high school or after one gap year. However, as the age-groups used in the data are quite wide, there is still some spread, but the general feeling is that the students are quite close in age. It would perhaps be beneficial to try to make the classes more heterogeneous, as society today is more diverse. New ways of recruiting and admitting students could perhaps solve this. The Swedish university admittance system is rather standardised and doesn't offer much room when it comes to selecting candidates, something that differs from other universities, internationally.

The broad nature of the programme is something that has been debated. What does broad really mean, and do we want to be "broad"? As it stands the programme has chosen to make most of the Bachelor cycle mandatory to give all students a base of mechanics, mathematics, product development and material science, but also courses in economics, management and mechatronics/automated control. This means that students that already have a specialisation in mind can feel forced to take courses that they know they do not need, sacrificing a depth in the area they want to specialise in. On the other hand, this hopefully ensures that the students can view problems from different perspectives, even if they might not necessarily have a future career in the subject.

As there is not yet a clear picture of what the Mechanical engineer of the future will look like, it is difficult to decide on how to solve these issues. One suggestion that has been discussed is to let students choose future roles, such as "researcher", "manager", "innovator", and "technical expert" and have different course-bundles for the different roles, in addition to a common Mechanical engineering core, during the Bachelor cycle. Other solutions studied have been to have more elective courses, either organised as a minor (the elective courses should then be within the same field) or just a free choice of courses. One drawback with this increase in flexibility is that students might become more mono-disciplinary or bi-disciplinary, and many involved in this study have emphasised the importance of multi- and interdisciplinary engineers. The 3+2 programme structure gives the students the wide spectrum of subjects during the Bachelor cycle and the depth during the Master's programme, and most of the Master's programme directors seem happy with the Bachelor cycle in Mechanical engineering in general. The Master's programme directors want students from different Bachelor cycles, as they want diversity among the students' knowledge and background. Another reason is that they want more applicants to their programme as more students mean more resources. However, this desire results in different knowledge levels among the students accepted and it could be hard to find the right level of the courses. As the Bachelor cycle is only responsible for some of the available Master's programmes is it common

that these Master's programmes are prioritised in the programme development and the alignment of courses.

This raises the question of how the five year programme should be organised to educate the best Mechanical engineers, which becomes even more complicated as the five year programme consists of two academic degrees (B.Sc and M.Sc) together making one engineering degree. To get the best engineers the whole five year programme should be considered, however as some of the available Master's programmes are outside the control of the programme this becomes difficult. One solution could be to optimise the education towards the Master's programmes that the five year programme is responsible for, but this would mean that the five year programme favours some of the available Master's programmes and that students from other Bachelor cycles might not be able to attend them or find that the level of the courses doesn't fit them. Another solution is to focus on the best Mechanical engineering Bachelor cycle, but this could lead to the students being overqualified for the Master's programmes. Also, the Bachelor cycle should be an academic degree, but it might be more beneficial for the students' future careers in the engineering industry if the focus is on applied engineering skills instead.

That students have a difficult time seeing the end goal and the big picture of their education has been mentioned in both students' workshops and the surveys. Students expressed that they do not know what courses to choose and what they lead to but also that they do not know what is required of them if they choose a certain career path. All programmes at Chalmers have a guidance counsellor that they can go to discuss these issues, but because there are so many students and the guidance counsellor is very popular, there might not be enough time to reach all students. Other universities have solved this by having mentors and tutors, both older students and faculty, so that the students know that there are people around that can help them find their way through the uncertainties. A faculty member or a student will also have a different experience than a guidance counsellor which rarely has an engineering background. What system is best is difficult to predict, but there is clearly a need from the students for more guidance.

One observation during the process of the project is that there is sometimes a territorial nature to how professors view their subjects and their place in the curriculum. Professors tend to feel that their subject is the core of Mechanical engineering and because there is no unified image of the Mechanical engineer of the future it is possible that courses that should be part of a specialisation is now a core requirement. When the Aerospace Engineering education at Delft went through a major reorganisation it was openly stated that the professors should not have too big of a role in the decision-making of what subjects to involve or not, as they saw that the professors were biased towards their own subject and that they also had limited time available. From the beginning the Mechanical engineering programme incorporated the Industrial Engineering and Management, Naval and Ocean engineering, Industrial Design and the Automation and Mechatronics programmes but these have gradually been separated and turned into their own programmes. However, the Mechanical engineering programme still contains courses from these programmes, even if, perhaps, it should have been removed from the curriculum upon its separation. The question is who should make these decisions, and which stakeholders to involve and in what amount.

One point of discussion after the site visits has been the subject of being committed to the local industry or not to favour any industry no matter its location. The Mechanical engineering programme benefits greatly from a close connection with the companies and industries active in the Gothenburg region, but one interview highlighted a problem where the industry representative mentioned that their company could only guarantee that they would be active in the region for an additional 20-25 years after which they might be forced to move elsewhere. If that happens the programme is in a precarious situation because it has favoured an employer that has moved away.

The site visits at the universities have shown different ways of marketing, both online and on site. One thing that differs from Chalmers is that most other universities have more information about their individual degrees; Chalmers has only one rather standardised page per programme with just one student interview. For instance, DTU has a video clip and Linköping University have student blogs. Aalto and Olin showed ongoing and previous student projects in the corridors such as prototypes and A3-posters which showed what students were doing.

As mentioned previously it is important to remember that there is a significant difference in the budgets of the universities visited and the possibilities given to Mechanical engineering at Chalmers. There is a value in studying the universities as long as the context is kept in mind when analysing the data. Solutions used by other universities can to different extents be applied at the programme, and all good things from the universities don't require vast amounts of resources. Sources not strictly related to Mechanical engineering but more to engineering in general or closely related disciplines have been used, but again, these sources hold validity in the sense that their advice can be modified and then applied in the Mechanical engineering programme.

During the Mechanical engineering faculty conference faculty members were given the chance to come up with suggestions and give feedback on which improvements were to be given the highest priority. One popular suggestion brought up was to expand the current workshop or create a completely new makerspace or "fab-lab". The workshop in the basement of the Mechanical engineering building is becoming crowded and there is a demand for more flexible working areas like many of the universities studied have had. Other popular suggestions included producing course books from material developed by teachers and creating a "flipped-lab" series, where students can watch safety and lab instructions with quizzes before they arrive for their course labs. Resources should also be given to develop the competences of the teachers.

6 Recommendations

The recommendations have been created to address the identified challenges and critical things that have been brought up in discussions. The project aimed to update the visions and goal for the programme but it is vital that the first recommendation be taken care of prior to this for there to be any point in updating the vision and curriculum.

6.1 Overall

During the project many different views of what qualities the Mechanical engineer of the future should have. The challenges are based on what has been found to be the most important issues for the Mechanical engineering programme at Chalmers to handle, but they can be handled in different ways. The main concern for the programme is within the subject of uncertainty. The stakeholders have suggestions on several aspects and subjects the curriculum should include more of, but few or none that should be reduced. The studied universities have different approaches and focus, and one idea could be to take the best from each, but it might be hard to combine and would scatter the education even more which should be avoided. Different solutions have been investigated, e.g. tracks or a minor during the Bachelor cycle, however most stakeholders agree that the width, and the amount of mandatory courses, of the Bachelor cycle is one its strengths. Another point is the number of Master's programmes a Mechanical engineering student should be able to choose between, and what the connection between the B.Sc and M.Sc should be like. Today, the connection between the Bachelor years and Master's programmes differ depending on if the Master's programme is owned by the five year Mechanical engineering programme or not. This sums up the first recommendation, and they should handle the challenge *uncertainty*.

1. Agree on what should characterise a Master of Science in Mechanical engineering, i.e. the combined Bachelor cycle and Master's programme, at Chalmers.

To be able to agree upon this, the programme needs to decide how they should handle and prioritise their stakeholders and the 3+2 system. When these things have been decided upon it is possible to make changes to the curriculum and update the vision.

6.2 The five year programme

Communication, scientific theory and professional skills, collaboration with the industry and faculty, and collaboration with universities abroad are all areas that the stakeholders and the studied universities have emphasised the importance of. The aim is to start defining what these areas entail prior to the mapping and development of them, because it is important that everyone has the same definition and view to be able to work holistically.

The visiting committee, and several of the stakeholders, have emphasised the importance of the programme team, and to make sure that the knowledge this team has is retained within programme. The site visits at the universities, and the university web pages, all showed examples of what their students are doing and showed both ongoing and finished student projects. Displaying what is going on creates excitement and a sense of pride that would perhaps increase the popularity of the programme even more, as well as a serve as a means of communication

between different parts of the programme by letting people know what is/was going on and who did it. Other recommendations in this section include the creation of mentorship opportunities, improved contact with alumni and an extension and improvement of the workshop

2. Define, map and develop the use of different ways to teach communication

Today the project courses in the Bachelor cycle have a clear projection within the subject of communication, and many courses involve some communication, but mainly written assignments, and the students want more feedback. However, the students need more practice in communication not just written, but also oral and visual. Creating an overview over which types of communication skills are practiced and where will be helpful for both students and teachers, this would also facilitate the involvement of the communication support department.

3. Define, map and develop skills of the engineer

One common holistic approach to what scientific theory and common engineering skills are, is currently missing, which has been made clear during discussions with teachers. The programme needs to define what these are, when they are introduced and or practiced in the curriculum today and how they should be taught in the future. These skills should be useful for the future roles of the Mechanical engineering students, including their roles as researchers as well as in industry. Examples of these include project managing experience, communication and ethics. These skills can then be used in the marketing of the programme, as something that sets the Mechanical engineers of Chalmers apart from other Mechanical engineers.

4. Define, map and develop the collaboration with the industry and the faculty

The students made it clear that they wanted more collaboration with industry, and not just as guest lectures. Today, the collaboration with industry is mostly up to the individual teachers. In some of the visited universities one person was responsible for the contact, and that the collaboration for bigger projects went through this person. Currently, some departments are more visible than others during the B.Sc cycle and students and PhD students said they missed the opportunity to learn about current research within the departments. In this area there is a lot of development potential and an opportunity to involve the Areas of Advance. There is a system in place for letting people from industry attend Chalmers for one or a few courses to further their knowledge of a subject. This should be further expanded, as it creates diversity in the classroom and valuable insights for the students.

5. Define, map and develop the collaboration with universities internationally

The programme should decide if they want to focus on major collaboration with few universities or minor collaboration with more universities, and in which regions and areas these collaborations should take place. Today, some of the Master's programmes collaborate through projects, or the opportunity for the student to get a double degree from Chalmers and another international university. The reason to map the existing collaboration is to get an overview of what already exists and to make it easier to promote,

and develop these collaborations. Collaborations that are identified as advantageous should be further strengthened to include collaborations not only between faculties but between students as well. It is suggested that the programme build upon the contacts of faculty to include collaborations in courses, for instance in project courses where there can be partner teams at other universities.

6. Create succession plans for key persons within the programme

Today, the programme is very dependent on its programme team, and there needs to be a plan developed to retain their knowledge, and a succession plan so that the whole programme team doesn't change at once.

7. Investigate the possibility for mentorship and increased student guidance

Due to the uncertainties and the possibility of more curriculum flexibility there should be an investigation into how the students can be guided through their education in the best manner. Suggestions for how to solve this include designated faculty mentors, and/or older students acting as advisors like many of the universities studied have had.

8. Develop the contact with alumni

Today, some individual Master's programme directors are in contact with or have contact information to prior students, and it would be beneficial if this was more on a general level to facilitate future collaboration. Good suggestions for how to keep contact and to get feedback on the education include exit interviews like those conducted at MIT.

9. Improve the prototype lab (workshop)

The existing workshop has reached its capacity limit in terms of space and it is hard to meet an increased demand on project courses and workshop practice for the students. The faculty wants a "super lab" which should be large, flexible and have a good learning environment; there is also a wish among some of the teachers to get better skills themselves in the workshop.

10. Show off our strengths

The five year Mechanical engineering programme is excellent in many areas, but does not show it off to the extent it could. The programme should highlight current projects and the facilities both online and within the M-building. Ideas for this include publishing a series of course literature based on material created by teachers for their own courses and marketing it as "Mechanical Engineering's own literature" as suggested during the faculty conference, and also by gathering abstracts or short summaries of the theses written by Bachelor/Master's students and publishing them as books that are available to the class and other interested parties. A solution to highlight the facilities would be to use the screens adopted by Imperial to broadcast the availability in the different facilities, including labs, computer rooms, the workshops and project spaces.

6.3 The Bachelor cycle

Management and economics are currently two separate courses in the second year, and only minor assignments elsewhere relate to these subjects. By introducing them more clearly as parts of other subjects it is believed that they will be seen as more closely connected to the work tasks of the Mechanical engineers. One goal for Chalmers is to admit the most motivated students to their programmes. It has been questioned if grades and the national test are the best methods to decide this. Some five year programmes at Chalmers have other types of application methods, for instance specially designed entrance exams.

11. Connect economics and management to project courses

Economics and management should be better integrated into the project courses. Suggestions for how to go about this would be to involve a more thorough cost analysis and argumentations for certain production/organisation methods, as well as cases related to industries used in project courses. This would make the transition between the subjects more seamless and hopefully make the students even more cross disciplinary.

12. Investigate different application/admittance processes

It should be investigated what criteria this process should include and how it could be performed. The purpose of a new application process is to ascertain that the best potential Mechanical engineers are admitted into the programme.

6.4 The Master's programmes

The next two recommendations are things that should be established at Master's programme level, to facilitate the connection with the Bachelor cycle and to develop the Master's programme as a whole together with the stakeholders.

13. Establish and use a complete design matrix for all available combinations of combined Bachelor and Master's programmes to make certain that students have or acquire the necessary skills.

These design matrices give the programmes, the teachers, and the students an overview over what the students should learn where and how the subjects are connected. Today the Bachelor cycle and some of the Master's programmes have their own matrices, however to get an overview all combinations should be available. When this has been developed, so called band-aid courses can be created to ascertain that all students in the Master's programme can pass through the programmes on even footing.

14. Establish advisory boards at all Master's programmes.

Today the combined Bachelor and Master's programme has one common advisory board, but due to the amount of Master's programmes and the limited number of meetings the focus is mostly on the Bachelor cycle. The advisory board consists of the programme team, faculty representatives including a PhD student, industry and student representatives. Currently, only the Naval Architecture and Ocean engineering programme has its own advisory board.

6.5 The courses

Both the students and the teachers have mentioned different types of learning activities and examination, other than the traditional lecture, exercise and written exams.

15. Use different learning activities and types of examinations/assessments

The goal of having other types of learning activities and examinations is that they should be a support for learning, and examine the right things, this means that they need to be adapted to the context: the subject, the teacher, the level of the course and the students. An idea from Stanford was to establish “course-development boot camps” where teachers can try out new learning activities in a safe environment before trying it on a new group of students. This might encourage teachers to try new things, if they are allowed a trial run prior to using it in class. It was also suggested during the faculty conference that teachers might like more training in these areas, perhaps through courses or workshops.

6.6 Action plan

The recommendations consist of both quick fixes and long term development, and should be implemented together by the persons affected by them. The recommendations should also be presented and discussed with the faculty members and programmes affected by them.

6.6.1 Overall

A workshop should be held with the advisory board and some additional members to cover the diversity of Mechanical engineering with the aim to define how to handle the stakeholders and how to develop the curriculum. The additional members should consist of representatives from the faculty (covering all departments and sub departments that give courses at the five year programme), and industry to cover more types of industries than today, and also cover small and medium sized companies. The workshop’s members should have access to this report prior to the workshop.

When: The workshop should be held in the spring of 2015, and the curriculum development follows the results of the workshop.

6.6.2 The five year programme

For recommendations 2 to 10, it should be decided upon who is responsible for the different recommendations, and which people should be involved. Recommendation 9 needs a long term development plan to cover all aspects and to decide how to proceed as it needs big investments.

When: Start spring 2015, followed by continuous improvement.

6.6.3 The Bachelor cycle

Decide upon who should be responsible and perform the investigation of different application processes for recommendation 11. Recommendation 12 requires the involvement and the agreement of the teachers within the courses involved.

When: Spring 2015 and autumn 2015, respectively.

6.6.4 The Master's programmes

The Master's programme directors should be responsible for the matrix for his/her Master programme, and the director of the five year mechanical engineering programme assembles the matrix combinations. The establishing of advisory boards and who should be involved should be performed in the spring, to start the implementation in the autumn.

When: Matrix - spring of 2015, Advisory boards - autumn of 2015

6.6.5 The teachers

During the faculty conference the teachers discussed different types of learning activities and examination formats and there was a wish to learn more. Therefore this recommendation consists of further training, sharing of ideas on what could be done and encouragement to try new ideas.

When: Spring of 2015, and future

7 Impact of the project

The project has already made some impact, which includes a pilot project with Penn State and strategic discussions with the faculty related to the Mechanical engineering programme, the advisory board, and with the Dean of education of the educational area. The pilot project with Penn State includes two global project teams for students at the Mechanical engineering programme at Chalmers, and at Penn State. The projects are the Bachelor thesis, and the Cap stone projects respectively, and are performed together with AB Volvo, Sweden and North America. The discussion with the faculty concerned the 3+2 structure, how it is currently and should be future. The other discussions focused more on the recommendations in this report.

The site visits and contacts initiated by this project have also served as a type of benchmarking, and as a way to market the programme internationally. The project has also been recognised internationally, it has shown that it is possible for students to lead strategic development projects for their education and that students at Chalmers are engaged in their education.

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CHALMERS

The Mechanical Engineer of the Future - Appendix

Data Collection

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Appendix - Data Collection

The appendix includes the data collected during the project. The first parts focus on the following stakeholders: students, Chalmers, and the industry. The other parts of the appendix consist of a review of the universities involved in this study. Universities are ordered in chronological order according to the date of the visits.

Innehåll

| | | |
|------|---|----|
| 1 | Students, and alumni | 2 |
| 1.1 | The questionnaire and workshop | 2 |
| 1.2 | Interview with former students | 7 |
| 1.3 | Secondary data from Chalmers..... | 7 |
| 2 | Chalmers University of Technology | 11 |
| 2.1 | Interviews with master programme directors | 11 |
| 2.2 | Other interviews within Chalmers | 14 |
| 2.3 | Input from other five year programmes at Chalmers..... | 15 |
| 3 | The industry | 17 |
| 3.1 | Volvo Cars | 17 |
| 3.2 | The Advisory Board | 18 |
| 3.3 | Mats Nordlund | 20 |
| 3.4 | IF Metall - a workers' Union..... | 22 |
| 4 | Universities | 23 |
| 4.1 | Stanford University – USA..... | 23 |
| 4.2 | Massachusetts Institute of Technology (MIT), USA | 23 |
| 4.3 | Mechanical Engineering at RWTH Aachen University, Germany..... | 25 |
| 4.4 | Mechanical Engineering, ETH Zurich, Switzerland..... | 26 |
| 4.5 | Mechanical Engineering at Linköping University, Sweden | 26 |
| 4.6 | Design Factory at Aalto University, Finland | 27 |
| 4.7 | Mechanical Engineering at Aalto University, Finland | 28 |
| 4.8 | Mechanical Engineering and Engineering Design and Applied Mechanics at Technical University of Denmark (DTU), Denmark | 28 |
| 4.9 | Mechanical Engineering at Royal Institute of Technology (KTH), Sweden | 31 |
| 4.10 | Aerospace engineering at Delft University of Technology, The Netherlands..... | 31 |
| 4.11 | Imperial College London | 34 |
| 4.12 | Cape Stone Project and Aerospace Engineering at Pennsylvania State University (Penn State), Pennsylvania, USA..... | 34 |
| | The Learning Factory..... | 34 |
| | Professor Lesieutre – Aerospace Engineering | 37 |
| 4.13 | Olin College of Engineering, Massachusetts, USA | 37 |
| 5 | References | 41 |

1 Students, and alumni

A questionnaire was used to gain information from present students at the programme, and it consisted of three questions. In total there were more than 300 responses, of which over 80 came from the respective bachelor classes, and almost 70 answers from the master level. The responses from the master students covered 14 different master programmes, and there were some more answers from students in the fifth year, than in the fourth. As well as gathering data, the questionnaire also worked as the foundation during workshops with students. A questionnaire was also sent out to a number of alumni. In addition, some former students were interviewed; primarily PhD students, from different scientific fields but all had studied mechanical engineering at Chalmers. Some secondary data from Chalmers has also been analysed to give a more holistic picture. This data includes: statistics on first choice of master programme for students in the third year of the mechanical engineering programme, a questionnaire to first year students, and a questionnaire to alumni, i.e. former students at the five year mechanical engineering programme.

1.1 The questionnaire and workshop

The first question concerned which areas the students thought the mechanical engineering programme should focus and not focus on, in the future, table 1-1. The question was a multiple choice question, where the alternatives consisted of ideas from some early study visits to two universities (MIT and Stanford). The other two questions were free text answers; one asked the students if they had missed something (so far) during their time at the five year mechanical engineering programme. The last question was about qualities the students thought their future employers would value.

Table 1-1: The first question in the questionnaire (The question is translated into English from Swedish.)

What two areas do you think are the most priorities/least priorities?

1. More projects with students from other programmes
2. Internship/summer jobs could give credits
3. More collaboration with industry
4. More elective courses (types of courses and when)
5. Less elective courses (types of courses and when)
6. Freedom in study pace (how much you study)
7. Other ideas (please specify)

The answer for question 1 is displayed in Figure 1-1 below, and the numbers refer to the alternative in table 1-1.

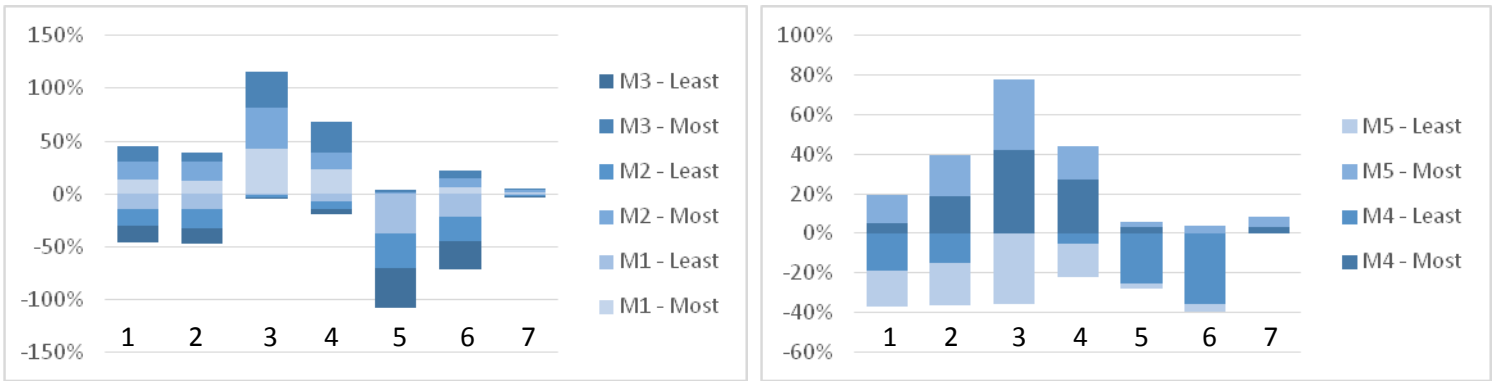


Figure 1-1: The students' answers to question 1: What two areas do you think are the most prioritised/least prioritised?

Responses to the first question showed that the students agreed in some areas, but disagreed in others. In three areas, the students' answers were uniform: more connection with the industry, no need for freedom in study pace and not fewer elective courses. However, some students thought freedom in study pace would be good. The students in the bachelor cycle wanted more elective courses, but students in the last years seemed to be more satisfied with the current structure¹. There were two categories where the students did not agree: credits for internship and projects with students from other programmes. One observation that was made was that some students wanted internships, but they did not like the idea of getting credits for it. Other students thought that it is up to the students themselves to get internships or summer jobs, i.e. not something the university should do for the students. The students at the workshops mostly agreed with these answers.

The answers to the second question (regarding if the students feel that something has been missing during their education) have been grouped into categories to make the analysis easier, Figure 1-2.

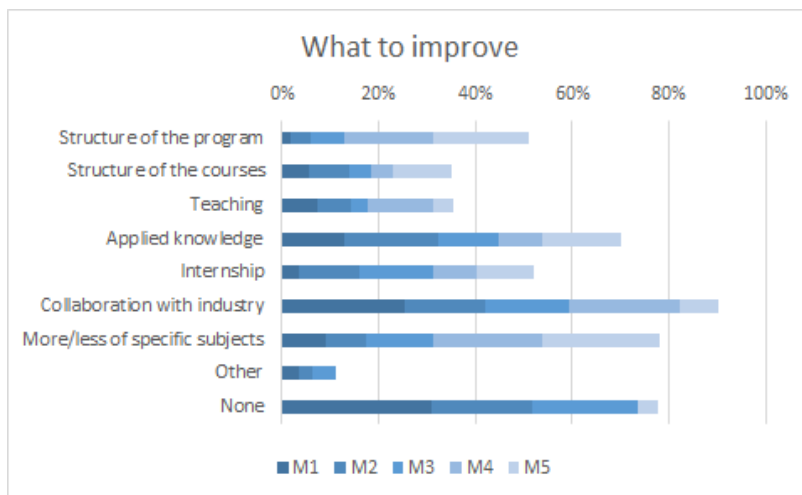


Figure 1-2: The students' answers to question 2: Have you missed something during your education?

¹ The master programmes have a lot more elective courses than the bachelor cycle.

This question confirmed that the students want more collaboration with industry, but the interest is lower for the oldest students. The students at the workshops mentioned several reasons for why they want to have more collaboration with the industry, see table 1-2. A few students also mentioned the connection to research and the departments at Chalmers.

Table 1-2: Why students want more collaboration with industry

- want their education to be close to the reality
- to know what a future career could look like
- to stay motivated
- to know how, and that, they will use the things they learn in the courses
- to know how the industry works
- want real world problems
- want insight into the job market to know which direction (master) to study
- want to be more attractive on the job market, by having work experience from real case(s)
- don't want the university and studies to be in a "bubble"
- want to see how theory is applied in industry

There are a number of ways to collaborate with the industry, but the most common way, a guest lecture as part of a course, isn't beneficial if the lecturer mainly promotes the company and him/herself. The students say that they want to know about how theory is applied within the company and what their role could be as an employee with the company. Table 1-3 shows some different ways to interact with the industry that was suggested by the students. One thing to have in mind is that the students want to interact with engineers in industry and not human resources or just get an event paid for by a company. The students did not agree upon if the need for collaboration between the bachelor and master level was the same or if it differed, and if it should be adapted or not.

Table 1-3: Ideas on how to include the industry in the education

- Mingle events
- Case projects
- Study visits
- Mentors
- Real projects from/performed in industry
- Study trips, (possibly abroad)
- Guest lectures
- Mentorship
- Contact with alumni within courses

The students mentioned in question 2 that they want clearer guidelines as to what career opportunities the education gives them, and one student writes that it is easier to feel motivated if you know what you can become. One student from the master programme Product Development says that the industry sometimes requests a portfolio of reality-based projects, and that it feels like the education is lacking in this area. It is noticeable that several students answered that they wanted internships, but that they thought it was a bad idea to get credits for them, as suggested in question 1. The students also

requested more applied knowledge/skills, and to learn about what happens in the real world. One student wrote that the education was too theoretical and that it felt like it was pretend. The students have suggestion for changes in courses and the programme structure, and some students say they miss time for reflection because of the pace of their studies. Other students would like to have other types of examination than written exams, because there are no exams in the industry and students have different learning styles. It is noticeable that there were a significant amount of students from the bachelor cycle that actively chose to answer “no” to if there were things they would like to change with their education, and many students that did not answer this question, the latter is not showed in the figure above.

The students at the workshops, the PhD-students and answers from question 2 in the questionnaire, figure Y, suggested new or an increased amount of some subjects, see table 1-4. However, they had a hard time trying to decide what parts or courses to decrease or eliminate. One way to be able to study more different subjects is to increase the amount of elective courses. As the master programmes have at least 30 credits that are elective, the discussions about increasing the number of elective courses has mostly concerned the bachelor cycle.

Table 1-4: Areas/subjects sought after by the students

- Foreign languages
- Law
- General principles in programming
- Bachelor courses within the future master area (e.g.mathematics based courses, chemistry, management, programming)
- Communication and written skills
- Social skills and more projects
- Less projects and more individual work

Several of the students at the workshops were concerned about the quality of the mechanical engineer of the future if there would be more elective courses in the bachelor cycle. This fear comes from their perception that there is a lot of basic knowledge that a mechanical engineer should know, and if there were a lot of electives, the students would take “the easy way through the education” and so the meaning of “mechanical engineer” would be diluted. The discussions also circled around the fact that many students choose to study the mechanical engineering programme because of its width, and some students think they have to choose elective courses too early today², while other said that you have to select a path some time, you cannot wait forever. The students also said that they would rather have more opportunities to take elective courses, with fewer choices per opportunity, than many choices for only a few courses. One way to do this is to introduce tracks, which could maintain the red thread through the education. However, it is important that the students get enough of information about the industry and future career expectations, which were emphasized by one of the PhD students. One other PhD student highlighted that if there are elective courses within subjects that aren’t mandatory for the master programme, but in the same field, there is a large risk of overlap.

² Today the students choose their first elective course in the spring of their second year.

The students at the workshops and answers from the questionnaires suggested some improvements of today's courses. They want more integration between courses, teachers with better pedagogical skills, better structure of the courses, more open and applied problems, and that the laboratory work should be improved. One course where the pedagogical structure divides the students in half is the course in Mathematical Statistics, some think it is a great structure while others struggle with it. The students also disagreed on how project should be organised. Most students saw benefits with having projects with other students outside the mechanical engineering programme. But some of them have bad experiences working with students from other programmes, and think it is enough projects at the master level where the groups consist of students from different bachelor programmes. There was also a discussion if the groups should be pre-determined or if the students should be able to choose for themselves and several of the students said that they don't like to be graded as a group. If grading is done on a group-basis, the students would like to be able to put together their own groups so that the ambition level can be someone homogeneous among the group members. One risk identified with working in projects, except that it can be uncomfortable, is that the students only practice the parts they are good at, e.g. one student likes to write and therefore produces the main part of the report, and another student does all the calculations.

In one area the students from the different years agreed, and it was the need of communication, report writing and social skills, see table 4. These qualities were both highlighted in the questionnaire (question 2 and 3) and at the workshops. The students think these are qualities that are needed and they would like to practice them more. Instructions for written reports is preferred, and also that the teachers set demands on the structure of the report as well as the content. At the moment, some students feel that there is no point in focusing on the structure of the report as the teachers don't pay any attention anyway.

Table 1-5: What the students would like to practice within the subject of "communication"

- Lab reports
- More presentations
- Feedback of the language as well as the oral presentations
- Evaluation of sources
- Technical English

Question 3 in the questionnaire concerning what qualities the students think future employers will value showed a variety of answers, both between the years years, and the different master programmes. The students should mention three qualities, which have been analysed to find correlations. The students in all years think that the personality is important. Twice as many students say that social- and communication skills are important, rather than the ability to work independently. Around one fourth of the students mention technical skills, problem solving, and the ability to think holistically, but among the students in their last year more than 40 % think this is important. It is noticeable that very few students that have mentioned leadership skills.

1.2 Interview with former students

Some of the PhD students, but also some present students, thought that it is more important to focus on the technical skills than the social skills, because these will be developed during a career, while others said they didn't learn how to write formal reports until the PhD studies. One PhD student from Systems Control and Mechatronics said that he felt that he could spend a lot of time in projects within a course without learning the actual subject in depth, which he would have liked to have done. Another PhD student said that he was so used to working in teams during the bachelor and master studies, that it was a challenge at first to work independently as a PhD student. He thought this jump partly depended on that his research area was new for the department. Other former students have said that the project work had helped them in their career, as they work with open problems.

Observations made by some of the PhD students indicated some differences between students from the mechanical engineering bachelor cycle compared with students from other bachelor cycles. The feeling was that some students from the bachelor part in mechanical engineering are to some extent more focused on exam results and a future job, than the actual subject, i.e. when a PhD student compared the student population from mechanical engineering to the one at chemical engineering. However, compared with students from management and economics, the mechanical engineering students focus more on outcome of the current project than meeting the expectations of a future work role, beyond the direct problem solving aspect.

Grades were discussed with one of the PhD students, and this was focused around the question: *What is that the companies request when they say they want high grades? Do the companies want high grades in certain subjects, all subject or high average grades? Is it certain knowledge, the ability to learn, interest in certain subject/s, what the students know when taking the exam, someone to lead a project or someone that have all the theoretical knowledge they are looking for? What expectations do the companies have of newly graduated? A complete product of someone with the possibility to learn and grow within the field?*

One former student within the field of entrepreneurship and business design, had some thoughts that were not entirely aligned with the other master students. She discussed the advantages of interdisciplinary work; understanding of others' competencies, taking advantage of the competencies of others and the possibility to have different roles in a project. She thought internships could help the students to be better engineers, problem solvers and thinking outside the theoretical base and known methods box. She emphasized the fact that the programme has need to consider if they want to educate individuals or stereotypes, i.e. a lot of elective courses or not.

1.3 Secondary data from Chalmers

One reason that the students within the mechanical engineering programme have different opinions about relevant subjects and the need of elective courses could be that the degree is very diverse in terms of the possible master's programmes. Figure 1-3 shows the first choice of master's programmes, within Chalmers, for students from the bachelor cycle in mechanical engineering during the last four years. It shows that the students chose programmes in a variety of fields, from applied mechanics, energy systems and naval architecture and ocean engineering, to product development, production

engineering and master programmes within economics and management. The master's programmes in figure X with an underline are owned by the mechanical engineering programme, but this is mostly an organisational structure rather having an actual impact on the studies.

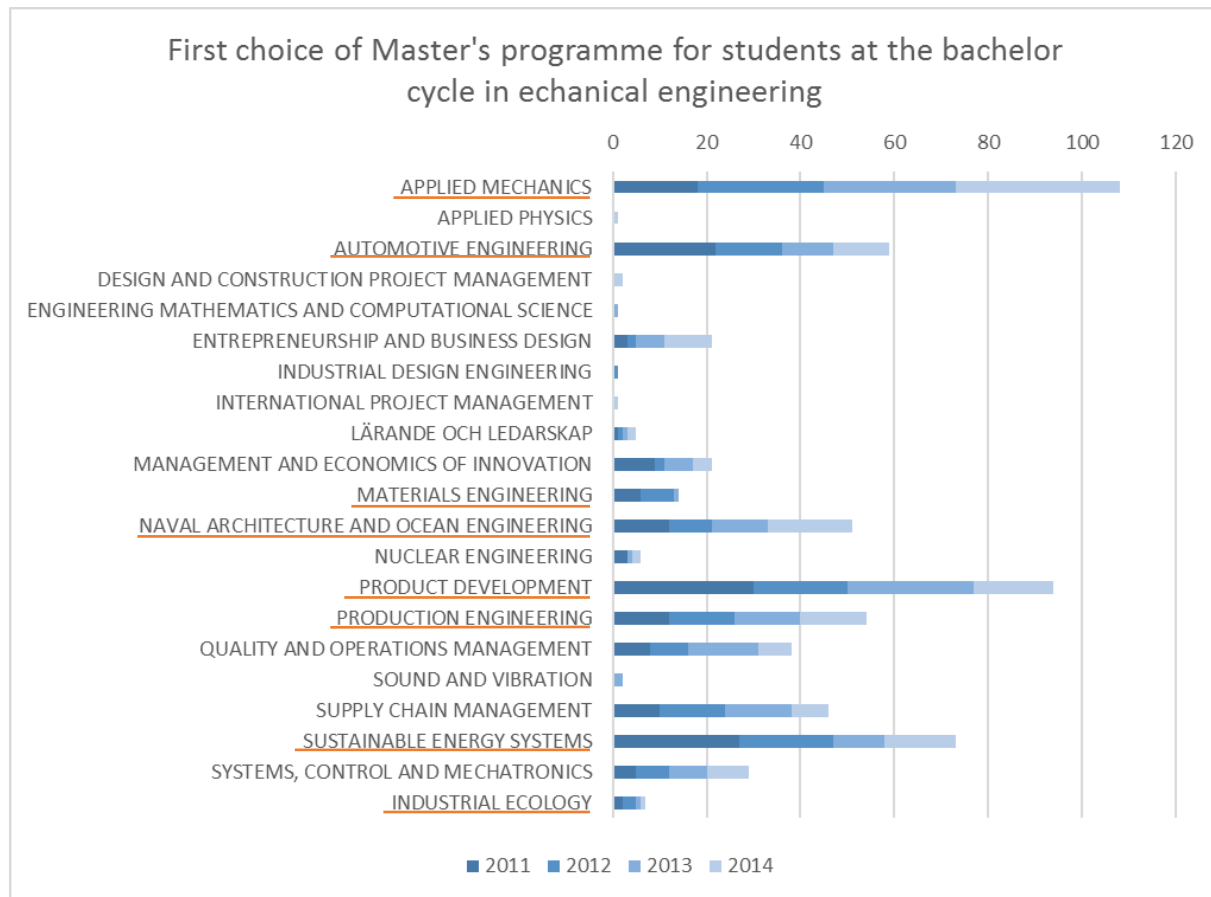


Figure 1-3: First choice of Master's programme for students at the bachelor cycle in (Sandström, 2014)

The last couple of years Chalmers has sent out a questionnaire to all first year students at the bachelor level, regarding their choice of studies. Figure 1-4 shows the results from the question "Why did you choose your programme?", and compares the students from Chalmers overall with the students in their first year at the five year mechanical engineering programme. The answers from mechanical engineering students differ in several aspects from the students from the rest of the university, and the programme's good reputation stands out as a central aspect. There were more students that chose the five year mechanical engineering programme based on its width, future work tasks and the possibility to

study a specific master’s programme than the general Chalmers student. There are also more mechanical engineering students that were encouraged by others and that also seem unsure as to why they chose the programme compared to the whole university. None of the students claim that they chose the five year mechanical engineering programme to pursue a PhD.

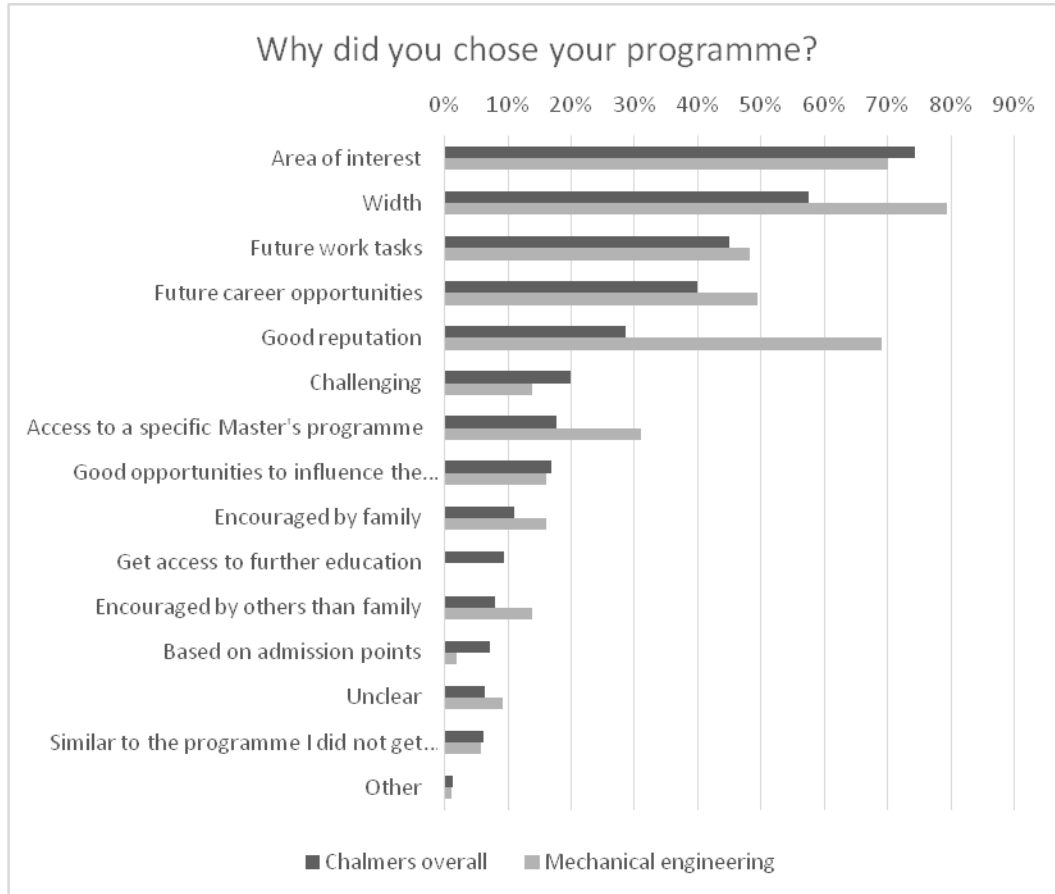


Figure 1-4: Question to newly admitted students: Why did you chose your programme? (The question is translated to English from Swedish.) (Sandström, 2013)

Chalmers sends out an alumni survey every year to the students that graduated three years previously, and the answers are analysed per degree. Nearly 40 graduates from the five years programme in mechanical engineering gave their view though this questionnaire. It is made clear that the alumni have diverse careers, but the three most common jobs are within product development/construction/design, analysis/simulation, and project management. The graduates’ responsibilities are within these areas: project manager (over 40 percent), technical specialist (over 40 percent), and development and construction, and none of the respondent has responsibility for personnel. Several of the alumni have responsibilities within several areas. Most valued was the specialisation, and the width of science and technology in the programme. (Alumnienkät, 2013) However, the former students felt they were weaker within the field of economics, management and entrepreneurship and sustainability (Alumnienkät 2013).

The variety of interest and career is seen in the graduates' own thoughts about the education, as the opinions differ which subjects were of interest and missed. For instance some graduates think that economics and leadership, should be mandatory because "every engineer will need it", while others had wanted to focus more on their speciality, or the possibility to focus on combinations of specialisations. The same pattern is shown regarding mathematics, as some wanted to have more and others less. However, the graduates seem to agree that they would like to have more collaboration with industry, work with real world problems, learn software that the industry uses, and more focus on presentation and communication skills. Some of the graduates highlight that the width of the mechanical engineering programme is a strength. (Alumnienkäten 2013)

2 Chalmers University of Technology

The students at the five year mechanical engineering programme can choose between more than 15 master programmes, listed in table 2-1. To involve this diversity in the study the directors of the master's programmes owned by the five year mechanical engineering programme have been interviewed, as have some other directors of master's programmes that are popular among the mechanical engineering students. In addition, some other interviews and studies within Chalmers have been performed to learn from other areas within the university.

Table 2-1: Master programmes that have been involved in this study

| | |
|---|------------------------------------|
| Applied Mechanics, | Product Development, |
| Automotive Engineering, | Production Engineering, |
| Industrial Ecology, | Quality and Operations Management, |
| Learning and Leadership ³ , | Supply Chain Management, |
| Management and Economics of Innovation, | Sustainable Energy Systems, and |
| Materials Engineering, | Systems, Control and Mechatronics |
| Naval Architecture and Ocean Engineering, | |

2.1 Interviews with master programme directors

The interviews with the directors of the master's programmes focused on the master's programme's perspective on the mechanical engineering bachelor cycle, what is characteristic for the master's programme, and also to gather good examples from them. In general, the directors were satisfied with the bachelor cycle at mechanical engineering, and they valued its width. The directors wanted to attract students from different bachelor cycles. Master's programmes have none or few requirements of courses the student needs to take to apply to the programme that are outside the bachelor programme plans. The master's programme Production Engineering has lowered their requirements and the master's programme in Applied Mechanics has discussed the future of the prerequisite in the Finite Element Method. Some directors mentioned that it was a challenge with the different knowledge levels and skills among the students (e.g. the master's programmes within economics and management), but they wanted the width of knowledge between the students. If the mechanical engineering students would have more courses within the subject of the master's programme during the bachelor, the master's programme would have to raise the bar of their courses which would limit the number of bachelor cycles that fulfil prerequisites to the master's programme, or the students from the mechanical engineering bachelor cycle would have to repeat courses in the master's programme. However, the director of the master's programme Naval Architecture and Ocean Design, said that the two first courses at the master's programme could have been mandatory elective courses for the student that want to study Naval Architecture. One of the directors said that he either wanted the students to have broad knowledge or having students specialized in different disciplines and then combine them during the master's studies.

³ A master degree taught in Swedish, which is both an M.Sc degree and a teaching degree. The programme is called Lärande och Ledarskap in Swedish

The directors were, in general, sceptical to the introduction of more elective courses or tracks during the bachelor cycle. In addition to what have been mentioned above, individual directors expressed the following: the bachelor might become too “scattered”, when the industry would rather have standardisation. With this in mind, tracks seem to be a better choice than elective courses because the university is probably better suited to find a red thread through the education than individual students. Moreover, if the number of elective courses increases, the demand on the university to inform and guide the students would be higher and the same resources (money and staff) would have to be spread out over more courses.

Most directors had some ideas on what could be improved in the bachelor cycle of mechanical engineering. Both the former director for Product development and the director of Naval Architecture and Ocean Design had a feeling that the students skills in mathematics and technical subjects were decreasing, even if the course content and learning outcomes seem to be at the right level at the bachelor courses. All new students at Naval Architecture and Ocean Design take a diagnostic test and the results show a downward trend, which forces the teachers in the first courses to focus on repetition during the first weeks. This challenge might be related to pedagogics and the students ability to absorb knowledge, or possibly that it has become too easy to pass the exams. Some of the directors thought the technical skills were lacking on the behalf of the social soft skills, report and presentation skills, while other said the students need to improve these skills as well, especially the language skills, and in comparison to students from Management and Economics, the presentations skills. Table 2-2 covered the directors thoughts of what could be improved during the bachelor programme.

Table 2-2: Ideas of improvement of the bachelor programme in Mechanical Engineering

- Search and assimilate feedback
- Clarify two entrances to product development; innovations, and incremental development/evolvement which sets different constraints
- Intellectual property rights
- Quality aspects and fluctuations
- Indirect pre constraints in projects and different stakeholders
- Open problems, the students are used to straightforward questions and to use all information they get.
- Specific courses valid for the master programme, e.g. mathematics, applied mathematics and thermodynamics for the master in Sustainable Energy Systems or a bigger/addition course in Industrial Economics for the master programmes in Management and Economics
- Report and presentation skills, having a standard report
- All aspects of sustainability and to have enough depth in knowledge to make it relevant and interesting
- The ability to work with many ideas, not just limit it to a few
- Scientific theory
- Work with different approaches and ethics
- Be able to work independently, even in projects

The interviews also concerned the future of the students. The master’s programmes focus both on the industry and the academics, but the main focus is in general towards the industry. Several of the programmes have a close connection to industry, especially in the more “applied fields” such as Management and Economics, Product Development, and Production Engineering. The latter two said they didn’t want to educate the students to certain roles in the industry, because these already have competent people and the students should meet and shape the future and that the industry is changing continuously. The discussion about the different degrees, the academic master’s degree contra the 5 year engineering degree, is hard to have with industry because, generally, they do not know the difference. Some of the directors mentioned that the personal characteristics, the ability to work independently and the thesis are important for the first job, and that companies in general values the width but that some specialised competencies might be needed. The directors had some thoughts about what will be important in the future, see table 2-3.

Table 2-3: The master programme directors’ thoughts of what is important

- Interdisciplinary and cross-fertilisation
- Fluffy holistic context
- The politics and market context/constraint
- Holistic view and understanding
- Technology’s role in society
- Have a basic theoretical knowledge, be able to draw conclusions and have a dialog with different stakeholders

The master programme directors also gave some ideas and concerns, table 2-4.

Table 2-4: Ideas from some of the Master’s programme directors

| Ideas | Concerns |
|--|--|
| Give the students feedback during presentations | It is hard to develop the skills among the teachers when we do not want to talk about “bad teachers” |
| Flipped classrooms, i.e. have discussions within the classrooms, and new material between classes | If we would use the 3+2 degrees optimally, studies at other universities (in Sweden and abroad) should be encouraged |
| Get influences from Institute of Making in London | The students do not seem used to repeat knowledge from previous courses |
| Use “host companies”, the students are divided among the same companies for several courses (Used today at Supply Chain Management) | Too many credits in the master degree can be from courses at bachelor level |
| Individual research projects to both practice the academic part of the study and to work independently (Used today at Supply Chain Management) | Students can perform their thesis even if they lack many credits |

| | |
|---|---|
| Have a “face” for the programme | It feels like some students do not do an active choice of master programme, and do not have any expectations |
| Opportunity to learn the basic knowledge in the Office software | Some master programmes are more visible than others during the bachelor cycle |
| Engineers that attend classes and help the teacher to connect the course content to the reality “master-engineer” | It is hard to have the right level of difficulty in the courses, and it is especially difficult with international students |
| | It is hard/it is not encouraged to promote individual master programmes internationally (miss potential students) |

Some of the directors felt like their field didn’t get enough attention during the bachelor studies, or that the focus might be wrong. According to the director of materials engineering, students think material science is narrower than it is, and that it is just to decide materials, and missed the strong link between the product development processes. In reality there is a lot of variation in material properties, an issue of material risk management and one needs to consider the context in a product development process. The director of Industrial Ecology thinks there is a need of a full course (7.5 credits) within environmental sustainability in the bachelor programme to be able to cover environmental methods, otherwise there is a risk the course will only cover one method, for instance LCA, and miss the fundamentals about sustainability.

2.2 Other interviews within Chalmers

The interview with the director of the master programme Learning and Leadership⁴ focused more on good examples than on its view of the bachelor programme in mechanical engineering, as few mechanical engineering students study that programme and the programme differs from the traditional master programmes. The focus of the master programme is on didactic skills and interpersonal relations, which can lead to both a future teaching career and a future engineering career. He believes that some engineers should be experts in technical areas, but it is also important to have engineers with their expertise in communication and leadership, as industry and society need both. The programme involves four internships periods and two high school teachers as “master-teachers”. One idea that was discussed was the possibility to have “master-engineers” at the bachelor level, someone from industry that is present during lectures and could connect the content to a professional role. On the master level on the other hand, one idea could be to let companies invest their employees’ time in studying master courses and that the employees could contribute to the course’s connection to industry and the programme’s development. He was more positive to elective courses than the other directors, as he thought that free choice and motivation are connected. The interview also covered the pedagogical structure of bachelor cycles and master programmes and that it might be wise to have a structured way

⁴ The master programme is in Swedish (called Lärande och Ledarskap) and the students get both an engineering and teaching degree

to study during the bachelor and then gradually give the students more and more freedom and responsibility.

An interview was conducted with one of the driving forces behind Challenge Lab. The objective of Challenge Lab is to include sustainability in research, education and industry. No one can solve the issues of sustainability by themselves, and Challenges Lab focuses on multidisciplinary projects (such as master theses) and teaches the students to work with multiple stakeholders. The person interviewed thinks the method behind Challenge Lab is possible to adapt in courses and projects at Chalmers, and that courses could have their own space, where students and teachers could meet spontaneously and where the projects could be visualised at the walls. Other ideas that were discussed were: tours in the different departments and labs at Chalmers for teachers, new students and students, and to include schoolchildren in the world of the university.

During the project, MOOCs⁵ have been highlighted from different stakeholders, and therefore a meeting was arranged with one representative from the Executive Committee for Education at Chalmers, which has discussed MOOCs during the year. Chalmers, and Sweden, doesn't consider a MOOC a course, as they do in the US, rather as a way to acquire new knowledge without credits, exams, and grades. Chalmers is investing in two MOOCs, for marketing and further education, and equipment and knowledge has been obtained.

2.3 Input from other five year programmes at Chalmers

Chalmers has a goal to recruit the most motivated students, and therefore the admission process has been investigated during this project. A couple of programmes at Chalmers have an additional admission paths in addition to grades and the Swedish Scholastic Aptitude Test; a test in mathematics and physics, and a test in architecture. The test in mathematics and physics is a written exam, while the architecture exam consists of two parts, firstly one home assignment, and if passed, a two day assignment at Chalmers. The director of the programme in architecture explained that the four architecture schools in Sweden collaborate to create these assignments. The assignments were introduced in the 80's to broaden the recruitment, e.g. recruit older age groups, and students with lower grades as good high school grades might not necessarily make a great architect. Architecture is a lot more about judgment than engineering, and the assignments are constructed in a way to challenge the applicants. They have seen that the students accepted on the test manage their studies well, at the same level as the other students, and that very few that drop out of their studies, as they are usually highly motivated.

During this study the advantages and disadvantages of tracks in the bachelor cycle have been discussed. At Chalmers the five year programme in Industrial Engineering and Management has several tracks in their bachelor cycle. One of the goals with the tracks within this programme is to give the students a foundation within one area of engineering to be able to relate it to economics and management. The advantages to arrange these courses within tracks, is that it is possible to create a red thread through the courses, and to balance the workload and the schedule. The students have four tracks to choose between, and also a possibility to make their own track that fulfils certain requirements. These

⁵ Massive Open Online Course

requirements are that the students should focus to deepen their knowledge in one area, it should be theoretical (not applied), prepare for a master programme and the courses should fit into the schedule. The track consists of 30 credits, evenly spread across four courses, two courses in the second year and two in the third. The students choose a track in their first year, and according to an administrator within this programme, few students regret their choice because most of them continue to a master programme within Industrial Engineering and Management, which they have access to anyway.

3 The industry

Another stakeholder of the programme is industry. A majority of the students that graduate from the five year programme in mechanical engineering go on to get jobs in industry, and this is also a path for science and technology to spread through society. The project has therefore researched the views of the industry on the mechanical engineer of the future.

3.1 Volvo Cars

Sit down interview with Mats Moberg, vice president of Volvo Cars

Mats Moberg is a member of the programme advisory board at mechanical engineering, and didn't have the opportunity to attend the workshop conducted for the advisory board. Hence, it was decided to conduct a separate interview with him, where he could give his opinion from the view point of industry. Furthermore, a large part of the graduating class of Mechanical Engineering go on to get jobs at Volvo, so their opinion is important when it comes to what skills are needed of the mechanical engineers of the future.

Volvo needs students with skills in product development, mechanics mechanical elements and that are able to work on projects, in groups or individually. The importance of teamwork was stressed several times, and the groups should be heterogenous rather than homogenous to be able to see the problem from different angles. There seems to be a trend that shows that international students are more theoretical than national students. They feel that the students educated at mechanical engineering are over-competent, 5-year engineers get jobs made for 3-year engineers, 3 year engineers get jobs for highschool engineers and so on. Product development should feature early on in the curriculum, to teach the students a method that they can apply in their future projects.

The five year programme creates more analytical engineers whereas the 3 year programme creates engineers with more hands on know-how. Even though several theoretical subjects were pointed out as important, it was emphasised that bringing a product to a customer is more than an equation. It takes many different skills and qualities, and therefore Volvo likes the idea of flexibility of the curriculum. Students should choose courses based on what they like and build on that, rather than what should be expected of them. When recruiting they look at what courses students have taken, and, perhaps contrary to most employers, they don't always go for the applicants with the highest grades. They want a mid-way grade set, not at the bottom and not at the top, and they look at what has been going on outside of the studies. What responsibilities have the students had in the student union? Do they have experiences that make them interesting from an insight perspective? Basic values, ethics and morals, were also stressed as important factors. Communication skills, being able to argue for one's opinion, both in writing but mostly orally, are important as "sometimes you don't have time to write things down". Mr Moberg believes in feedback, corrective assessment and repetition, let the students go back to their work and see what went wrong and change it.

There needs to be a good balance between theory and application, students need to feel secure in that they can solve problems with their knowledge and skills. A good example of this is Formula Student.

Sustainable development is important to mechanical engineers as they need to realise that their actions have consequences for society. They also need this insight if they intend on a future in business or industry. The engineers need to critically reflect on what their choices mean for the surrounding environment and for society as a whole.

Volvo has committed to working in the Gothenburg region for 20-25 years, after that they cannot say, it all depends in environmental and other regulations.

Several examples of how a closer cooperation between the university and the companies could be established were given, and Mr Moberg stated that companies are trying to get closer to universities but find it increasingly difficult because they only have a limited amount of working hours and it was easier “back in the day” to find time to cooperate with universities. Cases and real world examples in courses, as well as site-visits, would be a possible route. Thesis projects could be created regarding “interesting technology” that the companies have and that they want explored, an example of this was driver-less cars which Volvo is currently working on. Students could do apprenticeships but there is a fear that the university would view it as the company is doing it for “free labour”. For a cooperation to work they need to be mutually beneficial, both the university and the company need to feel like they are getting something out of it.

3.2 The Advisory Board

Workshop with the advisory board of the mechanical engineering programme.

When it comes to the contents of the programme, the broad nature of the subject of mechanical engineering was considered a strength. It was stressed, however, that the theoretic foundations be improved; rather than emphasising software and tools for doing simulations the actual theory behind it should be focused on. The general consensus was that theory is constant whereas applications and software vary depending on company and industry and so a solid foundation was the best thing to give the students. Strong knowledge in mechanics and mathematics is fundamental for the future roles of the engineers, and isn't something that companies would be willing to educate them in. Both of these subjects appear early in the curriculum and would perhaps need repeating later. One problem that was raised was that the basic concepts can't be repeated in the same way over and over, efforts need to be put into repeating them so that they are still interesting to the students. There is a possibility that the programme has gotten too scattered in its quest to please everyone, there is no model that will please everyone, student or future employer. It was questioned whether the programme has too many associated master programmes, and whether this has led to the superficial covering of some subjects. There is also a danger of there being financial gain for departments in getting more students to their courses/master programmes. In recent years many courses/programmes have dropped their prerequisite courses and so every course/programme has to start from scratch to get all students to the same level, which leads to repetition for some students.

But everything isn't theory, students also need to be able to communicate and to argue for their opinions. After showing the advisory board the opinion of the students, that they feel they need more

practise in both written and verbal communication, they responded that the students are probably better at communicating than they realise, but that there is a need for strong communication skills.

Having an exam at the end of a course was mentioned as a particularly effective way to evaluate knowledge; it is individual and also lets students reflect on the entire course before they use their knowledge. The mode of examination depends on the subject, but in general a final exam was the best solution. Continuous examinations could become too stressful for students that already have a lot of things to do. It is important that there is quality control of the examination. ÅF, for instance, doesn't always trust the grades received by students and instead give them a small diagnostic test during their interview. This then shows if the students have the necessary skills. The education today is mostly passive with students listening to lectures, maybe it would be good to introduced more "flipped classroom" pedagogics and things that would activate the students.

The CDIO model has worked well for the programme, and the "from idea to product" approach creates good engineers, as evidenced by Formula student

When it comes to the marketing of the programme it needs to reflect what mechanical engineering wants to be. Show the creativity and the solutions rather than the small details. Cars rather than engines, wind power stations rather than cogs. Both the input and the output are important, more efforts need to be put towards encouraging younger kids to study engineer, and special efforts towards women as well. Why is it that Chemical engineering and Civil engineering have more women? How do they market themselves? Mechanical engineering needs to show the group work involved, that the students are equipped to solve the problems of today by tomorrow. There could also be a problem in the way the different degrees are marketed. It is difficult to understand the difference between "Civilingenjör" and "högskoleingenjör" as well as the difference between "civilingenjör" and "master of science", this needs to be made clear, both to prospective and current students and to companies and society as a whole.

Internships and apprenticeships are difficult to find and plan with companies, and they can also be rather expensive for companies to set up. It is requested because there is too much theory and too little applied material in the curriculum, and maybe it would be easier to organise in some other way than to put in internships for course credit. It would also be difficult to fit into the programme as it looks now, and the advisory board favours summer jobs rather than "academic internships". Maybe the school could work with the companies to create summer jobs for students. For instance, ÅF has a programme that recruits promising students in between their third and fourth year, when they are most likely to take a gap-year, and gives them jobs for their year away from university. This gives the students insight into industry, but it isn't part of the mechanical engineering programme per se.

3.3 Mats Nordlund

Sit down interview with Dr Mats Nordlund, vice president of research Skolkovo Institute of Science and Technology, and with extensive previous experience from industry

The first part of the discussion concerned the administration surrounding the master thesis. For the most part, the thesis is used as a prolonged job interview by companies, as a way for them to test the students before they offer them jobs. It can also be used as a means for companies to gain new insights, what is going on at universities, and what is the latest research in their area. It can also be a way for companies to secure the competence development of their employees and to spread their knowledge. Well defined master thesis projects pose little risk to companies and they are also of relatively low cost compared to their potential gain. One risk, however is that certain countries use these projects as ways of “spying on” or “stealing technology”, it can also be the case that certain nationalities, due to sanctions, aren’t allowed to work on certain projects. This can even extend to software and tools and certain subjects*. The benefit to companies of using international master thesis workers is that the students can bring the name of the company back to their home country, thereby spreading the word and the name of the company all over the world. To create a good master thesis project a well motivated professor is required, and if this isn’t the case the companies can feel cheated and not want to offer more thesis projects to students. Ways of getting around this would be to create a database of professor where poorly functioning professors get black-listed and aren’t allowed to act as supervisors. To argue for the offering of master thesis projects the university needs to investigate the need and motivation of the companies, one idea would be to offer workshops in “How to deliver a great master thesis project”. It is vital to realise that a master thesis project needs to be a win-win situation for the company, the student and the university (professor).

The discussion then went on to the specific topic of Mechanical engineering at chalmers. Will the programme be useful in 2020? What does useful even mean in this context? Starting out with the notion that “useful” means that students are “recruitable” and competitive on the job market and by looking at the prevalent jobs of the mechanical engineering alumni some key rolls were established;

- Researcher – examining and looking for answers. Working with what is interesting not necessarily focused around a problem.
- Leaders – with a technical profil
- Project managers
- Line managers
- Constructors- system and detail
- Innovators and entrepreneurs.

Chalmers should be able to deliver all of these. It is all about the individual, and by helping them find their passion. Students should get a theoretical base (whether it be mathematics, mechanics, physics, chemistry), the knowledge should be applied through the use of CDIO, and the master programme should be about finding the passion, what the individual is good at.

The bachelor years could be used as a foundation and then the specialisation can come later. But the university is responsible for the student, the more choice they offer the more academic advisors need to be made available for the students. There is currently no good way for people to get back from industry and into a university programme at Chalmers. Maybe companies should be allowed to buy places in certain courses, this would most certainly be appreciated by industry, would create a different dynamic in the classroom and give the students a different insight than what they are used to, from the “students” from industry. It would also serve as a good way to network between students and companies.

New universities have somewhat moved on from the idea of traditional “university programmes” and have instead adapted a “problem” approach where students centre around a problem, let say sustainable energy, and then take courses related to that. This has been adopted by Skolkovo tech according to the matrix system below (picture)

To make the programme relevant it needs to realise what we have that other programmes and universities don't. What knowledge is “chalmers knowledge”? Everyone knows Newton's second theorem, and can find it easily online, but not everyone has the latest research going on at chalmers. This should be taught, most definitely in the masters programme but preferably also in the bachelor level as a means to motivate students. New research recommends expanding the practical approach to subjects, know-how and hands-on learning, this should be leveraged as there are good conditions to explore it at chalmers. Many universities focus on producing papers and articles, and whereas these have a good diffusion rate in academia it doesn't transfer as easily to industry. The industry would rather read patents, so universities should look into these possibilities.

A natural flow of people coming and going is a good thing. The different insights should be used to gain advantage over competitors.

When marketing the different degrees it is important to make clear the differences between them. What differentiates one engineer from the other? Industry is trying to understand, when they might be unsure of the kind of engineers they need, the kind they want or the kind they think they want they need to at least know what is being offered to them. Something similar can be said for students early on in their education, they might not know what electives to take or how to specialise, and in that sense tracks are a good idea. The option to pick and choose your own degree is also a good idea, and should be made available for students that know what they want. More electives and chances to customise their education may lead to happier, more motivated students, and is worth exploring. When looking into tracks there are several different ways to look at it, the general thought should be that the tracks individually should be broad, but not too scattered, and give a clear guidance to students.

The American university system uses more and different ways of examination, from homework to essays, exams and attendance. With these modes of examination comes the need for quick and clear feedback. This motivates students as they can monitor their own progress, and also encourages continuous studying.

Swedish engineering education used to have mandatory apprenticeships/internships as part of the degree, this because it is important for students to see what goes on “on the shop floor”. One suggestion is to adopt a model of “a degree with a year in industry” perhaps between the bachelor and master level so students can find their passion. When it comes to developing qualities in students outside the university foreign exchanges is a good idea, but what is the goal of this? Can another university in the same country be considered an exchange or is it only an international exchange that counts? There seems to be a mentality of “if you have partaken in an exchange you are somehow better than your peers” but what is it exactly that is better? Foreign languages and experience in dealing with different cultures can be seen as bonuses by companies, especially if they are in some way related to the company itself. The ability to embrace change was also mentioned as one of the benefits of students having part-taken in exchanges.

3.4 IF Metall - a workers' Union

Sit down interview with Ola Asplund, Senior Advisor to the union IF Metall.

During the project one of the Swedish engineering union presidents wrote a column in the engineering news paper “Ny teknik” stating the importance of practical experience for the engineers of tomorrow. The column was co-written with the president of ABB and because of the modest number of answers to the questionnaires sent out by the project-team, it was considered interesting to see what the union thought about both the future of mechanical engineers but also the low number of answers. It should be mentioned that the union IF Metall is not the main union for graduates of the five year mechanical engineering programme but rather for operators and metal workers.

The interview was conducted in mostly general and broad terms due to the fact that Mr Asplund understandably doesn't have explicit knowledge of the mechanical engineering programme in particular, nor the Chalmers educational system in general. What was highlighted however was that it is considered very beneficial when recent graduates come out into the workforce with prior experience of having worked on the “shop-floor”. This reduces the risk of differences in attitudes and personalities as the graduates aren't completely unprepared for what life is like outside university. It also gives valuable practice for students as to how to apply the knowledge they've gained at university in an industry setting.

Other points discussed centred around the skills of the engineer of the future. A project is currently undergoing with the aim of distinguishing what qualities set Swedish engineers apart from engineers educated internationally, and how these qualities can be used to market Swedish engineers both nationally but also internationally.

4 Universities

The universities are arranged in the order they were visited/contacted. Due to changes to the project the direction of the interviewed changed as the project progressed.

4.1 Stanford University - USA.

Interview with Sheri Sheppard, the Burton J and DeeDee McMurtry University fellow in undergraduate education and Professor of Mechanical Engineering at Stanford University.

Stanford benefits from being a university teaching a wide array of subjects. Because of the freedom of choice in the American university system students can combine several different courses in their degree.

There are voices in the department that would like to add less structure to the current programme, perhaps with a recommended programme plan or similar, to make it easier for students to choose courses and customize their program to their own goals.

Financial assistance is in place to help students be able to afford their education. This ensures that the students admitted aren't of a homogenous group (in their financial status) but can come from minorities and disadvantaged social groups. This is seen as one of the strengths of the university.

When a new teacher goes about implementing a new course there is a workshop series or a "boot-camp" where the theories and pedagogics can be tested on other members of the workshop (teachers). This to eliminate the "child-illnesses" of first-time teachers, while exposing these new educators to new types of pedagogics. Course design workshops are also available more generally to faculty.

Course evaluations are not mandatory but students are greatly encouraged to fill them in. The incentive comes in the form of advance notice of grades, if the student fills out the questionnaires.

Stanford tries not to focus on Silicon Valley as a target group for their students, but equally they know that many students go there upon graduation.

4.2 Massachusetts Institute of Technology (MIT), USA

Interview with Dan Frey Professor of Mechanical engineering at MIT and member of the Mechanical engineering visiting committee.

Only 7% of applicants admitted to the undergraduate class, and the graduation rate is considered to be high. Hardly any students graduate early from the programme as "there would be no point". A few students need extra year.

Students get introduced to the mechanical programme through preview weekends and first few weeks at the university. After this the department has office hours that some students use to ask questions. There are also events with students and faculty together, e.g. lunches.

At the programme, 92% of undergraduates are American, which gives a slight national focus but not a local focus meaning that there isn't a focus to supply New England companies with employees.

The mechanical engineering department ensures quality of their courses by having several teachers able to teach each class. This means that foundation courses such as mathematics or mechanics can be taught all year around and this gives the students more flexibility in when they want to take their courses. The department has different recommended study plans but they also have students with individual study plans which are then approved by a professor/advisor at the start of the year... This means that the degrees are quite flexible, a major in mechanical engineering with the right courses can culminate in a second engineering degree (Technology, u.d.). It is up to the students to find a balance in their courses and their workload, but the balance between academic subjects and engineering subjects is important.

Alumni questionnaires are used to get feedback from students on their education, special importance given to general skills such as communication versus usefulness of single subjects. Like the mechanical engineering programme at Chalmers, the programme at MIT also has a visiting committee. They also use exit interviews with students shortly after graduation.

There is a centralised course evaluation process with roughly 10 standard questions. However, contrary to Chalmers there is no demand for midcourse reviews as this would be considered extra work by both faculty and students.

Records are maintained of course evaluations which in the long term can affect the salary of a faculty member negatively. However, for that to happen the problems would have to be significant and long-term. At start of a faculty member's position at MIT they are given an introduction to teaching and giving courses.

MIT uses a fairly standardised teaching system with lectures, exercises and exams. Newer pedagogics have been tested but students preferred the standardised system. A project was started in the late 1990's called TEAL, Technology Enhanced Active Learning, where investigations have been made into the use of technology in the delivery of education (specifically in physics courses). There are specially designed TEAL classrooms that have been developed with the aim of increase the interactive nature of the lectures and exercises, and several assessments have shown that this method of teaching has proved successful. (Technology, u.d.)

The department heads work on the strategy, and they focus on the long term, meaning 10 rather than 5 years. The level of students' skills show a lot of variability with high highs and low lows. The criteria used to evaluate engineering students are shown below.

Table 4-1: ABET criterias a-k

- an ability to apply knowledge of mathematics, science and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- an ability to function on multidisciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively (3g1 orally, 3g2 written)
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- a recognition of the need for, and an ability to engage in life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

4.3 Mechanical Engineering at RWTH Aachen University, Germany

Skype interview with a student representative at the Mechanical Engineering faculty

Mechanical Engineering is the oldest field within RWTH Aachen University, and the faculty of Mechanical Engineering awards both bachelor and master degrees (RWTH Aachen University, 2014). A Skype meeting was arranged with a student representative from the bachelor programme within Mechanical Engineering, and he gave the information summarised below.

Every year, around 1800 student enrol in to the Mechanical Engineering faculty, and about 50 % of them get an actual degree. When the students start their studies they are divided in groups of 15 students with an older student as a tutor to guide them in the start of their study. The students have six courses in parallel, and the first two years consist mainly of lectures and exams.

Question: Is it common for Mechanical Engineering students in Germany to have internship?

Answer: *Yes, for mechanical engineers, we are not physicists.*

The students have two periods for internships during the bachelor, which in total are 20 weeks. The first internship should be performed before the students even start at the programme, preferably during the summer prior to the study. The internship is six weeks long, and is performed at shop floor level in industry. The second internship is a 14 week long internship, which is performed before the bachelor thesis. This internship is an engineering job, and most students perform a longer internship than required, up to six months.

4.4 Mechanical Engineering, ETH Zurich, Switzerland

Email exchange with a coordinator of studies at the department of Mechanical and Process Engineering

ETH Zurich is a university that almost doubled the number of students during the last ten years, the majority of this increase is in students at the master level (ETH Zürich, 2013). In the mechanical field the increase has been from 200 new bachelor students in 2003, to over 460 newly admitted in 2014 (ETH Zürich, 2014). The department of Mechanical and Process Engineering was contacted, and the coordinator of studies has answered the questions, which are summarised below.

The department of Mechanical and Process Engineering interacts with the industry in several ways, for example research projects with the industry, an industrial advisory board, and internships for the students. At the bachelor level it is mandatory for the students to perform an internship of five weeks at the shop floor, and at the master level there is a three month internship required. Students have the possibility to become teacher assistants, to support the learning in courses.

The students have courses within social and humanities, at both the bachelor level and the master level, and the university has started a “Critical Thinking” Initiative. It is designed to support the students to develop both their critical thinking and communication skills, as well as their ability to work independently and in multidisciplinary teams (ETH Zürich, 2014).

The professors work with the short term development of courses, and can get help from the center for innovation in teaching (LET). They also have student evaluation of the courses, which is connected with the learning outcomes of the courses. The long term development of the programme is based on a revision of the programmes every 4-5 years.

4.5 Mechanical Engineering at Linköping University, Sweden

Presentation by the director of the Mechanical Engineering programme at the seminar “Simulation in education” and email correspondence with a former student representative at the Mechanical Engineering programme.

The Mechanical Engineering programme at Linköping University values its width and the possibilities for the students to be specialized within a field of their own interest. The first years of the programme focus on math, physics and classic “mechanical engineering”. In the fourth year the students choose between seven master profiles, which give them their specialisation within Mechanical Engineering. (Linköpings Universitet, 2014)

The programme starts with an introduction course where the students perform both individual assignments and a group project, which ends with a competition between the groups. A student from the programme said the course is popular among the students as it is concrete and fun.

The programme gives the students the possibility to study courses in English, French, Spanish and German. The student says that the English course is more appreciated than the other courses, but due to the fact that courses are taken outside of the programme, there are not too many students that take them. These courses are more like high school courses in the structure, which the students have trouble

with, and they would want them to be more technical than they are. There is also a possibility to study a communication course, but very few students that do this.

The university hires some students from every programme to blog for and about their study at the university, with the goal to get more prospective students interested by increasing insight into the programmes. The student bloggers have some guidelines from the university, but in general it is common sense that matters, and that at least half the content should be about the education.

4.6 Design Factory at Aalto University, Finland

Study visit at the Design Factory and interview with Kalevi Ekman, the founder and director of the Design Factory.

The Design Factory is a cross-disciplinary project of Aalto University, which opened in 2008. It focuses on conceptual thinking, hands-on doing and the collaboration between industry, students and university. The concept values a practical approach of problem solving to support theoretical studies. (Aalto University Design Factory, u.d.)

“Design Factory aims to develop a passion-based student-centric learning culture for the Aalto University.” (Aalto University Design Factory, u.d.)

The following information is from the interview, except the descriptions of the work places which are from the tour around the Design Factory.

Kalevi Ekman thinks the world is much more multi-disciplinary today than it used to be, and that it is not enough to study just one field, like mechanics. Instead the strength is within the combination of fields. However, one can't be excellent at everything, and he thinks the students should know the basics, and then be really good at something. But what this something is, is less important as the industry will always continue to change, and he emphasizes passion, strong commitment, and continuous learning. It is also important to be able to ask the right questions, and to determine if there is enough information. He believes the goal for the university is “to prepare students for work that doesn't exist and technology that isn't here yet”.

The Design Factory has flexible spaces, no one has their own room, which facilitates interaction between students working on school projects, industry people working on “real” projects and teachers supporting the students. Design Factory is also a place for the teachers to develop their teaching skills and to research within learning and education.

Our student will work in 2050, what will change and what won't change? - The soft skills.
From the Aalto introduction presentation

The tour around the facility showed a lot of different types of spaces, there were rooms that were dedicated for Skype meetings, for smaller meetings, and for brain storming sessions, figure 4-1. There were also a lot of open spaces with whiteboards, sofas, and tables to be adapted for the specific project. The facility also included a kitchen with coffee and lunch room and a prototype workshop. Many of the walls within the facility were covered by A3 posters of present and previous projects, and in the

entrance hall research papers that the Design Factory had been involved in were showed. Next door there was a facility dedicated for start-up companies, called start-up sauna.



Figure 4-1: Two of the rooms within the Design Factory

4.7 Mechanical Engineering at Aalto University, Finland

Site interview with a student at the Mechanical Engineering programme.

When visiting the Design Factory at Aalto University, a meeting was arranged with a student at the Mechanical Engineering programme. She described the following.

The bachelor programme in Mechanical Engineering consists of four major parts: 70 credits in basic engineering like mathematics, IT, chemistry, project and languages, 60 credits within the mechanical field, which includes the bachelor thesis of 10 credits, the last 50 credits are divided equally over a minor and free choice of courses. The minor should support the bachelor degree, by being either interdisciplinary or deepening the knowledge. Most courses are 5 credits, but there's also elements of one credit, these result in quite complex schedule when the students should mix 50 credits of their own choice, i.e. the minor and elective courses. One newly started (2013) minor is performed at the Design Factory, and this is an international minor. The minor is performed over several years with students from different programmes, and ends with the bachelor thesis. Focus is on product development and entrepreneurship.

The students are recommended to participate in international studies. Internships used to be mandatory, but today it is an elective of maximum 4 credits. However, the students have a compulsory course of one credit in CV writing and job searching.

4.8 Mechanical Engineering and Engineering Design and Applied Mechanics at Technical University of Denmark (DTU), Denmark

Study visit at DTU and interview with the Director of BSc in Mechanical Engineering and the Director of MSc in Engineering Design and Applied Mechanics.

DTU has both bachelor of science (BSc) and bachelor of engineering (BEng) in mechanical engineering, one difference is that BEng includes a six month internship and that the student moves to master level

after the BSc programme (Technical University of Denmark, u.d.). Both programmes are in Danish Bachelor (BEng and BSc), but the university offers over 400 courses in English from the third year (Technical University of Denmark, 2014). The BSc programme highlights the following: creating things, theory and practice, and design and cooperation (Technical University of Denmark, 2014). During the visit to the university the directors of Mechanical Engineering programme (BSc) and the Engineering Design and Applied Mechanics programme (MSc) were interviewed, and the following information is from this interview and the tour around the facilities.

The bachelor programmes at DTU consist of four equal parts, and the mechanical engineering programme is divided as follows (45 credits of each): basic subjects, specific for the mechanical engineering programme, credits within project and engineering subjects, and the last 45 credits are elective. Most courses consist of five credits and the students have a course in scientific theory. To handle the relatively large amount of elective courses, the students create their own study plan, which they have the opportunity to have reviewed and discussed with a teacher every year. When they start studying at the programme they are divided in groups of eight students, that gets its own teacher who helps them with their study plan, and a tutor. The tutor is an older student that helps the younger students with practical matters.

One semester is divided in 13 weeks of study, two weeks of exams and ends with an intensive course over three weeks. The first intensive course is after the Christmas holiday, the students spend time in the workshops and learn how to mill, grind and drill et cetera. This course is then followed by theory within manufacturing techniques the next semester.

The mechanical engineering programme develops their courses continuously, and core teachers and student representatives meet every semester to discuss to the programme. The master programmes have their own advisory board that consist of representatives from the faculty, industry and students.



Figure 4-2: Two flipped classrooms in the mechanical engineering building at DTU

The tour around the facilities showed classrooms, study halls and several workshops. Some of the classrooms were designed to facilitate discussions within the classroom, so called flipped classrooms, and not just traditional lecturing. These classrooms consisted of movable chairs and tables that were arranged for both group discussions and lecturing, figure 4-2. The workshops consisted of several different rooms dedicated to separate manufacturing processes, e.g. milling, welding and casting.

4.9 Mechanical Engineering at Royal Institute of Technology (KTH), Sweden

Phone interview with a former student representative at the Mechanical Engineering programme.

The Mechanical Engineering programme at KTH highlights the width of the programme, and that the students will have the possibility of many different career paths at both small and big companies (Studentrekrytering på KTH, 2014). There is also a possibility for the students to study language in the second year, and to study abroad during one semester within the bachelor degree (Studentrekrytering på KTH, 2014). A former student representative was contacted, and the following information is from this interview.

The two first years of the bachelor programme consists of basic mandatory courses, with a lot of passive learning, the third year includes 30 credits of elective courses and is more project based. All master programmes have some required mandatory courses the students should study prior the start of the master programme, and many students are worried about the course selection in the third year.

There is a possibility to study abroad during the bachelor level, which is relatively new. This is a separate programme, and involves courses in French, German and Spanish, to prepare the students to study in the local language for their studies abroad. The advantage of this programme is that the students will study abroad in the bachelor when the course content is similar between universities and they can be sure that all courses will give credits towards their degree.

The master's programme that the student interviewed has studied includes an industry project, which is performed in groups of six to ten students with different competencies, during one year. She thinks this is a great way to work and that these kinds of projects should include students from different master's programmes to take advantage of different students' specialisation. In this way the students will develop their skills in working in groups with different competencies and approaches.

4.10 Aerospace engineering at Delft University of Technology, The Netherlands

Study visit and interview with the director of Education, Faculty of Aerospace Engineering.

Delft University has both a bachelor degree and a master degree within Aerospace Engineering (Webredactie M&C, u.d.). The bachelor programme was redesigned in 2006-2010, and an active teaching approach was introduced (Kamp & Klaassen, 2013). Kamp and Klaassen (2013) states that educational change is social complex, even if it is not so difficult technically. A meeting was arranged with the head of education in Aerospace Engineering at Delft University, due to their focus on CDIO and

the fact that the bachelor programme has gone through a radical reconstruction process. The following information is from this meeting with Professor Adlert Kamp, the same person that had been a driving force behind the reconstruction, and ends with some comments from the tour.

Professor Adlert Kamp said that the bachelor programme had a good reputation before the redesign, but coherence and cohesion of the curriculum had deteriorated over time, and many students took too long time to finish their education. In the redesign they handled the five years as a whole, i.e. the bachelor degree and the master degree, as most students continues to the master in Aerospace engineering. However, they wanted to give the bachelor programme and the master programme their own identities. The bachelor programme should give the students the base and a width to be able to interact with and understand different fields, and the master programme should give the students depth in one area. They also aimed to have a maximum of three courses in parallel. They made a point about that the professors should not be too involved in the reconstruction process, they should only be involved on a consultancy basis, and in task forces to solve very specific, often political issues. The professors were not given any leading role in the reconstruction, because they are often biased towards their own subject and they have limited time. Many professors have little or no practical engineering experience, and might know what is needed of scientists but not of engineers.

Adlert Kamp has identified 12 aspects of the engineer of tomorrow:

1. Rigour of engineering (what to focus on in the BSc program and the MSc program respectively)
2. Unstructured problem solving (no predefined problems)
3. System thinking (holistic thinking)
4. Interdisciplinary thinking (not only mono- or multi-disciplinary)
5. Critical thinking
6. Creativity, imagination and initiative (important to implement these in course)
7. Communication and collaboration
8. Global thinking, mobility and diversity
9. Employability (including ethics)
10. Student engagement
11. Professional learning and teaching
12. Lifelong learning

At the bachelor level all courses are mandatory, except 30 credits that create a minor. The students choose a minor for the autumn in the third year, and they can choose between 40-50 minors from the whole university, and from many other Dutch universities, (technical or natural sciences, humanities, social sciences). There is also a possibility for students to create their own minor. The minor gives the students the possibility to strengthen their knowledge multidisciplinary, and many students from Aerospace engineering take a minor in economics and management. The bachelor students choose a master programme, and which master programmes the students can choose between is registered nationally in Netherlands.

All courses at the university are filmed and recorded, and the university would like to have more online courses than they have today. The director of Education would like to have new lecture material online,

to make room for discussions in the classrooms. The programme includes several project courses, and they are assessed both an individually and as a team component, because everyone should contribute and show that they have learned. The bachelor programme has compulsory training in Study Skills and Guidance, but many of the students do not appreciate it because they think they don't need it, until it is too late. Both the bachelor and the master programme are taught in English. The students get training and tests within technical writing and oral presentations, from another department at the university, and the students are graded on those grounds. They have also introduced more blended learning in the classroom, enabling the following of lectures online and making room for discussions and experimentation in the classrooms.

The bachelor programme ends with the presentation of the bachelor thesis, which is a big event, where industry and parents are invited. The presentations consist of an A3-poster and a regular presentation, where an international jury of experts from industry, partner universities and research institutes awards the best project/s. A ten page summary of every thesis is also collected in a yearbook, (which the students receives), and this is used by the faculty in public relation affairs.

The master programme involves a twelve week internship, and the programme has 800 companies worldwide involved in the internship scheme. The purpose of this is, among other things, that the students should learn to be independent and to think ethically. The programme values the collaboration with industry, and it gives valuable feedback to the faculty about the students' knowledge. Most students end up in industry, and even the student who decides on an academic career at a university has experienced at least 3 months in the industry.

The tour included a visit to the university's library on campus, figure 4-3, and workplaces for the students at Aerospace engineering, figure 4-4. The library was modern and consisted of a lot of study places, and students sitting there and studying for their upcoming exams. The workplaces for Aerospace engineering students mainly consisted of classrooms with computers and tables for group work. It is common that the students work in teams, and the teams get dedicated spaces to work in. These spaces consists of tables, two computers with the appropriate software, lockers, and access to a whiteboard.

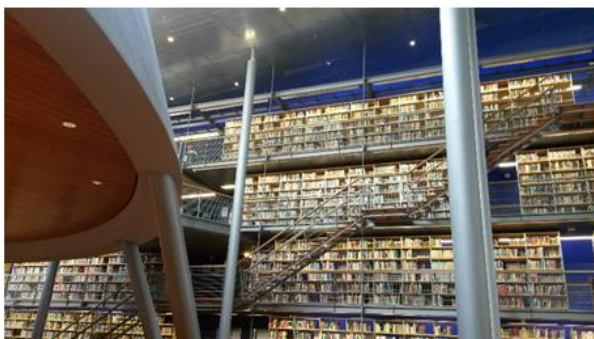


Figure-4-3: The library ¶



Figure-4-4: Study place for the students at Aerospace engineering ¶

4.11 Imperial College London

Interview with Pat Levers, director of studies at Imperial College London.

Students admitted to the programme receive a student handbook with important information including, but not limited to curriculum, important contact details. It also includes tips and tricks of student life.

Each student also receives a mentor or tutor, a faculty member with whom the student meets regularly. Furthermore, older students can also be assigned as student mentors.

The curriculum of the mechanical engineering programme at Imperial is quite similar to the mechanical engineering programme at Chalmers, but there are fewer master programmes attached to it.

Many of the students of the programme go on to work in the City, in finance or other sectors not directly related to mechanical engineering, but this does not affect the way the programme is designed. The intent is still on educating mechanical engineers rather than workers in the finance sector.

The students have few opportunities to go to study visits in the manufacturing industry, due to its location in London (where there isn't a lot of those industries around) but the students still seem satisfied with the amount of study visits offered.

After graduation and some work experience, students can choose to become Certified Mechanical engineers by applying to the Chartered Institute of Engineers. There are also other requirements that need to be fulfilled. (Council, u.d.)

4.12 Cape Stone Project and Aerospace Engineering at Pennsylvania State University (Penn State), Pennsylvania, USA

Study visits to Penn State and the Learning Factory, attending the autumn kick-off of the Learning Factory and interviews with the responsible for Bachelor of Science in Mechanical engineering and in nuclear engineering, and the head of Aerospace engineering.

Penn State University includes 24 campuses, 17 000 faculty and staff, and 100 000 students (Penn State, u.d.), and around half of the students are located at the main campus in State College. The Penn State Engineering College consists of twelve departments, and around 10 000 students (Penn State College of Engineering, u.d.).

The Learning Factory

"Bring the real-world into the classroom", is the mission of the Learning Factory. The Learning Factory is both a capstone design project, which is performed by the seniors at several programmes at Penn State, and a facility, with hands-on prototyping and design laboratory to support the projects. In the 2012/2013 academic year the learning factory consisted of 170 engineering projects, the majority in the autumn, and around 750 students were involved. The projects are mono- or multi-disciplinary, and conducted in teams of four to five students, over a period of 15 weeks. (College of engineering, u.d.)

The Learning Factory is seen as a win-win-win concept, as the purpose is that industry, the students and the faculty will benefit from it. The capstone project ends with a design showcase when industry and the

public are invited to take part of the result of the projects, and awards are handed out. All projects are sponsored by companies, which shall be available during the project, and the cost is \$3000, whereof \$1000 is the budget for the student team, which includes travel and materials. There is a possibility for the companies to own the *intellectual property* of the project that the students develop, but it has to be agreed upon prior to the start of the project. The learning factory also has industry advisory board, which consist of representatives from the industry, and has supervised the development of the Learning Factory. (College of engineering, u.d.)

The process of Learning Factory is design, build, test and repeat.

Doctor Mary Frecker, Professor of Mechanical Engineering and Bioengineering, is the director of the learning factory and she is the link between the industry and the faculty in the process of recruiting new projects and assign them to appropriate departments. There are 11 departments involved in the learning factory. There are also two other persons involved in recruiting sponsors, and the sponsors range from start-ups, to large companies. All industry representatives were invited to the kick-off, to get information about the process and to promote their project/s to the students, through an exhibition. The students then get to choose which project they want, the companies can have prerequisites, and in the end, is it the teachers that make the matches. During her presentation, professor Frecker emphasized the importance of arranging a site visit to the company, have weekly contact with the student teams, and twice during the project give them feedback. The companies should also demand professionalism from the students. The companies were also encouraged to think about the main purpose of the project and make sure they and the student team were on the same page. The presentations end with, not only student's awards, but also a sponsor award, which is based on the students' evaluations.

During the exhibition of the projects, sponsors were approached with the intent of finding out how they had heard about the Learning Factory and why they wanted to be involved, and what the strengths of the Learning Factory are, according to them. The general impression was that the companies really wanted to collaborate with Penn State, and other reasons are gathered in table 4-2

Table 4-2: Answers from companies involved in the Cape Stone project on why they are involved, and the benefits of the Learning Factory

| How companies found out about Learning Factory and why they are involved | The strength of the Learning Factory |
|--|---|
| Employees students from Penn State and are looking for good students (future employees) | An organized and good web page |
| The company has many employees that have studied at Penn State | Relative cheap |
| I am a Penn State alumni and wanted to collaborate with the university and find the web page | Have the possibility to sign a confidentiality agreement and intellectual property rights |

| | |
|--|---|
| Through connections, word of mouth | Interdisciplinary projects |
| Have other connections to Penn State and then heard about it | A way to get projects done |
| Has a child that studies at Penn State and heard about it | Find future employees |
| The company has chosen some universities to support, including Penn State, and this is one way | Hires from Penn State and this is a way to be seen |
| | To get new ideas and input to projects |
| | Get things done, that isn't super important but are beneficial if they are done |

Professor Martin Trethewey, responsible for Bachelor of Science in Mechanical engineering and in Nuclear engineering. When discussing learning, he said that he thinks the ability to train to be a lifelong independent learner is crucial. He also thinks there is a transition from book learning to open problems, and to have a broader perspective. For instance working with industry based projects, for example the Learning Factory. They did an interesting observation around the 2008 crisis, because they had feared that the number of companies that wanted to be involved in the Learning Factory would drop dramatically, but the opposite happened. He thinks one of the reasons was that the companies saw a possibility to get work done at a low cost.

Have tried to let the students choose their roles, but it easier to just let it happen.

//Professor Martin Trethewey

He said that one vision is to create global student teams, and today they have some partner universities. They have had some projects within the Learning Factory with mixed student groups, with students from Penn State and another university, where the sponsors are located at both locations. The whole team never met, and they had their communication over the internet and they managed to handle the time differences, which could be as large as 13 hours. Professor Trethewey says it is more demanding than usual projects, for both the students and the teachers and the students become aware about the culture differences.

According to professor Trethewey one of the strengths of Penn State is that they have diversity among the faculty members, including a lot of international staff. He thinks this limits the usual "university bubble". Among the students around 85-90 % will eventually work within the industry and the rest of the students will choose an academic career, so their education has to be relevant for both. It is the faculty that decides what should be included in the Mechanical engineering degree, but a professional society accreditation organization establishes the lowest limits for number of credits in mathematics and science.

Professor Lesieutre - Aerospace Engineering

A meeting was arranged with professor Lesieutre, head of Aerospace engineering, to determine the similarities between the bachelors of Science in Mechanical engineering and in Aerospace engineering, and the following information is from this meeting. The major in Aerospace engineering is highly technical, as 75 percent of the credits are in mathematics, science and engineering (Department of Aerospace Engineering Penn State, u.d.).

Professor Lesieutre said that the first two years at Penn State are quite similar for all engineering students, focusing on mathematics, physics, chemistry, English, economics and health education, with only a little "engineering." The students start to specialise during their third year. The bachelor in Aerospace engineering requires more prescribed courses than many other majors, including programs at other universities. The reason for this is that the department thinks it is important that the students learn both about aeronautics and astronautics, and students do not join the major until the third year. There used to be a description on a national level (associated with the accreditation board, ABET) about what Aerospace engineering students should learn, but this description does not exist anymore, and today it is the faculty that defines it (and ABET mainly monitors the process). Some of the students pursue a minor in addition to their major in Aerospace engineering, and it can usually be fit within their four year program. Internships are also offered; perhaps 10 percent of the students take the formal opportunity, and more informally.

The program aims to provide students with a system-level understanding of aerospace vehicles and the constituent technologies. The Aerospace engineering program includes a full-year capstone design course, not a one-semester project as in Mechanical engineering (i.e. the Learning Factory). Many students also join different aerospace competitions, e.g. "AIAA Design-Build-Fly", sometimes for credit and sometimes as an extracurricular activity, and many of these involve "hands-on" engineering projects. These design courses, projects, and competitions emphasize the importance of working in teams as well as the ability to synthesize and integrate course material. When talking about the future, professor Lesieutre thinks technology will continue to evolve, which will change the way of working, but the ability to think analytically and critically will always be important. For instance to question the output that is given by computer programs and not just accepting them. For the bachelor program he feels that they do not have to market extensively to attract students, they have all they can handle given the size of the faculty. But it is more important at the masters and doctoral level as half of the students come from outside the US. The university does some advertising, and the college of engineering, and the faculty does some advertising as well.

4.13 Olin College of Engineering, Massachusetts, USA

Study visits to Olin, and a guided tour with an Olin student, year of graduation 2016, and interview with Christopher Lee, associate Professor of Mechanical Engineering

One of the first things the visitor sees at Olin's webpage is "Olin is different", and Olin College highlights five aspects: People-Inspired, Real World, Innovation, Impact, and Collaboration (Olin College of Engineering, u.d.). Olin wants to educate innovators for solving the global challenges of today and

tomorrow (Olin College of Engineering, u.d.). The thought of Olin College was developed in the 90s as a reaction to the way future engineers were educated by Olin's founding, and the first class was admitted in the autumn of 2002 (Wagner, 2012). The college wanted to create engineers with entrepreneurial thinking (Wagner, 2012).



Figure 4-5: Classrooms and corridor at Olin College

Rick Miller says there are three bases of learning: memorisation based project based, and design based (Wagner, 2012). He says that most education focus on the project based where the problems are pre-determined in contrast to design based where the student first has to define the problem (Wagner, 2012). At Olin the students work with complex-real-world problem and the students collaborate in projects from the start (Berrett, 2013). Olin wants their students to be *creators*, instead of *consumers*, and the courses are hands-on, and include student-led classes and self- and team evaluation (Wagner, 2012). The students design their own study plans, and decides on an engineering major according to it (Olin College of Engineering, u.d.). Olin also thinks it is important that the students develop an understanding of seeing and handling problems from multiple perspectives, because the real world is not just one discipline (Wagner, 2012). Every year around 85 students admitted are to Olin, and in 2013 was there 803 applicants (Olin College of Engineering, 2014)The students are selected through a solid process, which includes an interview and workshop weekend (Olin College of Engineering, u.d.). There are three interconnected themes at Olin, Design & Entrepreneurship, Modelling & Analysis, and Systems & Control, which all students take courses within (Olin College of Engineering, u.d.). The students also take courses within either Art, Humanities, & Social Science or in Entrepreneurship, and Olin has partner schools that offer courses by teachers with the right competences. The faculty is cross-disciplinary (Olin College of Engineering, 2014) and creative risk takers as they want their graduates to be recognised for their creativity, teamwork and risk-taking (Olin College of Engineering, u.d.). The tour around Campus

with the Olin student showed that all classrooms, except the “lecture-hall”, were designed for team work, see figures below. One common sight was islands of tables within the classrooms, and white boards around all four walls. There was also a lot of lab equipment in the classrooms, but no computers, as all Olin students got their own when they started with all the software they needed already installed. One of the classrooms had been re-designed during the summer by a student team, and they had changed the design to encourage collaboration between the student teams in courses by having a big table in the middle of the room, for all teams, and small tables around the walls, for the specific teams. The guide said that during the term, the walls and white-board were full of post-its and notes of the existing projects. The students have access to the classroom all the time, and are encouraged to study there, instead of in their dorms, and during class it common that a couple of teachers circle around the room. The corridors were full of models and posters from previous projects, figures below, from all four school years.

After the guided tour an interview was arranged with *Christopher Lee, associate Professor of Mechanical Engineering*, and the following information is from this interview. Around 40 percent of the students focus on a major within Mechanical engineering, and there are five specific classes, one elective class, and one elective mathematics course required for this degree. Olin also offers a degree in Electrical and Computer engineering and the possibility to create a personalised degree. Olin has two specified, required mathematics courses, and some additional mathematics courses the students should choose between, Olin also strives to integrate math in their project courses. All students are highly motivated and Olin makes emphasises its honour code, it is an important part of the school's culture, which makes it suitable to have homework and home exams.

Lee said that Olin focuses on the skills that the students need for their first job, as presentation- and social skills and teamwork, and that they therefore have a lot of project based courses. He says there is a trade-off, the students from Olin are better prepared for their first job than a student from another college, but the students that continue for a master’s degree at another university are lacking some technical skills. However, they are better socially, and it will not take too much time before they have caught up in the technical areas. Most students go to other companies than traditional manufacturing companies. Manufacturing companies mainly want more traditional engineers. He also thinks the future needs more of a system engineer than just engineers that are specialized within the mechanical area. Table 4-3 shows some characteristics that were discussed about the three interconnected themes.

Table 4-3: The three interconnected themes at Olin

| | |
|---------------------------|--|
| Design & Entrepreneurship | “How do I get the resources I need” |
| Modelling & Analysis | Use software tools to solve complex problems, and be able to verify the result. They use various tools including experiments and estimation-type calculations. |
| Systems & Control | “How does it fit in the big pictures” |

The design process, from idea to final product, and the user, are the focus at Olin. He said that every student is introduced to the design process, and the students are encouraged to develop a personal approach. It is crucial to involve the user, as everything starts and ends with the user. In one course during the first year the students should design a toy for fourth graders, and the students meet their customers at the beginning and at the end of the project. The fourth graders evaluate the toys designed by the students. Feedback and iterations are other central concepts at Olin, to improve the design process and the product. No one can know from the beginning, and they focus on encouraging the students to try. The students usually have four to five courses in parallel, and the majority are project based courses. In most projects the students choose their roles, but in some they are predefined. It is hard for the teacher to decide the leader, as the leader needs to be accepted by the group. However, the students are encouraged to work in fields where they need to strengthen their skills. The students also get a faculty advisor, who works as a mentor and help them choose between classes.

The Olin studies ends with a senior capstone program in engineering, which consists of industry sponsored projects. Olin has a faculty member that is responsible for the collaboration with the companies, as the workload would be too high on the professors if they would be responsible.

The interview ends with “It is the people, size, structure that makes Olin work.” Other universities and colleges should not just copy what Olin does, what works at Olin may not work at other universities, the size and culture might differ and changes must fit to the context.

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