Exploring the dual nature of engineering education

Opportunities and challenges in integrating the academic and professional aspects in the curriculum

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“You don’t get good work without good ideas, but the ideas come from the work. [...] And learning to listen to the work that you’ve already made is really where all the core ideas come from. One work is the mother of the next.”

Antony Gormley (CNN, 2015)
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Abstract

The theme of this thesis is the dual nature of higher engineering education, meaning that it is simultaneously academic, emphasising theory in a range of subjects, and professional, preparing students for engineering practice. The dual nature ideal is however also a source of tensions. Taking a critical approach and embracing the complexities of the issues, the theme is explored in the context of engineering education development, here represented by the CDIO (Conceive, Design, Implement, Operate) approach, founded in 2000 by MIT, Chalmers, KTH, and Linköping University. Cases on programme and course level illustrate how the dual nature ideal is pursued in the development of the integrated curriculum. CDIO is also compared with PBL (problem/project-based learning), which leads to an investigation of opportunities to further emphasise research in the CDIO community.

Two critical investigations are made to deepen the understanding of the theme. First, taking a historical perspective, the CDIO approach is compared with the writings of Carl Richard Söderberg (1895-1979), showing the persistence of the academic-professional tension. Further, many of his ideals, arguments, and proposed strategies are fully recognisable in today’s discussion. Notably, Söderberg and CDIO share the ideal of mutually supporting professional and disciplinary preparation, implying that there need not be a zero-sum game in the curriculum. This leads to a critique of the common swinging pendulum metaphor. Next, another critical retrospection is used to problematize engineering education development. Accounts of unsustainable change leads to a model called organisational gravity, explaining the stability of programmes. The model implies two change strategies, each with different availability, risks, resource demands, and sustainability of results. Another consequence was to conceptualise educational development as compensatory work, promoting such values that are necessary for education but insufficiently represented in the organisation.

Both these critical accounts suggest widening the perspective from curriculum development per se, to exploring the organisational conditions. Refuting a rationalist “machine” view on the organisation, an alternative theoretical framework is assembled, based on institutional theory. In particular, an institutional logics perspective is applied, focusing on practices and identities in the organisation, and discussing the scope of institutional innovation in the interplay between the organisation and actors on the field level.

In the light of the theoretical framework, a tension between two competing professional logics within engineering education is identified: the logics of the engineering profession that we educate for, with the assumption that education is about teaching future engineers, and the logics of the educators’ academic profession, consistent with the assumption that teaching is about conveying theory. A corresponding tension is identified within the research practice: between the university as academia, seeking knowledge for its own sake, and as public service,
seeking useful knowledge. The first is consistent with the logics of the academic profession, while the latter shares many values with the logics of the engineering profession. The analysis suggests a double hegemony where the logics of the academic profession are the strongest in both education and research. The two practices are also strongly interdependent, and therefore the more the research practice is dominated by the academic logics, and the more research dominates over education, the more the balance will be tilted also in education, in favour of teaching theory over (other) professional preparation. Analysing the integrated curriculum strategy, leads to the conclusion that its success on the course level is contingent on educators’ ability to unite theoretical and professional aspects, and the success of the programme level is further contingent on the collegial capacity for coordination, between the programme and the courses, and between courses. Finally, the CDIO initiative is conceptualised as a field-level driver of institutional innovation. Some of the strategies are analysed in the light of the theoretical framework, leading to suggestions for strengthening the approach and the community.
Svensk sammanfattning (Swedish abstract)


Båda dessa kritiska skildringar talar för att perspektivet behöver vidgas från ett fokus på utveckling av utbildningsprogrammen i sig, till att även undersöka villkoren i organisationen. En rationell "maskinmässig" syn på organisationen avfärdas som otillräcklig, och i stället sammanställs ett teoretiskt ramverk som bygger på institutionell teori. Speciellt används det begreppliga ramverket institutionella logiker, med fokus på praktiker och identiteter inom organisationen, och där samspel mellan organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält- och inom organisationen och aktörer på fält-

I ljuset av det teoretiska ramverket identifieras två konkurrerande institutionella logiker inom ingenjörsutbildningen, som kan härledas till två professioner: dels ingenjörsprofessionen, som vi utbildar för, som är förenlig med antagandet att utbildningen syftar till att utbilda nästa generations ingenjörer; dels lärarnas
akademiska profession, som är förenlig med antagandet att utbildningen syftar till att förmedla teori. En motsvarande spänning identifieras inom forskningen: mellan synen på universitetet som akademi, som söker kunskap för kunskapens egen skull, och synen på universitetet som public service, som söker användbar kunskap. Det första alternativet hänger samman med den akademiska professionens logik, medan det senare har flera gemensamma värden med ingenjörsprofessionens logik. Analysen visar att den akademiska professionens logik dominerar både inom utbildningen och forskningen. Eftersom utbildningen och forskningen också är starkt samberoende är slutsatsen att ju mer forskningen domineras av den akademiska professionens logik, och ju mer forskningen dominerar över utbildningen, desto mer påverkas balansen i utbildningen att tippa över mot teoriundervisning, på bekostnad av den (övriga) yrkesmässiga förberedelsen. En analys av strategin med integrerat curriculum visar att framgången på kursnivå är beroende av enskilda lärare förmåga att förena de teoretiska och professionella aspekterna, och framgången på programnivå även är beroende av lärarkollegiets kapacitet för koordination, dels mellan kurs och program och dels mellan kurserna. Slutligen skildras CDIO-initiativet som en aktör på fält- och programnivå som driver på institutionell innovation. Några av strategierna diskuteras i ljuset av teorin vilket leder till förslag för att stärka konceptet och de gemensamma aktiviteterna.
1. INTRODUCTION TO THE THESIS

1.1. Theme and research questions

5.1. 1.1.1. The dual nature of higher engineering education

The overall theme addressed in this thesis is the dual nature of higher engineering education. By dual nature is implied that engineering education is simultaneously academic, emphasising theory in a range of disciplines, and professional, preparing students for engineering practice. Hence, the theoretical and the professional aspects are not merely two separate components that need to be balanced in appropriate proportions, but they should also be in meaningful relationships in the curriculum. While the academic-professional duality is an ideal, it is however also a source of tensions.

This is a consequential issue for all stakeholders of engineering education, i.e. students, educators, employers, and society in general. And while this thesis explores the theme from the perspective of engineering education development, the same ideals and tensions are also present in other domains. The academic-professional duality is consistent with the stated aims of most engineering programmes, and conceptualised in policy work such as governance, evaluation, and accreditation of engineering education. Similar issues are also relevant for professional education in other fields, such as medicine (see for instance Bolander Laksov, McGrath, & Josephson, 2014; Christakis, 1995).

5.2. 1.1.2. Development as a starting point

The thesis investigates approaches and strategies deployed within endeavours to develop engineering education towards the dual nature ideal, as well as some of the challenges experienced. The relationship between disciplinary and professional aims is a key issue in several reform initiatives with international communities. In this thesis, engineering education development refers to efforts to improve engineering education, with the CDIO approach as the main case (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014). Such work is performed and promoted by people in many different roles, including educators in all subjects in engineering programmes, programme managers and other leaders including university management, student representatives and associations, administrators on all levels, specialised educational developers (like myself), professional representatives and their associations, as well as various international and national interest groups and associations. Hence, educational development refers here to the work itself, not to any particular category of people or role.

Not only is educational development the context for this thesis, but it is also taken to imply a critical perspective with focus on tensions and conflicting interests. Already
using the term *development* implies a favourable evaluation *a priori*, as it usually refers to deliberate change to the better. An even stronger normative statement is implied by *improvement*, which will here be used as a synonym. Both *development* and *improvement* are like vectors in that they have a *direction* as a part of their definition. The intended direction can also be called an agenda, which means that also *agency* is implied. In the discussion about what development is desirable, there are many different positions possible, but it is a normative, ideological or political debate, meaning that there is no objective or neutral position available. Barnett (1992, p. 6) puts it bluntly:

“The debate over quality in higher education should be seen for what it is: a power struggle where the use of terms reflects a jockeying for position in the attempt to impose own definitions of [the aims of] higher education.”

Any discussion about the aims of education takes us to contested grounds, with a whole chorus of stakeholders advocating their particular interests. More than half a century ago, Brown (1962, p. 343) observed:

“[The] diversity of needs, desires, and opportunities, both educational and professional, is so great that no single pattern of what an engineering education ought to be will serve.”

The thesis is also written from a basis of personal experiences in engineering education development. Hence, my role and identity embrace both that of researcher and developer. As a researcher I study opportunities and challenges for change – as a developer I am advocating, enabling and driving it. In Barnett’s terms I am jockeying for a position. Therefore, to maintain credibility as a researcher, I need to be aware of my own perspective, and be open about it. Hopefully, given the full disclosure, the insider perspective might also bring strengths, because “understanding change is just as much a matter of ‘doing’ reform as it is studying it” (Fullan, 1999). I will not pretend to be neutral and objective, since I hardly believe such a position exists, even for researchers. For instance, to embrace the dual nature of engineering education as an ideal, as I did above by making it sound natural and reasonable, is to take a normative stance. While most people would agree that this is an ideal, there are also other positions possible. The fact that the national qualifications framework supports (even mandates) this ideal does not make it neutral; it is still a value statement.

5.3. **1.1.3. Research questions and structure of the thesis**

The aim of the thesis is to explore the dual nature of engineering education, by which is meant the ideal that the academic and professional aspects should be mutually supporting. This ideal is however also a source of tensions. The focus here is in particular to investigate opportunities and challenges in efforts for developing engineering education according to the ideal. The investigation will take three main turns: first through the current strategies promoted in international educational development communities, then taking a historic perspective, then critically...
considering some of the underlying challenges for this kind of educational change. Finally, the strategies and challenges will be related to organisational matters.

The first part is an exploration of present-day models for engineering education reform. Focusing on the CDIO approach in particular, particular focus is placed on the strategies promoted to improve the education, and their underlying ideals and ideas about the relation between disciplinary theory and professional preparation. Then CDIO and PBL, another international community for educational development, are defined and related to each other. This also leads to a special investigation regarding the relationship between educational development and research. This interest is expressed as a sub-question:

- What approaches and change strategies can be identified in major engineering education development communities? (SQ1)

Next, the investigation tries to further deepen the understanding of the tensions between the academic and the professional aims of engineering education. This is done through an excursion into the past, tracing some of the historical roots of the issue. Of particular interest is to compare the arguments and positions used in the past with those that are advocated today, particularly in the CDIO approach. The sub-question is:

- How has the tension between the academic and professional aspects played out in the past, and what can be learned from comparing past and present ideals and debates? (SQ2)

Finally, the thesis critically explores some underlying challenges in curriculum development, in particular that of making change sustainable. This leads to a need for a more sophisticated understanding of the organisation, and the conditions for this kind of change. This corresponds to the third sub-question:

What challenges apply to the sustainability of educational development in engineering programmes, and how can we understand those challenges in relation to the university organisation as a context for the change? (SQ3)

1.2. Research approach and methodology

This section discusses the research approach adopted for this work, making an argument for building understandings through the engagement in practical problems situated in their natural context.

5.4. 1.2.1. A problem-led and naturalistic approach

The aim of the thesis is to produce more meaningful understandings of the relationship between the academic and the professional values in engineering education, in particular as seen from the perspective of educational development. This work thus takes its starting point in a problem, relevant for the practice of educators,
programme leaders, educational developers, and many others. Borrego and Bernhard (2011, p. 30) distinguish between method-led and problem-led research. They explain that the value of problem-led research lies in the “quality of the ideas and insights that are generated” and “the light shed on the problem under consideration”. Following Lincoln and Guba (1985, p. 189), it can also be argued that this issue *takes its meaning as much from its context as it does from itself*. They note that any observations are inevitably time- and context-dependent, and continue: “No phenomenon can be understood out of relationship to the context that spawned, harboured, and supported it”. Recognising the significance of the context where the tension and its different implications are manifest, it was therefore necessary to study it in its naturalistic setting. Since the issue is present on so many levels in engineering education and in the university organisation, it needed to be viewed from multiple angles and temporal perspectives. Relevant here is for instance how the tension is, has been, and can be enacted in the engineering curriculum, and in activities called engineering education development. Barnett and Coate (2004, p. 27) warn that “in the absence of explicit understandings of the curriculum, we are in danger of being steered towards inadequate or overly narrow conceptualizations of curricula”. The curriculum is not created in a social vacuum either, so I will also go further and locate the issues also in the university organisation, focusing on concrete implications for learning and for power. Hopefully, this research may challenge some taken-for-granted ways of working, in order to offer alternative understandings, which can sometimes inform action.

Robinson (1993, p. ix) points out that “when researchers intend their work to contribute to the improvement of practice”, it means that researchers should engage with the theorising of the people involved in the problem situation and focus on making holistic and accessible analyses. But as the aim is not necessarily to “solve” the problem, the research can be more or less intervention-based even when addressing a practical problem. As obviously no solution can do away with the tensions in education once and for all, the ambition here is rather to shed light on the problems that can be attributed to the tension, and discuss strategies for handling them more productively. The objective is then to deepen the understanding of the character of the problem and how it is manifest on different levels, questioning the current situation, and considering possible alternatives. In particular, Alvesson and Sandberg (2013, p. 63) argue for producing *alternative assumptions* as a way to increase understanding. These should be of interest both from an academic view and for people for whom the problem is real and consequential (see also Alvesson, Gabriel, & Paulsen, 2017).

5.5. **1.2.2. Educational development and critical educational research**

The engagement in engineering education, the experience base from which this thesis is written, consists of both development and research, with the ambition to bridge these two worlds. The point here is emphatically not that development is the “doing”
while research is the “thinking”, because both activities amalgamate doing and thinking. Due to differing requirements on the end results, however, the priority can be slightly differently balanced. Even when development is made in a reflective and well-informed way, the research mode can afford an additional level of reflexivity and distance. In such a context, the curiosity and confusion can be allowed take the lead, and it is possible to linger in the problematizing mode, as the immediate need for practical solutions is relaxed. Of course this may just as well spawn unproductive detours, and the lack of urgency can also become enervating. The demands created by actively working on consequential problems in real life situations, together with people who urgently need to address pressing issues, should not be underestimated; it creates a special kind of acuity, together with the benefits of immediate field test opportunities. In fact, the efforts to change things can be seen as a form of experimentation, an active probing which sometimes provokes interesting responses – potentially revealing clues to forces that are at play in the system, under the surface. Therefore, regardless of what other results are achieved, whether success or failure, educational development can also produce understanding. When new understandings come as by-products of educational development, it would be unethical not to harvest and make the most out of them, in order to grow wiser and to inform future work.

More than just a background, the professional activities in educational development constitute a direct breeding ground for the work reported here. It was these experiences that provided the inspiration for the theme and rationale for the research questions. The object of research is engineering education with its ideals and tensions, in particular as they are revealed in educational development activities, and people with an interest in educational development are, together with the research community, the main intended recipients of the results. But, educational development has also influenced the research approach in a more fundamental sense. As pointed out earlier, development attempts to transform practices into something better, and I chose to allow this critical stance to influence the research approach; perhaps this was even inevitable. There is therefore an affinity with the critical research tradition, in which the purpose is not only to understand, but also to confront, the status quo. Critical theory seeks to “uncover the interests at work in particular situations and to interrogate the legitimacy of those interests” (Cohen, Manion, & Morrison, 2011, p. 26). Following Habermas, Cohen et al. (2011, pp. 28-29) suggest that an emancipatory knowledge interest can be addressed by making sense of the current situation, penetrating its causes and purposes, analysing the power and legitimacy of the interests and ideologies at work, and proposing and testing an agenda for altering the situation. They suggest that the curriculum can be seen as a site for ideology and power:

“Ideologies can be treated unpejoratively as sets of beliefs, or, more sharply, as sets of beliefs emanating from powerful groups in society, designed to protect the interests of the dominant. If curricula are value-based then why is it that some values hold more sway than others? The link between values and power is strong. This theme asks not only what knowledge is important but
also whose knowledge is important in curricula, what and whose interests such knowledge serves, and how the curriculum and pedagogy serve (or do not serve) differing interests.” Cohen et al. (2011, p. 31)

By the same token, taking the consequences of research seriously also means considering whose interests are served by the research. This can happen in subtle ways, for instance as a side effect of focusing on some phenomenon or accepting some circumstance without reflection. Alvesson and Sköldberg (1994, p. 327) suggest that if research should not simply reinforce current elite positions, the independent researcher may strive to formulate such research questions that dominant groups may have little interest in having answered, but that are more pressing for disadvantaged groups.

### 5.6. 1.2.3. Engagements rather than measurement

Alvesson and Sköldberg identify a problematic circumstance for critical research, that researchers are subject to strong socialisation pressures from the research community to conform to established templates for desirable and legitimate research (1994, p. 329). One of the most common templates, also beyond the research community, is that research is all about producing solid evidence through the rigorous application of accepted procedures for generating, organising and interpreting data (see also Bernhard & Baillie, 2016, p. 2379). Following a system of conventions, data should be reduced to produce a limited sample, a well-defined “dataset”, which can be more completely analysed through a transparent process, available for anyone to scrutinise and reproduce. The point of this rigorous process is to “minimize the influence of the researcher’s individuality” (Bishop, 1992, p. 713). The risk with reducing complexity, however, is to diminish the relevance of the findings for the practical issue in its context (Cohen et al., 2011, p. 19). Here, the choice to study an almost omnipresent problem in its naturalistic setting does not suggest adopting formulaic methods, because the complex issues under investigation would be difficult to capture meaningfully, at least in this explorative stage. Therefore, this thesis does not attempt to follow the conventional template. Instead of restricting the mode of inquiry to any given set of operations and rules, pragmatic choices were made to drill gradually deeper into the problem, as it was understood in that given moment. Relinquishing formal reductionism made it necessary to accept and embrace the complexity and see the project as a search for meaning rather than for objective measurement. This places the thesis in the interpretive research tradition. It must be noted that the hope to reach objective truth is limited anyway, (especially) in matters of social reality. I side with Schwartz and Ogilvy (cited by Lincoln & Guba, 1985, p. 55): “There may, indeed, be an ultimate reality. However, every time we try to discover what it is, our efforts will be partial”.

In the absence of given formal procedures, Alvesson and Sköldberg (1994, p. 330) emphasise the importance of interpretation and reasoning, and of seeing phenomena in their broad societal context. They emphasise the role of engagement, and
recommend researchers to engage on a considerably wider front, applying their imagination, creativity and critical mind-set in a more varied way, than when engaging with a more limited and controlled empirical section. Nevertheless, ruthless selection must be applied in this situation of limitless opportunities, and here the guiding principle was to follow my own most urgent curiosity. This is not to claim that my excitement is sufficient to make the work interesting to others; it is however a necessary condition for being able to create anything of value at all. To exploit my personal engagement, while also sustaining and feeding it, I actively sought out puzzlements and sore spots in my own understandings. The ambition, then, was to do something similar to the description by Alvesson and Kårreman (2011, p. 43):

“[The] process of engagement, in which the languages and theories of the researcher are activated, is central rather than the passive mirroring of reality (e.g. through collecting data and coding, processing, and trying to ‘discover’ what is there). This view is different from most conventional approaches, guided by a wish to order, control, and domesticate what is studied. But the impulse to control – through measuring, codifying, checking, and so on – can be bracketed, and a desire to become challenged, surprised, bewildered, and confused may take centre stage in research.”

The thesis can be seen as a series of such engagements, highlighting different aspects of a common theme on different levels and from a range of temporal perspectives. Rather than following an initial grand design for the study as a whole, it was a series of open and explorative investigations. The design was emergent, in that each sub-project informed or even spawned from one another, or from work that was done previously or in parallel with the thesis project. The experience resembles the process described by sculptor Antony Gormley:

“You don’t get good work without good ideas, but the ideas come from the work. […] And learning to listen to the work that you’ve already made is really where all the core ideas come from. One work is the mother of the next.” (CNN, 2015)

Given the pervasive nature of the issue under investigation, there are numerous other matters that could potentially have been part of the thesis, and some are discussed in the section on future research.

5.7. 1.2.4. The insider and outsider perspective

My professional role in educational development has afforded me a simultaneous insider and outsider perspective. As an engineer I am an insider in engineering education, and also by being securely employed at a technical university for twenty years. In educational development I am an insider, through visits, consultancies, commissions, networking, collaborations and discussions with people from other universities worldwide. This has given me privileged access to many discussions and deliberations related to the very issues I am exploring, in a great variety of contexts.
Not least, it has allowed me to notice what was interesting also to others. As Weick (1989, p. 517) points out:

“…a theory is judged to be more plausible and of higher quality if it is interesting rather than obvious, irrelevant or absurd, obvious in novel ways, a source of unexpected connections, high in narrative rationality, aesthetically pleasing, or correspondent with presumed realities.”

The discussions also provided opportunities to test and refine many of the thoughts in this thesis, making them to some extent already jointly considered and validated, albeit informally.

At the same time I am also outside the mainstream, not having taken the normal route to a faculty position, through a PhD education in a technical field. However, my strongest outsider factor comes from the commitment to changing the order of things. Moss Kanter pointed out how the position outside the norm can be sensitising:

“The Other has to always be super conscious, whereas the dominant player can take everything for granted because the world just makes room for him. I think that dominant players are often less interested in knowing how the world works, because it is working for them, whereas those who feel like the Other are automatically more interested.” (Puffer & Moss Kanter, 2004)

Taking the time needed to write this thesis offered a long-lasting opportunity to partly distance myself also from the role as educational developer, to watch such activities from the outside perspective, and consider my own assumptions, motivations, and identity. To some extent this has supported defamiliarization – a strategy for interpretation by making the familiar seem remarkable and less taken for granted (Alvesson & Sköldberg, 1994). Hence, I’m taking a critical stance not only in relation to the status quo, but also to educational development per se. Perhaps this is also simply a sign of educational development coming of age (compare for instance Boud & Brew, 2013; Gibbs, 2013; Jessop & Bolander Laksov, 2017; Roxå & Mårtensson, 2017; Stensaker, 2017).

***

The main engagement in this thesis concerns the concepts and communities for engineering education development. The next chapter aims to illustrate what is here referred to as “engineering education development”.
2. EFFORTS TO INTEGRATE ACADEMIC AND PROFESSIONAL AIMS

The following chapter explores more precisely the nature of the endeavours referred to as “engineering education development” in this thesis. I have chosen to focus on the CDIO approach as a representative of attempts to integrate the academic and professional aims. It is also an important part of the professional experience that spawned this research. The chapter is structured as follows. First, the CDIO initiative is briefly introduced, followed by an exposition of its strategies for integrating the disciplinary theory and professional aims, in curriculum development on the programme and course level, and in faculty development. Along the way, a few mini-cases are presented as illustrations and some of the literature found useful in this endeavour is reviewed.

2.1. Engineering education development – the CDIO approach

5.8. 2.1.1. Taking the initiative

The CDIO Initiative for engineering education reform started as a project in 2000 by the Massachusetts Institute of Technology (MIT) in the United States, and three Swedish universities: Chalmers, KTH Royal Institute of Technology and Linköping University. The starting point was the recognition that engineering education had become increasingly distanced from engineering practice, as engineering science had replaced engineering practice as the dominant culture among faculty in the past decades (Crawley, 2001). This created a need to “educate students who understand how to Conceive-Design-Implement-Operate (CDIO) complex, value-added engineering systems, within a modern team-based engineering environment”. In the original funding application, the partners stated that by embedding hands-on engineering experience, “education will be improved in two ways: it will give students a deep working knowledge of the fundamentals; and it will simultaneously educate the students in the system development process” (MIT, 2000).

Each university chose a pilot programme as project partner: it was the Aeronautics and Astronautics programme at MIT, the Vehicle Engineering programme at KTH, the Mechanical Engineering programme at Chalmers, and the Electrical Engineering and Applied Physics programme at Linköping university. The four partners set out to jointly develop the reform concept methodology, and simultaneously applying it in their respective programmes. Quite soon, other universities showed an interest and were welcomed as collaborators. When the first edition of the book Rethinking Engineering Education: The CDIO approach was written (Crawley, Malmqvist, Östlund, & Brodeur, 2007) some twenty institutions had already joined, by the time of the second edition (Crawley et al., 2014) they had reached one hundred, and to date the CDIO Initiative is a worldwide community with over 140 member institutions.
See Figure 2.1 for a world map. The CDIO community holds two international meetings per year, one of which is the annual conference. Most regions, colour-coded in Figure 2.1, also organise annual regional meetings. The organisation has evolved with democratic elections of leaders and council members, whereas the ten first members previously held permanent seats. For more details on the history of CDIO see paper IV (Edström, forthcoming 2018). In the following, the resulting reform concept is described.

Figure 2.1. World map of CDIO collaborators, 2017, made with Google My Maps. Retrieved from www.cdio.org, where a complete list of collaborating institutions can also be found.

The programme-level scope is a key defining feature of CDIO. Since students experience a programme, it should not be seen “as a set of elements, but as a system in which each element carries both individual and collective learning objects for the program” (Crawley et al., 2007, p. 17). The CDIO curriculum model can essentially be characterised as programme-centric curriculum development with an outcomes-based approach. In essence, the curriculum theory implied in CDIO specifies a number of logical links, with the programme at the centre. The key characteristic of the integrated curriculum is the ideal to integrate the theoretical and the (other) professional aims, in every stage of this system:

- The starting point is to formulate a vision of what engineers do.
- What students therefore need to learn is expressed as intended learning outcomes at the programme level.
- These are apportioned to the course level, as course learning objectives.
- The course learning objectives are finally reflected in the design of learning activities and assessment of student learning outcomes.
- In the steady state, these links are continuously improved through cycles of evaluation and development involving the programme stakeholders.
It is worth noting that today the outcomes-based approach is mainstreamed in large parts of the world, but at the time when the CDIO initiative was started it was quite novel. This was not least true for the Swedish universities. At the time, the US-based Accreditation Board for Engineering and Technology (ABET) had adopted an outcomes-based accreditation scheme from 1997 (ABET, 1994), so the MIT team were ready to share experiences of formulating and using learning objectives. The Swedish partners could contribute to the curriculum model the ideas of constructive alignment (Biggs, 1999), which provided principles for outcomes-based course design. In 2007, when the same paradigm was implemented in Swedish higher education through the Bologna process (Prop. 2004/05:162), the CDIO collaborators had up to six years experience of outcomes-based curriculum development of their own volition. At the CDIO member universities there was considerable new expertise, which became sought after by colleagues in other programmes and in other universities. Hence the Bologna implementation could to a larger extent be interpreted as a genuine opportunity for meaningful development, and less as a bureaucratic imposition (cf. Aamodt, Frølich, & Stensaker, 2016; Bleiklie, Frølich, Sweetman, & Henkel, 2017; McGrath & Bolander Laksov, 2014).

The CDIO model for curriculum development is tightly controlled through the official documents, mainly the CDIO Syllabus and the CDIO Standards, and at the same time completely open source, meaning that one can pick and choose, modify and adapt as desired, even give it a new name. Together with the great diversity among member institutions with their various specific circumstances and needs, this makes implementations considerably different with many “dialects”. What will be presented here is a generic model, as defined by the standards, along with illustrations from implementations at Chalmers and KTH, both technical universities in the Swedish context and original CDIO founders.

The following description is structured along the framework of the CDIO Standards. The main objective is to show the attempts to integrate disciplinary theory and professional aims through curriculum development, first on the programme level, then on course level, and finally in faculty development. Here, it is worth reiterating that development is a normative activity; it is directed towards some values. Hence, there can be no such thing such as value-free development. This section will also show the values embedded in the CDIO concept, as well as some of the rhetoric used to promote these values.
5.9. 2.1.2. Programme level development

5.10. CDIO Standards for programme development

<table>
<thead>
<tr>
<th>Standard 1. The Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adoption of the principle that product, process, and system lifecycle development and deployment – Conceiving, Designing, Implementing and Operating – are the context for engineering education.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard 2. Learning Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard 3. Integrated Curriculum</th>
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</thead>
<tbody>
<tr>
<td>A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard 12. Program Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement.</td>
</tr>
</tbody>
</table>

The starting point for curriculum development is to form a vision for the professional competence of graduates (standard 1) and express it as intended learning outcomes for the programme (standard 2). The dual nature of engineering education is made explicit, by stating that the learning objectives should reflect a deep working knowledge of the fundamentals, as well as the professional competences for technology development and deployment. Standard 2 also specifies the need to engage with programme stakeholders. Per standard 3, the programme level objectives are broken down and assigned to the course level, integrating disciplinary fundamentals with professional engineering skills. The result, the integrated curriculum, is often documented by a matrix showing the responsibility of each course towards the programme learning objectives (Malmqvist, Östlund, & Edström, 2006). Standard 12 devises a continuous programme evaluation system, again involving stakeholders.

5.11. Programme-led curriculum development – the case of Mechanical Engineering at Chalmers

To illustrate the programme development in CDIO, we turn to the Mechanical Engineering programme at Chalmers, one of the four original project partners. It is a five-year programme, combining a Bachelor and Master of Science in Engineering. Their experiences are documented through a series of publications, not least in CDIO conferences. Though mechanical engineering can be the broadest of fields, the Mechanical Engineering programme has a vision of the work it should prepare students for, namely:

“to participate in and lead the development and design of industrial products, processes and systems for a sustainable society. The programme also prepares for positions in other areas of the society where skills in analysis and processing of complex open-ended problems are of great importance. During the studies, the student shall be able to develop her/his personal qualities and attitudes that will contribute to professional integrity and to a successful
professional life” (Malmqvist, Bankel, Enelund, Gustafsson, & Knutson Wedel, 2010, p. 3)

The curriculum development is documented in the programme description (Malmqvist et al., 2006). Its function is to communicate the current state of the programme and the rationale, and also the next steps. It makes it easier for the programme team to stay focused and prioritise among new ideas and proposed actions, since these will be discussed in terms of their contribution to the goals of the programme (Malmqvist et al., 2010). The programme description documents how ethics, communication and teamwork skills, etc., are integrated in the course learning objectives, according to standard 3.

For this thesis, one of the most interesting developments in the Mechanical Engineering programme has been the integration of computational mathematics, which has strengthened the connection between engineering and mathematics. The rationale was, in short, that students need to learn to solve more general, real-world problems, while they can spend less time “solving oversimplified problems that can be expressed analytically and with solutions that are already known in advance” (Enelund, Larsson, & Malmqvist, 2011). One of the guiding principles was that students should work on the complete problem: from setting up a mathematical model and solving it, to simulation of the system, using visualisation to assess the correctness of the model and the solution, and comparison with physical reality. The interventions in the programme involved new basic math courses including an introduction to programming in Matlab (a technical computing language and environment), new teaching materials (since most textbooks do not take advantage of the development in computing), integration of relevant mathematics topics in fundamental engineering courses (such as mechanics and control theory), and cross-cutting exercises, assignments and team projects shared between the mechanics and strengths of materials courses and mathematics courses. We can note that instead of seeing this as a task for mathematics teachers to solve within the mathematics courses, a programme-driven approach was applied, where making connections to mathematics in engineering subjects was at least as important as making connections to engineering in mathematics.

Just as in the previous example, the integration of sustainable development demonstrates how the programme approach enables systematic integration of important topics in several courses, while maintaining links to overall programme learning outcomes and ensuring progression (Enelund, Knutson Wedel, Lundqvist, & Malmqvist, 2013). Programme learning objectives express the sustainability competences in the Mechanical Engineering program, for instance that students should be able to “describe and estimate the economic, societal and environmental consequences of a product or system through its lifecycle”. Through the programme, sustainability elements are pervasive and adapted to the context. Course learning objectives show how courses carry partial responsibility in relation to these programme objectives, and in progression through the programme. Students first
encounter sustainability in the *Introduction to Mechanical Engineering* (standard 4). It is then integrated into several of the engineering fundamentals courses where it is applicable, e.g. in *Thermodynamics, Materials Science, Material and Manufacturing Technology*. There are also courses with sustainable development as a main topic, such as *Sustainable Product Development*. Finally, the specialisations on master level also have various degrees of sustainability focus.

A significant aspect of this case is how the education is organised, and here the model developed by the CDIO team in Mechanical Engineering has also had considerable influence across Chalmers. For strategic issues and prioritisations the programme leader is supported by an advisory board, with industry, students, admin and faculty represented. For operational issues, the programme office, with an administrator and a study counsellor, supports the programme leader. Chalmers has a “buyer-seller” model in which the programmes commission courses from the delivering departments. In a yearly cycle, the programme leaders reviews the evaluations for all courses, and negotiates next year’s course offering in a dialogue with the vice head of the delivering department. An *agreement* is written to document learning objectives, content, pedagogy and budget of the courses delivered by the department. While the agreement process is a collegial dialogue, in the end the programme controls the budget, approves the course syllabus documents, and is the recipient of course evaluations. As a result, this has enabled the programme team to implement the integrated curriculum, keeping the programme unified while still being a composite of courses from several departments and disciplines. As a result, the curriculum can also be further developed through a relatively agile process. In summary, the Mechanical Engineering programme has systematically created conditions for leading, planning and developing the programme, and for *constantly setting new goals*. It has come out on top of national evaluations, and attracted numerous awards (Malmqvist et al., 2010). Further, this organisational model, with the strong power bases in the programmes, has influenced the education organisation across Chalmers. For the university, it is a mechanism to ensure that the educational resources are spent where they benefit the programmes, as no course is established and offered unless a programme commissions it, and keeps including it in the yearly agreement.

### 5.12. 2.1.3. Course level development

#### 5.13. CDIO Standards for course design

<table>
<thead>
<tr>
<th>Standard 7. Integrated Learning Experiences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard 8. Active Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching and learning based on active experiential learning methods.</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Standard 11. Learning Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment of student learning in personal and interpersonal skills, and product, process and system building skills, as well as in disciplinary knowledge.</td>
</tr>
</tbody>
</table>
Standard 7, 8 and 11 constitute a course design model corresponding to constructive alignment: the learning objectives, learning activities, and assessment should be aligned. The integration between disciplinary knowledge and professional skills should apply in all these components. In the integrated curriculum (standard 3) each course accepts responsibility for a portion of the programme objectives regarding some professional competence, in addition to the deep working understanding of fundamentals in the subject. This integration should also be reflected in the way the course is taught (standard 7 and 8), and assessed (standard 11). For instance, in the Mechanical Engineering case above, the planning on programme-level (standard 3) went hand in hand with programme-driven course development, to address the learning objectives that were assigned to courses.

In the following, two cases are presented to illustrate CDIO educational development on course level. The two cases, one a subject course and the other a design project course, were chosen to represent the dual nature of educational development in CDIO, which recognises the discipline-led as well as the problem- or practice-led components of education. Table 2.1 shows some arguments for why both logics are necessary, and how they can form a productive relationship.

Table 2.1. The need for both discipline-led and problem/practice-led learning. Adapted from (Edström & Kolmos, 2014)

<table>
<thead>
<tr>
<th>Discipline-led learning is necessary for:</th>
<th>Problem/practice-led learning is necessary for:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Creating well-structured knowledge bases</td>
<td>• Integration and application, synthesis</td>
</tr>
<tr>
<td>• Understanding the relations between evidence/theory, and model/reality</td>
<td>• Open-ended problems, with ambiguity, trade-offs</td>
</tr>
<tr>
<td>• Methods to further the knowledge frontier</td>
<td>• Problems in context, including human, societal, ethical, economical, legal, etc. aspects</td>
</tr>
</tbody>
</table>

...while also connecting with problems and practice:
| • Deep working understanding (ability to apply) | • Practicing professional work modes |
| • Seeing the knowledge through the lens of problems | • Design – in Theodore von Kármán’s words: ”Scientists discover the world that exists; engineers create the world that never was” (NSF, 2013) |
| • Interconnecting the disciplines | • …while also connecting with disciplinary knowledge: |
| • Integrating skills, e.g. communication and collaboration | • Discovering how disciplinary knowledge is used |

These cases illustrate some of the improvements advocated by the CDIO approach, but they are examples and by no means complete. One reason for selecting them is that they share a common theme, which was to represent cost-effective implementations.
5.14.  Improving student learning in a subject course – a case study

Paper I in this thesis exemplifies CDIO development on the course level, in the context of discipline-led learning. The role of this paper is to indicate how a subject course can improve its contribution to professional preparation while at the same time strengthening students’ understanding of the technical fundamentals. Hence, it shows that the ideal of synergy between disciplinary and professional aims can be realised on the course level.


The paper describes and analyses the results of an intervention for improving learning in problem-solving sessions, called student-led exercises. Briefly, the teaching method works as follows: instead of the teacher demonstrating a set of problems on the board (which is considered “normal” or traditional at KTH), students are randomly selected to present their solutions, which they have prepared in advance. The paper describes how this teaching method was implemented at KTH in a course on Semiconductor Devices by the second author, Per-Erik Hellström. Further, Carl Henrik Görbitz applied the same method in the very large first-semester Introduction to Chemistry at the University of Oslo. The paper presents quantitative data in the form of course results, qualitative data in the form of student interviews made mainly for evaluation purposes, and teacher reflections over the experiences. From a methodological perspective it was valuable to have two contrasting implementations in different contexts (a very large, first-semester course vs. one in the third year with a smaller class), because they could provide different insights regarding the potential advantages of the teaching method. While the results of the Semiconductor Devices implementation indicated improved understanding and motivation, the most consequential result in the Introduction to Chemistry was a significant decrease in dropouts.

The results demonstrate how even a modest and cost-effective intervention can improve the contribution of subject courses, improving students’ understanding of disciplinary theory while also allowing them to practice communication skills (Standard 7). The point here is to demonstrate that every ordinary subject course should be able to contribute to the integrated curriculum at least on this very modest level. It also shows how the deliberate integration of relevant skills also generates an active learning format (Standard 8). The activity where students prepare, present, and discuss the solutions is far better aligned with professional practice than an activity where they are mainly copying given solutions, for cramming later. Since the intervention increases student understanding of the subject, and is cost-neutral in terms of teacher time, this is a contribution to professional preparation that every subject course should be able to achieve. In fact, even for an educator who is mainly focused on conveying theoretical understanding, the intervention is justified already.
by considering the improvement in student understanding, and the practicing of communication skills comes as a bonus.

To classify the quality of intended learning outcomes the Feisel-Schmitz taxonomy (Feisel, 1986) (see paper I for an explanation) has been found useful in CDIO because it makes a clear distinction between problem-solving with or without understanding. Problem-solving with understanding, labelled “Solve” in the taxonomy, precisely captures the aim referred to in CDIO as deeper working knowledge. Problem-solving without understanding, called “Compute” in the taxonomy, relates to one of the most problematic issues in engineering education: the focus on reproducing given solution procedures for standard types of problems. Therefore, taxonomies that downplay this distinction are unhelpful in the context of engineering education development. In the most widely used taxonomy, by Bloom (1956), the application category is placed, as a whole, on a higher level than understanding. In the revised Bloom’s taxonomy (Krathwohl, 2002), the parallelism between understanding and application is better recognised, and the new two-dimensional model can accommodate the distinction, although in a more complicated scheme than Feisel-Schmitz. As an analytic tool the Feisel-Schmitz taxonomy tends to resonate widely with engineering educators, including also those who are most interested in disciplinary accomplishments. Hence, the taxonomy has helped identifying common ground, by highlighting the importance of disciplinary theory for professional practice.

Approaches to learning are used to operationalize the quality of learning processes, given how a deep approach is associated with better learning outcomes than the surface approach (see for instance Marton, Hounsell, & Entwistle, 1984). Most notably this is a conceptual underpinning to constructive alignment (Biggs & Tang, 2011), which implies that learning objectives, learning activities, and assessment should be aligned to invite a deep approach, and discourage a surface approach. Extending the classic deep and surface approaches, Case and Marshall (2004) identified the deep and surface procedural approaches in relation to problem-solving. In paper I, we proposed an amendment to their model, arguing that the deep procedural approach should not only be treated as an intermediate stage towards a more desirable (conceptual) deep approach. While we agree that problem-solving as a learning activity is a means to reach conceptual understanding, it is not only that; it is also about learning to solve problems. This led us to position problem-solving as an aim in its own right, on the same level as understanding concepts and theory. Again, the intention is to find conceptual common ground, acceptable to those who emphasise disciplinary theory as well as those who emphasise what students can do with their understanding. Finally, if the approaches to learning focus on what students do to learn, based on their intentions, the research on epistemological views (Gainsburg, 2015; Perry, 1998) can further explain this by highlighting their views on knowledge. Gainsburg identifies that students with the more sophisticated views increasingly connect mathematical modelling of course problems with the real
problems they represent, and with the nature of problems and processes used in engineering practice.

5.15. CDIO Standards for problem- and project-led learning

<table>
<thead>
<tr>
<th>Standard 4. Introduction to Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>An introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard 5. Design-Implement Experiences</th>
</tr>
</thead>
<tbody>
<tr>
<td>A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level.</td>
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<table>
<thead>
<tr>
<th>Standard 6. Engineering Workspaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning.</td>
</tr>
</tbody>
</table>

PBL, or problem-based and project-organised learning, is an essential component in the CDIO curriculum model. Here, students can work in the logic of real problems (Jonassen, 2014; Jonassen, Strobel, & Lee, 2006). Standard 4 and 5 can be seen as special cases of standard 7, since both describe two kinds of integrated learning experiences. Standard 4 recommends an introduction to engineering early in the programme, to give students a first contact with engineering practice and the role of engineers. Standard 5 implies a sequence of design–implement experiences, with progression across the curriculum. By design-implement experiences are meant projects in which the students learn through the development and deployment of products, processes or systems, under working modes that resemble engineering practice. A key feature is to take solutions to a testable state, allowing students to evaluate and reflect on their work, with regards to the process and the results. Standard 6 is about creating a learning environment to accommodate such realistic engineering experiences. It is a cornerstone of the CDIO philosophy that the hands-on component should run continuously across the curriculum, starting early and progressing through the programme. This can be seen as a reaction to curricula where the first years are filled with basic theoretical subjects, where students risk losing sight of why they wanted to become engineers in the first place (see for instance Holmegaard, Madsen, & Ulriksen, 2016; Holmegaard, Ulriksen, & Madsen, 2010).

5.16. Improving student learning in a project course – a case study

The following case is based on the experiences in a master level design project course taught by Jakob Kuttenkeuler and Stefan Hallström, from the Vehicle Engineering department at KTH, one of the original founding partners of CDIO. The teachers have involved me in discussing and designing improvements to the teaching and assessment on a regular basis since 2001, and our joint reflections and experiences have been reported (Edström, El Gaidi, Hallström, & Kuttenkeuler, 2005; Edström, Hallström, & Kuttenkeuler, 2011; Hallström, Kuttenkeuler, & Edström, 2007) and in a book chapter (Hallström, Kuttenkeuler, Niewoehner, & Young, 2014).
It is not the intention here to explain project courses generally, but to describe the course and experiences sufficiently for illustrating two points:

- The **learning perspective** – The case shows a learning-centred design of teaching and assessment. In short, the purpose is not that the students should build things; it is that they should *learn* from building things.

- The **teaching perspective** – The case shows some principles for making this learning activity sustainable from a teaching perspective, as project-based learning is often assumed to be expensive and require high teaching effort.

The course mixes students from several programmes, and its name is *Naval Design* or *Lightweight Design* depending on which programme a student comes from. The scope is 20 ECTS credits spread over an entire academic year, i.e. allocating one third of students’ time. Students are divided into large groups, typically of 8-15 students, and given an open-ended task to design, manufacture and test a technical system, typically an unorthodox vehicle. Previous groups have built things like a solar powered aircraft, an autonomous underwater glider, a craft that can plane on the surface but also submerge, an electric single-hydrofoil vehicle for play, and a human-powered submarine (for video clips, see Kuttenkeuler, 2017). While the technical challenge is new for every group, the learning objectives are the same every year. See Table 2.2.

The course design and teaching philosophy is guided by some key principles. The first principle is that *students are directly exposed to real problems* in the project work. In other words, teachers do not stand between the students and the problems. Most previous courses follow the cognitive structure of a subject, where textbook problems are used to illustrate theory, and where the teacher knows the right answers in advance. There, it is often clear from the course context what sort of problem it is and what theory should be used. In contrast, the problems that emerge in the project work come without any labels telling students what theory is relevant. Some problems may require students to search for and use theory and methods that are new to them.
ting learning outcomes of the Naval/Lightweight Design course.

<table>
<thead>
<tr>
<th>Students should be able to:</th>
<th>Examples of related challenges:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• take on technical problems in a systems view</td>
<td>Knowing and prioritising the crucial challenges and keys to success. Where to start. Considering the implications of different concepts (solutions). Handling the interfaces between sub-systems.</td>
</tr>
<tr>
<td>• handle technical problems which are incompletely stated and subject to multiple constraints</td>
<td>How to handle interdependent tasks, e.g. idling while just waiting for data from each other. How can the work be assigned to individuals but the big picture maintained?</td>
</tr>
<tr>
<td>• develop strategies for systematic choice and use of available engineering methods and tools</td>
<td>Knowing what aspects matter most, and keeping focus on them. Choosing the right level of precision, e.g. start by sketching on napkins rather than using supercomputers.</td>
</tr>
<tr>
<td>• make estimations and appreciate their value and limitations</td>
<td>Using estimations correctly, revisiting and challenging them. Interpreting results in the light of assumptions.</td>
</tr>
<tr>
<td>• make decisions based on acquired knowledge</td>
<td>Creating a relevant basis for decisions. Act when the information is good enough. Documentation and traceability.</td>
</tr>
<tr>
<td>• pursue own ideas and realise them practically</td>
<td>Discussing, arguing, debating, standing up for your standpoint, and letting go of darlings. Struggling with real world conditions, e.g. there is no infinitely strong glue.</td>
</tr>
<tr>
<td>• assess quality of own work and work by others</td>
<td>Reflecting on different approaches. Seeing where one’s work made a difference. Reflecting on what can be improved. Role modelling.</td>
</tr>
<tr>
<td>• work in a true project setting that effectively utilises available resources</td>
<td>Decision-making. Minimising idling. Identifying time-critical tasks. Professionalism.</td>
</tr>
<tr>
<td>• explain mechanisms behind progress and difficulties in such a setting</td>
<td>How to interpret and handle problems. Getting true status overviews and responding appropriately.</td>
</tr>
<tr>
<td>• communicate engineering – orally, in writing and graphically</td>
<td>Using all possible modes of communication in authentic situations.</td>
</tr>
</tbody>
</table>

The course design and teaching philosophy is guided by some key principles. The first principle is that students are directly exposed to real problems in the project work. In other words, teachers do not stand between the students and the problems. Most previous courses follow the cognitive structure of a subject, where textbook problems are used to illustrate theory, and where the teacher knows the right answers in advance. There, it is often clear from the course context what sort of problem it is and what theory should be used. In contrast, the problems that emerge in the project work come without any labels telling students what theory is relevant. Some problems may require students to search for and use theory and methods that are new to them. At the same time, it can be troublesome for the students to recognise even the most fundamental theory in the wild, such as Newton’s Second Law, Ohm’s Law, or Archimedes’ Principle. As students need to learn how to handle unforeseen and poorly defined problems, the teachers avoid stepping in too hastily to “help” with “correct” interpretations. Further, since the problems are open-ended and in no way prepared or adjusted, there are no black-or-white right answers. Instead of using the teachers for convenient affirmation that answers and solutions are “right”, students need to seek different forms of validation and develop their own judgement. In other
words, students need to think for themselves, and this can only happen to the extent that the teachers can resist accommodating student expectations, i.e. the desire to get right answers or to avoid the stage of bewilderment. Until students get accustomed to this new order of things, their conceptions of student and teacher roles are often challenged, and so are their epistemological views. There is a tension here, between learning and task achievement. Naturally, if the teacher were constantly “helping” the students, they could build a better boat. Instead, they are allowed to face these highly relevant challenges, because learning is more important (Edström et al., 2005).

In order to prioritise learning, the student teams also need to take full responsibility and ownership. This principle is that the students own the project, all aspects of it. If teachers were to start taking initiatives, it could shift students to a more passive role. A major implication is that the teachers’ role is to coach and advise in the engineering process, but not to drive it, and never suggest solutions. Hence, students are not protected from mistakes, contradictions or confusion. As a result of this principle, the project results will reflect the proficiency of the students, not of the teachers. Again, learning is prioritised over the product performance. A related principle is that the project sets the logic, not the teachers. This means that teachers refrain from unnecessarily making decisions in the project. E.g. deadlines are not set by teachers, but by the project plan created by the student team. Teachers do not specify the length of a report; it is inferred by what it needs to achieve in the project. For instance, when the project commissions an investigation by a sub-team, their report should contain precisely the information needed to make the subsequent decision – and the length, and the deadline, follow as consequences of its function. For many students this is the first time they write a document that actually has a function; previously they have mostly written to demonstrate to teachers that they deserve a grade, so their normal mind-set is: “What does the teacher want?” When they let go of the teacher orientation, and start to become project-oriented, their work becomes much more meaningful, and easier. Obviously, when teachers refrain from managing (and micro managing) the project, it also makes the course far more sustainable in terms of teacher time.

The assessment system is also designed to generate learning. We note that it is common in project courses to grade group products (or final reports). In our opinion, product grades are loosely related to learning outcomes, and they create disincentives for learning, because when students focus on task achievement they tend to share the task so each of them can do what they already do best. Group grades are also aggregated to hide individual attainment – which is inherently unfair and often creates conflicts due to different levels of ambition. In this course, instead, teachers grade students individually based on the learning outcomes as evidenced in the process. Since students work on many different tasks, the principle is that the students take responsibility for their own learning outcomes, individually. Furthermore, we believe that doing is not sufficient for learning; students need to reflect in order to turn experience into learning. A portfolio assessment system (for details, see Edström et
al., 2005) is designed to generate reflection in relation to the learning goals. For a mid-course formative peer feedback round, each student submits a one-page self-evaluation, which is distributed to all members of the team. It is based on the portfolio and structured according to the learning objectives, with any claims substantiated by referencing project documents that are openly available on the project website.

Writing feedback to up to 14 teammates is a comprehensive task, but it is justified by the reflection it elicits. The mid-course feedback comes when students still have another semester ahead of them to make adjustments. For instance, students may discover that they need to engage in different tasks in order to reach all the learning objectives. At the end of the course, after a second peer feedback round, grades are set, individually and in relation to the learning objectives, by the two teachers. Each teacher notes preliminary grades independently, based on a holistic assessment of the portfolios and the work referenced, the feedback given and received, as well as continuous observations throughout the course. They then meet to compare and discuss until reaching consensus. From a teaching perspective, the assessment takes no more time than in other (so called normal) courses. The portfolio model reverses the burden of proof; it is up to the students to show evidence of their individual learning. Furthermore, teachers do not take it upon themselves to provide written feedback; when the students give (formative) feedback to each other, they learn from both the act of giving and of receiving.

The experiences in these two cases, in Hellström’s subject course and in Hallström’s and Kuttenkeuler’s project course, clearly showed new demands on the teacher competence, regarding what to teach, and how to design the learning activities and learning assessment. Next, we turn to the matter of faculty development.

5.17. 2.1.4. Faculty development

5.18. CDIO Standards for faculty development

<table>
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<tr>
<th>Standard 9. Enhancement of Faculty Competence</th>
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<td>Actions that enhance faculty competence in personal and interpersonal skills, and product, process, and system building skills.</td>
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<tr>
<th>Standard 10. Enhancement of Faculty Teaching Competence</th>
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<tbody>
<tr>
<td>Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning.</td>
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Standard 9 and 10 both concern enhancement of faculty competence. These are also the standards that are the least discussed, and for which the least progress has been reported by CDIO implementers (Malmqvist, Hugo, & Kjellberg, 2015). The term “enhancement” has often been taken synonymously with activities supporting the further development of the existing faculty, but it may just as well refer to the composition of the faculty, for instance through hiring and promotion criteria (Theodorsdottir, Saemundsdoottir, Malmqvist, Turenne, & Rouvrais, 2013). One general challenge with recommending faculty development as part of a programme-centred development concept is that although it is an important condition for success
– in fact often the most critical – it is often a domain in which the programme has little influence. This was the case at Chalmers, for instance, where the programme buys courses from departments, but has no (formal) influence on processes ensuring teacher competence, such as hiring and promotion (Malmqvist et al., 2010). Even in systems where a department owns a programme, faculty recruitment and development may prioritise the needs of research over those of education. Cautious steps are taken in many places to strengthen faculty engineering competence and teaching competence. Such policies are most often university-wide. At MIT, a limited number of *Professors of the Practice* can be hired (de Weck, 2004; MIT, 2017). In every hiring and promotion case at Chalmers, at least one of the external evaluators is a teaching expert focusing on the teaching competence of the candidate. In addition, the Chalmers appointment regulations specify special positions based on professional skills, as well as positions up to Professor (not holding a chair) with emphasis on pedagogical expertise (Chalmers, 2013).

Though CDIO Standard 9 is simply named enhancement of “faculty competence”, it really refers to faculty *professional engineering* competence, expressed as their “personal and interpersonal skills, and product, process, and system building skills”, which are best developed “in contexts of professional engineering practice”. Examples of actions to support faculty engineering competence are: sabbaticals to work in industry (including the public sector), partnerships with industry in research and education projects, valuing engineering practice as a merit in hiring and promotion, allowing and encouraging consultancy work, and professional development activities at the university (Malmqvist, Gunnarsson, & Vigild, 2008). It can be noted that the theoretical and scientific competence of faculty is not even mentioned; this is taken for granted, perhaps reflecting the prevailing academic culture of the research-intensive universities where the CDIO approach was first developed.

CDIO Standard 10 concerns enhancement of faculty teaching competence. In the Swedish context, most universities offer courses on teaching and learning to faculty. One reason is that ten weeks of such training was for many years a national eligibility requirement for senior lecturers and professors (Lindberg-Sand et al., 2005). At KTH, the faculty development activity created an opportunity for mainstreaming the CDIO approach to course and programme development. One of the faculty development courses, *Teaching and Learning in Higher Education*, 7.5 ECTS credits (i.e. half the requirement), was redesigned in 2004 to emphasise matters of course design, inspired by the experiences with CDIO. Some 700 participants took the course during the decade when it was offered. One teaching strategy applied in this course was to engage other faculty members as guest teachers, presenting their own experiences of course development. Those cases were analysed as examples, to derive theoretical principles for guiding practical implementation. The presence of the guest teachers also demonstrated locally developed proofs-of-concept, showing that *it works here*. The most prominent cases were the cases discussed above, the design project course
presented by Jakob Kuttenkeuler and Stefan Hallström, and the student-led exercises (featuring in paper I), presented by Per-Erik Hellström. The cases in this chapter can therefore also to some extent serve as illustrations of standard 10.

An increasing emphasis on scholarship in CDIO conferences (discussed in the next chapter) could also be seen as a dimension of faculty development, by generating more systematic and scholarly reflection and documentation.

2.2. Further development of the CDIO concept and community

The previous section discussed the development of the CDIO approach (Crawley et al., 2007; Crawley et al., 2014), and showed its strategies for integrating disciplinary and professional learning through curriculum development, and faculty development. CDIO was chosen not because it is the only model available, but because it is representative of an effort to address the tension that is the theme here, and part of the professional engagement that is the background. The rest of this chapter will discuss two engagements to further develop the approach and the community. First, CDIO will be compared with PBL, another educational development concept with a large international community that also addresses the tension between professional and disciplinary aspects. Finally we discuss a present proposal to connect the CDIO community and the field of engineering education research.

5.19. 2.2.1. Comparing CDIO and PBL

In paper II, CDIO is compared with PBL (problem-based/project-organised learning). Both are models for reforming engineering education with organised international communities. This study came about because both authors, rooted in the PBL and CDIO communities respectively, had often been asked, “Should we do PBL or CDIO?” We felt the need to produce a thorough answer with a systematic approach. The resulting publication was:


In this study, the main methodological challenge was to generate a framework for the analysis, and this was done in stages through an inductive, participatory, and iterative approach. The project started by generating a gross list of aspects that could be compared. In three conference workshops, with a total of 70 experienced practitioners as participants, our first iterations of comparisons were presented and discussed. During the workshops some aspects emerged as most salient and productive in generating insights, by revealing similarities, differences, surprises, misconceptions, or unreflected assumptions. The final framework consisted of the following core aspects: history, community, definition, curriculum design, relation to disciplines, engineering projects, and change strategy. Through a correspondence between the
authors, complemented with document studies, these aspects were then examined and analysed for PBL and CDIO, respectively, then contrasted. See Table 2.3.

Table 2.3. Summary of the PBL and CDIO comparison (Edström & Kolmos, 2014).

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<thead>
<tr>
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<th>PBL</th>
<th>CDIO</th>
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<tr>
<td><strong>Starting point</strong></td>
<td>The starting point is the learning process. Started in reform universities in the 1960s and 1970s, in response to critical student movements. Applicable in medicine, engineering, science and many other fields.</td>
<td>The starting point is a vision of graduates’ competence expressed as learning outcomes. Started at MIT in the late 1990s, forming a project with three Swedish universities, in response to distancing of engineering education from engineering practice.</td>
</tr>
<tr>
<td><strong>Communities</strong></td>
<td>Implementation of PBL cannot be estimated, due to different levels of implementation from a single course to whole universities. Several international networks: PBL Global Network, International PBL Symposium, Pan-American Network for PBL.</td>
<td>About 140 institutions are formally CDIO collaborators in the CDIO Initiative. Extent of CDIO implementation is difficult to estimate.</td>
</tr>
<tr>
<td><strong>Definitions</strong></td>
<td>A broad educational approach, focusing on the learning process, and loosely defined. The principles can be applied on course, programme, or institutional level, in different fields of education, and any level from school to university. Practices vary, with the McMaster/ Maastricht and Aalborg models well documented.</td>
<td>The CDIO Syllabus addresses what students learn. The CDIO Standards address strategies for curriculum and faculty development. Practices vary among implementing institutions.</td>
</tr>
<tr>
<td><strong>Curriculum design</strong></td>
<td>Projects are the platform for student learning.</td>
<td>The 12 CDIO Standards describe an outcomes-based approach for designing the integrated curriculum.</td>
</tr>
<tr>
<td><strong>Relation to disciplines</strong></td>
<td>Many hybrid models where at least half the curriculum is subject-based.</td>
<td>Subject courses a major part of the curriculum as integrated learning experiences: students should master a deeper working knowledge of technical fundamentals and simultaneously develop professionally relevant skills.</td>
</tr>
<tr>
<td><strong>Projects</strong></td>
<td>Discipline projects, students apply theory to problems in order to reach mainly disciplinary learning outcomes. Problem projects, where students address real problems with contextual and societal dimensions; here the problem determines what theory is used.</td>
<td>Project-based learning features most notably in a sequence of engineering projects, design-implement experiences, where students conceive, design, implement and operate products, processes and systems. Progression through the programme. The intention is not to replace subject courses as the primary site to systematically learn disciplinary knowledge.</td>
</tr>
<tr>
<td><strong>Change strategies</strong></td>
<td>Research evidence to show the positive effects of PBL. Well-documented institution-wide implementations. A change management perspective to handle resistance.</td>
<td>CDIO has its origin in engineering, and is created by engineering faculty. Curriculum development as engineering design. Working within the discipline-based structures. Stakeholder involvement.</td>
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Both communities have important roles as centres for jointly developing, sharing and qualifying a knowledge base, consisting of the approaches in themselves, as well as the collective experiences in applying them. The knowledge base and the communities serve to strengthen local change agents, who are otherwise often isolated with only their own developed strategies, specific experiences, and limited opportunities for critical reflection. Hence, the communities contribute to the identities of practitioners, and helps legitimise their work. This paper also identified some significant differences in how each community conceptualises and handles the relationship between disciplinary fundamentals and professional aspects. Significant differences were seen in the starting point, the proposed role of disciplines, and the scope of the concepts. In PBL the starting point is the learning process, in that a problem- and project-based approach is advocated, for any type of learning outcomes. PBL is implemented in single courses, whole programmes, or whole universities. It is the PBL format in itself that prepares students for professional practice, through its similarity to working life. Despite the fact that some half of the curriculum in PBL universities is discipline-based, this is less addressed. In CDIO the starting point is to align the learning outcomes with professional practice. This led to the ideal of including both discipline-led and problem/project-led approaches in the curriculum, and there are strategies for both developing the contributions of both types of courses.

After the comparative paper (Edström & Kolmos, 2014) was published, our joint reflections on the differences between the communities continued. In retrospect, it struck us as remarkable that one potential point of comparison was absent. Although the role of research is clearly a key difference between the two communities, it did not emerge as a separate category from our process of generating the comparative framework. One reason might be that the categories were generated in CDIO and SEFI conferences, but not in a pure PBL conference where research is more emphasised. The difference was however still visible in the results of the study, for instance when comparing the communities and change strategies. This lack of connection between CDIO and the emerging engineering education research (EER) community became a lasting conundrum, and the source of a new engagement.

5.20. 2.2.2. Connecting CDIO and engineering education research

Although much work in CDIO had been documented and published, also in international peer-reviewed journals, it was still seen exclusively as a community for educational development. Why the community has not been engaging more in the emerging engineering education research community was therefore truly puzzling. It was even stated already in the original application to the Wallenberg foundation that “a research program on teaching and learning is embedded in our initiative” (MIT, 2000). This led to a new engagement to organise an arena for educational research within the CDIO community, more specifically by establishing a research track starting in the annual conference in 2016. In opening for engineering education research, the hope is to further improve the knowledge base of the work, and
strengthen the legitimacy of practitioners, but there are also risks of losing important values. Therefore it felt important to transparently discuss the rationale for this move, and this became the theme for paper III:


The objective of this study was to consider the relationship between engineering education development and engineering education research, from the perspective of the CDIO community. It traces the development of engineering education research (EER) and some of the debates that are relevant for the formation of the field. The narrative is informed by observations during several years in various research and development communities, so here it mattered to be an insider. The development of the EER field, limited to the US and Europe, is distilled to a very short summary presented with support from a number of sources, in particular the key journals involved. It discusses the nature of research that might be most relevant for engineering education development and for furthering the community, by highlighting and comparing three concepts related to different aims of research: Boyer’s four scholarships (Boyer, 1990), Mode 1 and 2 (Gibbons et al., 1994), and Pasteur’s Quadrant (Brooks, 1967a; Stokes, 1997). The aim was to provide perspectives to help make sense of the available opportunities in EER, and discuss implications. In particular, Pasteur’s quadrant appeared useful to keep the hopes up that the research mission need not thwart ambitions to improve engineering education. See Figure 2.2.

![Figure 2.2. Pasteur’s Quadrant (based on Brooks 1967; Söderberg 1967; Stokes 1997), from paper III (Edström, in press, 2017).](image)
The ensuing proposal for review criteria in the CDIO conference research track was intended to take a stance in the debates by combining considerations for scholarliness and usefulness. In the 12th International CDIO Conference, held in Turku 2016, the new research track attracted 40 proposals. After the peer review process, 14 full papers were published in this track (Björkqvist et al., 2016). The following year, 40 proposals were submitted for the 13th International CDIO Conference held in Calgary, finally resulting in 11 full papers (Brennan et al., 2017). Further, a special issue on the theme “Scholarly Development of Engineering Education – the CDIO approach” was announced in the European Journal of Engineering Education (2016), with contributions currently in the review process. It is an issue for future research to evaluate the results of this move, whether it will actually provide new understandings that are scholarly or useful, or both, or neither, and what other consequences it may bring about.

***

This chapter described the CDIO approach for engineering education development. CDIO was chosen, not because it is the only model available, but to represent what is meant in this thesis by “engineering education development”. The chapter laid out, in some detail, the attempted strategies to integrate disciplinary knowledge and professional aspects in the curriculum, on the programme and course level, and in faculty development. Then, some engagements to increase self-reflection and support the further development of the CDIO approach and community were discussed. The first was a comparison of CDIO and PBL, and the second was a subsequent effort to connect the CDIO community with the emerging engineering education research community.

The next two chapters take a more problematizing view on the conditions for engineering education development. We start by uncovering some historical roots of the main theme: the tension between the academic and the professional.
3. A PERENNIAL TENSION

Up to this point, this thesis has quite straightforwardly discussed the what, why and how of engineering educational development – which refers to the work performed by educators, leaders of programmes and departments, committees, educational developers, and many other kinds of other change agents. In this section, I will use a historical perspective to problematize our understanding of the theme of this thesis, the tension in engineering education between engineering and engineering science.

3.1. A state of déjà vu

Seely (2005) pointed out that when we consider educational reform it is useful to see what has led to the situation that we have now, and to recognise patterns in the history of reform attempts. To be somewhat self-critical about the discourse in engineering education development: we sometimes seem to act as if the problems we work on were discovered in our time, and we seem to devise solutions as if nobody has suggested or tried them before. Perhaps the historical innocence is even a necessary prerequisite for taking on this kind of work with optimism. It is easy to empathise with the historian complaining about a persistent state of déjà vu, caused by the engineering education community, publishing

“...study after study that would benefit from expanding the analytical lens from primarily viewing students and curricula to include organizations, vested interests, and the accretion of decades of competing initiatives that structure current reform efforts” (Wisnioski, 2015).

By exploring some of the history and comparing past and present discussions, I will show not only how the issue that this thesis focuses on has a long history, but also that many of the arguments and proposed strategies are very similar across time. As a result, the déjà vu will instead become mine.

5.2.1. 3.1.1. Carl Richard Söderberg (1895 – 1979)

The engagement with the past came about serendipitously, during background research for paper III. Reading a piece by Harvey Brooks (1967) in a report to the US Congress, my eyes fell on a text in the same volume by Carl Richard Söderberg: A Note on Engineering Education. His name was vaguely familiar, thanks to a short mention by Seely (1999). Reading the Note, I was immediately struck by the similarities with today’s discussion on engineering education, in particular the CDIO approach. This discovery led to a historical excursion, resulting in paper IV:

Edström, K. Academic and professional values in engineering education: Engaging with history to explore a persistent tension.

This study explores how the tension between the theoretical and professional preparation has been discussed for a long time. Seely uses the swinging pendulum as a metaphor to describe the turn from practice to science, when engineering education in
the United States was transformed due to a dramatic increase in research that started during World War II. The engineering science endeavour was a strategy for status and a strategy for institutional growth. Over time, this “avalanche” of government research funding changed the character of faculty, and the dominant culture went from engineering practice to engineering science, leading to increasingly theoretical curricula. While science and theory were originally intended to improve professional preparation, it came instead to dominate the education.

The interesting life and work of Carl Richard Söderberg is traced against this background, focusing in particular on his views of engineering education. Besides the Note, the most important sources were the report of the Lewis committee (MIT, 1949), of which he was a participant, and his personal memoirs (Söderberg, 1979). Other sources were reports and papers, and correspondence and other documents found in archives in Sweden and the United States. Söderberg was born in 1895 as the first child in a large fishing family on Ulvön, famous for its fermented herring. Carl Richard’s aptitude for technical things was revealed when he at the age of ten became the best expert on the first boat engine in the family, with one cylinder. He was sent to technical school and then to study Shipbuilding at Chalmers. After graduation he received a scholarship to study for a year at MIT, after which he stayed in the US for a successful engineering career in industry. In 1938 he was invited back to MIT as professor, making an illustrious academic career, and ending as Dean of Engineering. During all his years at MIT he was always still practicing engineering through extensive industrial consultancies in the US and Sweden. While Söderberg was a proponent of the science-based curriculum, this was because of his experience with real problems in industry and society, and he eventually came to harshly criticise how the education had become distanced from engineering practice (1967).

5.22. 3.1.2. Comparing the ideals of CDIO and Söderberg
The next step in the study was to compare Söderberg’s views on engineering education, based on his writings, with those of CDIO. What follows is a different comparison than the one in paper IV. Here, the structure is reversed, with Söderberg’s views analysed through the lens of CDIO. For each CDIO standard, quotes are used to illustrate the extent to which Söderberg’s views match these principles. (This is included here because it could be of interest to implementers of CDIO. For the complete comparison, see the paper.)

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1 Carl Richard Söderberg’s father and uncle were pioneers in packaging the fermented herring (surströmming) in tins. It had previously been distributed in small wooden barrels, with the disadvantages of not quite containing the smell, and also keeping the fishermen in hard work producing hundreds of barrels during winter.
5.23. Standards 1, 2 and 12 – Aims, Learning outcomes and Evaluation

CDIO standard 1 declares that engineering education is a professional education, and “what engineers do” is expressed as conceiving, designing, implementing and operating products, processes, and systems. CDIO standard 2 recognises that learning outcomes should reflect the dual nature of professional education, i.e. both the understanding of disciplinary knowledge and professional competence. In many ways, these standards embrace Söderberg’s ideals, asserting the dignity of useful knowledge and advocating that education should prepare students for the practice of engineering, by acquiring the strengths of the disciplines as well as the abilities to deal with real problems in all their messiness. However, when CDIO describes engineering practice in analytic terms – conceiving, designing, implementing and operating, Söderberg would most likely have used holistic terms: problem-solving and the process of technology. I also believe that he would have mentioned that the ultimate aim is to advance the human condition. His engineering education ideals also emphasise the integration of general education aims more clearly, as a part of becoming a better engineer, but also for personal development.

CDIO standard 2 advocates that the intended learning outcomes should be formulated in dialogue with stakeholders, and standard 12 recommends regular collection of feedback through a number of methods, to be reported to all stakeholders, and form the basis for decisions about the programme and its continuous improvement. The idea of consulting with external stakeholders has little equivalent in Söderberg’s writings. While the process of the Lewis committee constitutes an excellent role model for deep and insightful self-evaluation, they consulted only internally within the faculty. One difference, however, is that Söderberg was always an active engineer in industry and government consultancies, and was most likely in an excellent position to consider the needs of industry and society. This is less common in today’s faculty.

5.24. Standards 3 and 7 – The integrated curriculum

CDIO standards 3 and 7 identify the strategy of integrating the disciplinary fundamentals with the development of professional competences. Söderberg (1967, p. 400) comments that, “the purity of discipline orientation does not seem realistic for professional institutions of learning.” Likewise: “The division of a curriculum into isolated subjects each taught by a specialist may be a necessary expedient, but we need to be continually reminded that it is essentially unrealistic and that the ideal lies in the opposite direction” (MIT, 1949, p. 30). When CDIO calls for mutually supporting disciplinary courses it implies that integration cannot be left to the students, but every instructor should have some interest in and knowledge of the contribution of other subjects in the programme. The Lewis committee also urges that the curriculum needs to support integration and that faculty must be role models, “If each subject is narrowly compartmentalized and if the student sees each teacher as a specialist interested only in his own field, then the student’s task of integrating his
educational experiences will be nearly hopeless” (MIT, 1949, p. 93). They further advocate integration of professional skills, as instructors “must insist on competence in such subjects and make the students understand that bad human relations or careless writing, for example, can be the cause of failure in an engineering problem in school just as it can be in professional life” (MIT, 1949, p. 31).

5.25. **Standard 4, 5, and 6 – Engineering projects**

CDIO standards 5 and 6 address students’ need to learn to handle real engineering projects under conditions that are characteristic for professional life. CDIO curriculum development implies a sequence of such experiences, starting early in their education and with progression through the years. Here, students practice working on problems that increasingly include the full contextual aspects, under near-authentic conditions and working modes. Such learning activities can also reinforce students’ disciplinary understanding, through the opportunity to express and apply theory, and increase their motivation for learning new theory. Likewise, Söderberg calls for an educational environment in which professional work is being pursued, and emphasises that “more of the problems chosen for study could be full multidimensional ones, like the real problems of professional life, which rarely respect academic departmental barriers; problems requiring evaluation and judgment as well as calculation, [not ignoring the] social setting and human and even ethical dimensions” (MIT, 1949, p. 30). Moreover, Söderberg (1954, p. 62) appealed for such learning experiences to start early in the curriculum. He cited the need to break the monotonous sequence of fundamentals followed by application, “Many of us have felt that this sequence overlooks the elementary facts of [student] motivation. Their enthusiasm has all but vanished by the time they reach any of these applications.” This sentiment is exactly echoed in CDIO standard 4 (and 7). Söderberg also describes as a novelty what we today would call a capstone course. He reports: “the search for educational experiences in imaginative design [have] given encouraging results”, however he also has concerns about the resource requirements (Söderberg, 1967, p. 411). Half a century later, the CDIO initiative and others have gained much more experience and addressed resource-effective ways to organise design-based education, to some extent refuting Söderberg’s concerns.

5.26. **Standard 8 – Active Learning**

CDIO standard 8, Active Learning, recommends engaging students directly in appropriate learning activities, manipulating, applying, analysing, and evaluating ideas and taking on roles that emulate engineering practice. Likewise, the Lewis committee (MIT, 1949, p. 29), identified as a key value the “insistence on active participation by the learner rather than passive absorption.” The students must “by their own efforts convert facts into the body of their personal experience” (p. 9).
5.27. **Standards 9 and 10 – Faculty Competence**

CDIO standards 9 and 10 recognise, just like the Lewis report, that the “performance of an institution is determined in the ultimate by its staff” (MIT, 1949, p. 33). Söderberg came to complain that faculty were increasingly shaped by research, “The teachers are gradually becoming more strongly oriented towards the scientific and theoretical, and the universities are gradually getting less competent for the task of teaching professional engineering” (Söderberg, 1962). He suggests: “the disciplinary specialist must be sufficiently in tune with the professional environment… capable of forming a bridge between the discipline and the profession” (Söderberg, 1967, p. 407). CDIO standard 9 recognises the need to strengthen the professional competence of the faculty, because the strategy of integration skills will be feasible only as far as faculty can support it. A key idea is also the mutually supporting courses, implying that each course has a function in the programme as a whole. This requires, as the Lewis committee suggests, that the instructor, “should have some interest in and knowledge of the contribution of other subjects to the education of his students. As a contributing scholar his responsibility may be confined to a narrow specialty, but as a teacher his responsibility is not limited by the boundaries of a particular subject” (MIT, 1949, p. 31). They continue: “the teacher must be… professionally competent” and “maintain some sort of inspiring contact” with the professional field (p. 32).

With regards to faculty teaching competence, CDIO standard 10, the Lewis committee emphasise in particular the criteria for appointment and promotion, “It is our opinion that more emphasis should be placed on searching out and rewarding the great teacher as well as the outstanding scholar” (MIT, 1949, p. 143). In CDIO, work along standard 10 has included activities directly addressing faculty development of teaching skills, such as workshops and courses, but also recognition of teaching merits, and educational scholarship.

5.28. **Standard 11 – Learning Assessment**

CDIO standard 11 emphasises that effective assessment processes are necessary for evaluating the full range of intended student learning outcomes. The principle of integrated learning extends also to the assessment of learning. What must be practised and assessed is authentic performance where these aspects are interwoven; in short, integrated learning calls for integrated assessment (Edström et al., 2005). Also the Lewis committee noted the importance of assessment, and recommended “vigorous experimentation with testing methods with a view to making the examination a better educational experience and a better instrument for evaluating a student’s judgment and intellectual power rather than the memory”. They also recommend that professional skills be taken into account in assessment, as instructors “must insist on competence in such subjects and make the students understand that bad human relations or careless writing, for example, can be the cause of failure in an engineering problem in school just as it can be in professional life” (MIT, 1949, p. 31).
In summary, the agreement between Söderberg’s writings and the CDIO approach is considerable.

3.2. Learning from the past

5.29. 3.2.1. Decommissioning the pendulum metaphor

Reviewing Söderberg’s views together with CDIO confirms Seely’s conclusion that this challenge has “remained remarkably consistent over time” (2005, p. 125). Since the tensions between the academic and professional values are expected to remain, a better understanding is needed to support the productive relationship in the curriculum. The comparison showed remarkably similar positions regarding the dual nature ideal, integrating disciplinary theory and the other aspects of professional preparation. However, there were difficulties in the practical realisation of this ideal, also in the past. An imbalance in resources, in favour of basic research, came to shape the faculty and the organisation, and this soon led observers to lament, already fifty years ago, how education had come to reflect the primacy that engineering science had achieved over engineering practice.

While Söderberg wanted to improve a practical education by integrating much needed theoretical aspects, the CDIO Initiative emerged as a reaction to a theoretical education, and wants to improve it by integrating (also other) much needed professional aspects. This means that they arrived at a common ideal from exactly opposite paths. Both Söderberg and CDIO recognise the dual nature of engineering education, and refuse to single out one side over the other. This shows that Seely’s swinging pendulum metaphor fails to challenge the misconception that engineering education must necessarily lean either to the academic or to the professional side. When Söderberg advocated a more theoretical approach, it was to strengthen professional practice. Likewise, when CDIO advocates professional competence, the deeper working understanding of disciplinary fundamentals constitutes a critical preparation for practice. The common ideal identified here is to make the professional and disciplinary preparation mutually supporting. The conclusion is that engineering education would benefit from ending the trench wars over “how much” should be theoretical or practice-oriented, and make more efforts to strengthen the meaningful relationship between these aspects in the curriculum. One conclusion is to let go of the swinging pendulum metaphor. Instead of seeking balance and compromise, as the pendulum imagery would suggest, we should seek syntheses and synergies.

5.30. 3.2.2. Faculty, not curriculum

In my opinion, the ideal of mutually supporting disciplinary theory and professional preparation is not unrealistic; it is fully feasible to devise such curricula, using for
instance the strategies devised in the CDIO approach. But, Harvey Brooks\(^2\) pointed out, “the main fault of engineering education is the excessive preoccupation with curriculum.” Instead, according to him, “the heart of the problem lies in the character and orientation of the engineering faculty. In the long run the courses and curriculum, and the knowledge and motivations of the students, are bound to reflect the research interests, the consulting experience, and the values of the faculty.” (Brooks, 1967b)

The challenge, then, is to shape a faculty whose collective competence can support curricula closer to the ideal.

The focus on Söderberg as a person also makes a point because he so clearly combined the practical and theoretical interest, himself embodying the dual nature of engineering. This could suggest that to achieve the duality, we need enough people in the faculty who can simultaneously defend both the academic and the professional values. The binary view, with the pendulum image and the trench wars over the curriculum, may be unavoidable if too many people favour one side with little consideration for the other. In fact, engineering faculty need competence in three areas: theoretical-scientific expertise, professional competence, and teaching competence. If this seems daunting, we can look around our faculty and say, quoting the Lewis committee: “We have such people; we can have more” (MIT, 1949, p. 93).

5.31. 3.2.3. Using a historical perspective

Engaging in the past certainly gave a sense of *déjà vu*. While the history was already to some extent familiar through Seely’s work, including the understanding that the practice vs. theory conflict is as old as engineering education itself, the deeper engagement made a difference. Despite the warning that “while the debate may seem the same, the content has changed radically” (Jørgensen, 2014), it was exciting to hear the echo, across half a century, of almost exactly the same ideas and words that we are using today, in CDIO and in other engineering education communities. Perhaps the similarities are not so remarkable after all, because it was the *ideals* of the past and the present that were compared, not the actual curricula, and it is always easier to agree and resolve tensions on the abstract level.

The results of this engagement into the past can certainly prompt critical reflection. Just losing our historical innocence and knowing more about how deeply this issue runs makes a difference. It may increase the awareness of how necessary it is to defend these ideals in practice. Above all, a historical sensibility is part of knowing the issues in depth. As I demonstrated through this triangulation of the past and

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\(^2\) Harvey Brooks, 20 years younger than Söderberg, became Dean of the Division of Engineering and Applied Sciences at Harvard when Söderberg was Dean of Engineering at MIT.
present, it is a perspective that can strengthen our understanding and our arguments, as well as our reflexivity in our work.

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This chapter took a long-term perspective to inspire new ways to understand the tension between academic and professional preparation, by comparing how it is conceptualised in past and current initiatives for engineering education development. Taking us back much nearer the present time, the next chapter aims to provide another critical perspective, by considering unsustainable change.
4. MAKING SENSE OF UNSUSTAINABLE CHANGE

Taking the starting point in practical experiences when change has been unsustainable, this chapter makes a new interpretation of educational development.

4.1. Organisational gravity

5.32. 4.1.1. Experiences of unsustainable change

In 2011, I had been discussing engineering education development with educators, programme managers, deans, and educational developers for over a decade. They were based all over the world, and their change projects were of various types, not solely CDIO and PBL implementations. Over time a pattern began to emerge. Some of the colleagues confided that even projects that were considered highly successful had achieved smaller results than intended, and further, that change was not sustainable, in that engineering programmes tended to revert “back to normal”. My informants reported that they felt a need to constantly keep working hard just to sustain new practices in the programme. Otherwise, as soon as their attention turned to other matters, the new practices would wither away and the programme revert. Out of pure curiosity I began to informally ask more questions about their experiences, opportunistically during coffee breaks and conference dinners, in corridors and aisles, trains and airplanes, and bars. There was a common theme in their stories, some remarkable phenomenon, but what was it and how could it be understood? It also felt novel, in the sense that it was not part of the normal discourse about change in these circles. The poor sustainability of change had evidently come as a surprise to my colleagues; we did not have concepts to describe it. This indicated a need for a new way to think about educational development. Several new questions emerged: What makes programmes revert? What do they revert to – is there a particular ground state for a programme? If so, what defines or shapes it? Why is it more stable than other states?

The result of my reflections was a new theoretical model that connected the educational programme with the organisational characteristics of the organisation in which it is situated. Being an engineer and communicating with engineering educators, it was natural to use a technical metaphor:

Organisational gravity is a force acting on education programmes, causing them to reflect the inherent characteristics of the organisation providing it. The most stable state (lowest energy state) for a programme is thus to reflect the institution. This is the ground state. Every other state requires that some kind of energy is introduced into the system to counteract the gravity and ‘lift’ the programme to an alternative, more desired, state. Such energy can be applied in many different forms, for instance through money, leadership, attention, and other resources, in projects and interventions. But since the organisational
gravity keeps exerting its force on the programme, we must continuously add resources to keep it from reverting to the ground state. (Edström, 2011)

5.33. 4.1.2. Testing the model

The organisational gravity model postulated that the ground state for educational programmes is where it simply reflects the characteristics of the organisation. If so, it should be possible to analyse what type of educational development could be harder to achieve and sustain, and what types should be easier. I will explore this using two examples.

Example 1. Why do engineering curricula often consist of courses that reflect the organisational boundaries of the university?

Even when cross-disciplinary learning activities are considered desirable for the education it seems hard to form and sustain collaboration across organisational boundaries. The barriers are not only the different traditions of the subjects, but there are also considerable practical concerns. Several mundane issues have to be resolved to handle a course over different cost centres, administrative classifications, and staff territories. Relations between faculty members may be weaker; they may not even know each other in the first place. The physical setting often reflects organisational boundaries, with one building for scientists working on a class of problems called control theory, and other buildings for people working on programming, and so on. Even when we succeed in creating crosscutting collaborations, they tend to involve extra work to establish and maintain, and they are extra vulnerable to discontinuation since they often rely on personal connections and trust. It is consistent with the model that programmes consist mainly of courses corresponding to the administrative territories of the organisational chart. As most universities are organised along the disciplines, these disciplinary boundaries tend to be reflected in the courses of the programme.

Example 2. Why is it hard to integrate learning outcomes related to professional practice?

The degree requirements for engineering education in most higher education systems contain learning outcomes related to professional skills, including the ability to integrate knowledge and apply it to ‘real’ engineering problems. But real problems do not respect disciplinary boundaries, and solving them often requires integration of knowledge – including old knowledge, far from the research frontier. They further require interpretation of the context, and judgement and creativity in conceiving and implementing solutions. When hiring and promoting faculty, disciplinary research merits are more valued than strengths related to integration, application and professional practice. Therefore the faculty, at a collective level, has relatively little professional engineering experience. As a consequence, problems that are generated from within the disciplines are considered interesting in academia, while problems that do not map to the disciplines fall outside the perceived responsibility of most
researchers. To provide professional preparation, the university needs strengths related to integration and to application of knowledge. This is not easily provided in the discipline-based organisation, whose logic follows the research frontier: reduction, analysis, specialisation, and branching off new fields and sub-disciplines. Therefore it takes special effort in the programmes to address learning outcomes related to professional engineering practice. It is consistent with the model that some learning outcomes are more difficult to address in the education, because their representation in the organisation is too weak. This applies to learning outcomes related to real problems, to integration and application, and to the aims of engineering practice, i.e. innovation and entrepreneurship, or sustainable development.

The conclusion was that when values are not sufficiently represented in the setup of the organisation, they are harder to implement sustainably in programmes. Unfortunately, this applies to some of the most important learning outcomes in engineering education. No organisation can optimise on all goals simultaneously (Birnbaum, 1988, pp. 59-63), so if the organisation is optimised for the production of disciplinary knowledge, it can more easily provide the disciplinary theory, while it is more difficult to address the professional aspects.

5.3.4. 4.1.3. How things work around here

The organisational gravity model was an attempt to describe how the inherent characteristics of the organisation shape the education programme as an image of the organisation, unless resources are constantly applied to keep it in a more desirable state. Organisational characteristics are interpreted in a very wide sense – a simple working definition would be “how things work around here”. This is determined by formal matters such as structure and policy, but also by what values are embedded in the organisation. Table 4.1 lists some possible shaping mechanisms, classifying them as hard or soft and internal or external.

Table 4.1. Mechanisms shaping the organisational characteristics (Edström, 2011).

<table>
<thead>
<tr>
<th>Hard</th>
<th>Soft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organisational structure, policies and regulations, hiring and promotion processes, allocation of power and resources etc.</td>
<td>Funding systems, evaluations, accreditation, national policies, national and international collaborations, ranking, awards etc.</td>
</tr>
<tr>
<td>Language and conceptions, status, symbolic events, rituals, self-image etc.</td>
<td>Image, status, personal networks etc.</td>
</tr>
</tbody>
</table>

Despite the attempt to classify the factors, it is easy to see that they interplay and influence each other, and in particular, some factors will enable or limit change in others. For instance, many internal factors are influenced by the external. The internal resource allocation is often aligned with how resources are acquired by the institution, an external factor. Not only the volume of resources shapes the organisation but also
the logic of allocation. Incentive effects can be seen when resource grants are awarded in competition, based on (some operationalization of) excellence, while at the same time compensation for education is distributed according to quantity, rewarding all teaching equally, irrespective of quality. Further, soft and hard factors shape each other – “the symbolic takes part in creating the real” (Dahler-Larsen, 1998, p. 54). For instance, the status of the title ”professor” depends on whether the procedure for appointment is perceived as rigorous and related to socially shared values, and whether the title is associated with substantial rewards, such as independence and access to funding and power (hard factors). The design of such policies and procedures are in turn limited or enabled by the prevailing views on roles and identities in the organisation (soft factors).

4.2. Implications

5.35. 4.2.1. Two change strategies

A direct implication of the model is that there are in principle two kinds of change strategies available for developing educational programmes: the force strategy and the system strategy.

The force strategy is to add some kind of extra energy to move the programme to a more desirable state (a higher energy level). This energy can take many forms: funding, leadership, attention, alliances, evaluations, lobbying, personal energy, etc. One advantage is that the force strategy is available to all actors; everyone can just go ahead and make their contribution – using their force – top-down or bottom-up. The disadvantage is that force is continuously needed to counteract the organisational gravity and prevent the programme from reverting back to a lower energy level. The force strategy is therefore potentially not resource-efficient. This is not to say that it does not work, but it works with an agricultural logic: new seeds must be sown every year. Being aware of this logic will help set more correct expectations regarding the results and their sustainability, and make it possible to plan for a continuous supply of resources. In particular, the force strategy risks putting high strain on people, partly because of the high effort it takes to achieve results and to sustain them, and partly because their efforts are likely under-rewarded (more about that below).

The system strategy is to change the characteristics of the organisation to enable a more desired stable state for the education. Such change goes deeper; it is not only to change what we do in the education, but also who we are as an organisation. This can be labelled as a self-transformation ( Alvesson & Sveningsson, 2008, pp. 238-243). The values needed for the educational mission must then be present in the organisation. In other words: to sustainably change the education it is not sufficient to just change the education. This is also about the nature of research, since it will limit and enable education. Hence, in addition to the production of knowledge, the values
related to integration and application are necessary to create an organisation that can also accommodate professional education. Precisely because of its constitutional function, the system strategy is less available. Fewer actors have access to the most important shaping mechanisms, e.g. career systems, funding systems, and they also change rather seldom. The advantage is that even small changes, for instance in the appointment and promotions structure, can have considerable and lasting effects. The ideal is to align the university, as a system, with both its research and educational missions. Then, in theory, organisational gravity could become a positive force, pulling the programme in the right direction.

Thus, both strategies have their uses, as they have different strengths, weaknesses, availability, limitations, risks, and implications for resource-effectiveness and sustainability of results. Even if the force strategy seems like an unwise choice at first sight, the Sisyphean labour may actually be justified. It is also understandable if university leaders hesitate to use the system strategy. If it is mainly research-related indicators that will de facto determine the long-term survival and prosperity of the institution, there could be risks associated with creating an organisation that can accommodate good research and good education.

5.36. 4.2.2. Educational development as a compensatory activity

One final observation is that the model can shed new light on educational development. With the exception of new issues such as digitalisation, the label educational development seems to denote a remarkably stable set of issues. They often relate to the professional side of education (e.g. development of professional skills and judgement, integration and application of disciplinary knowledge, problem-based and active learning). Therefore I suggest that the role of many educational development activities is to compensate for such values that are necessary for education but not sufficiently represented in the organisation. In the words of the model, educational development is about moving the education programme to a more desired state, and keeping it there; the work is about counteracting the organisational gravity.

One implication could be that educational development consists of precisely such work that the organisation is not set up for, which is why such compensation was needed. For anyone engaged in educational development, this is a sobering thought. If it is true that educational development is about compensating for the values that are not sufficiently embedded in the setup of the organisation, then we can suspect that merits related to educational development constitute by definition such achievements that do not build a career in the university.
4.3. Reflections

5.37. 4.3.1. The value of the model

The organisational gravity model and the accompanying discussion were created to capture in abstract form what practitioners (educators, deans, programme leaders, educational developers, and administrators) had reported about their flesh and blood experiences. Despite the technical imagery it should not be confused with a law. Instead the model is an explanatory device:

“That both [models and theories] may be seen as explanatory devices or schemes having a broadly conceptual framework, though models are often characterised by the use of analogies to give a more graphic or visual representation of a particular phenomenon” (Cohen et al., 2011, p. 13).

Hence, this representation of an empirical phenomenon is offered to practitioners as a lens for interpreting and discussing their experiences. This is theorizing in the context of discovery rather than the context of justification (Swedberg, 2012, 2016). The justification, finding out whether the effect can be observed, is left for empirical investigation. In other words, the point here is not to “prove” that organisational gravity “exists”. Nor is it implied that educational development projects in general will revert; in fact, the cases described in chapter 2 have persisted for 10 to 15 years and counting, which contributes to the opposite picture. The message is not that change will be unsustainable (predictive power), but that if and when it is, there is a language for it and we can perceive and discuss these experiences (sense-making function). Weick (1976) aptly pointed out how concepts can help perception: “The guiding principle is a reversal of the common assertion ‘I’ll believe it when I see it’ and presumes an epistemology that asserts ‘I’ll see it when I believe it’”. At this stage, the value of the model rests not in its “truth”, but in whether practitioners find it compatible with empirical reality “in terms of resonance, understanding, explanation, or utility” (Walther et al., 2017, p. 403). If it resonates with practitioners’ experience it has face validity (Cohen et al., 2011, p. 163). It could also have catalytic validity, which refers to the degree to which it helps practitioners understand reality in order to transform it (Marshall & Rossman, 2010, p. 42).

5.38. 4.3.2. Similar concepts

I included the organisational gravity model here just as I formulated it in 2011. This original version also documents my reflections, as an educational developer during that period. Later, I have come across similar ideas expressed by several authors, which can confirm that others have seen similar phenomena.

Accounts of unsustainable change are common. Meyer, Scott, and Deal (1983) mention how educational organisations “adopt and slough off” changes (p. 56), and how changes “sweep through and die out”, and are “unlikely to persist” (p.60).
Graham also identifies the reversion process in her study on engineering education reform\(^3\), where she observed:

“significant challenges associated with sustaining change, with the majority of reform endeavours reverting to the status quo ante in the years following implementation. […] Most experience a gradual course-by-course ‘drift’ back to a more traditional curriculum” (Graham, 2012, p. 3).

Reflecting on a comprehensive international study of outstanding teaching environments in eleven research-intensive universities, Knapper (2016) says:

“in many cases the momentum and enthusiasm for the new approach diminished over time and there appeared to be what we termed a ‘recidivism to the traditional’ […] it shows radical change is difficult to sustain without constant pressure” (p. 110).

Elmore and McLaughlin (1988) studied school reforms in the United States, calling it steady work, similar to what I called the force strategy:

“measured by substantial changes in what is taught and how, the rewards are puny; but the work is steady, because of the seemingly limitless supply of new ideas for how schools should be changed and no shortage of political and social pressure to force those ideas onto the political agenda.”

By the same token, Christensen and Ernø-Kjølhede (2012) call the issue of integrating contextual issues and socio-technical competencies a never-ending story: “There appears to be no optimal and final solutions in implementing theory of science in engineering education but only temporary solutions reached by negotiation and compromise” (p. 16).

The need for system-level change is also identified by Miles and Ekholm (1991), who depict how schools revert changes, unless they are made “normal”: “Schools, like other organizations, have a way of weathering down changes, or subtly ejecting them, unless they are built in to the school, become embedded, a part and parcel of ‘normal life’.” They further mention that institutionalisation is directed toward “saving energy in the organization”.

It is also easy to draw parallels to the work of Argyris and Schön (1996), who distinguish between two forms of organisational learning. Single-loop learning refers to the adaptive behaviour of a stable system. In contrast, double-loop learning means that the system itself changes by modifying values, strategies, and assumptions. Argyris and Schön comment that “most organizational ‘fixes’ are of the single-loop variety”, but such “reforms and fixes tend to be subverted, over time”. They identify defensive patterns that hinder double-loop learning, in particular the preference to locate problems only in “discussable domains”, and limit solutions “to deal with discussable features of the problems” (p. 281).

\(^3\) Disclosure: I was one of Graham’s 187 informants in this study and shared the organisational gravity model in the interview.
This chapter, and the previous one, have in different ways problematized engineering education development. The following section will follow up on the suspicions generated here, that the crux of the matter can be found in the relation between the nature of change and the setup of the organisation. Whether it is in discussable domains or not, we need to consider how things work around here.
5. AN ORGANISATIONAL PERSPECTIVE

The previous chapter considered the challenges of unsustainable educational development. One key hypothesis was that the nature of change matters, which makes it harder to accommodate some of the most desired goals of professional engineering education. My hypothesis in the previous chapter was that whether change was successful or not had to do with how well the nature of change matches the values inherent in the setup of the organisation – or what I called how things work around here. This line of reasoning found support also in the historical case of MIT, which showed how research funding changed the priorities of the faculty and the university, with the consequence that the education became more theoretical and lost some of its professional character. The focus of this chapter is therefore to take an organisational perspective on the tension between the academic and professional aims in engineering education.

5.1. Understanding organisations and institutions

5.39. 5.1.1. The university as a machine

To understand change it is necessary to begin with an understanding of how things work in the first place. This chapter constructs a theoretical framework to support a more sophisticated understanding of the university as an organisation, in particular as an environment for the kind of educational development that is in focus here. It might appear counterintuitive to focus on the status quo when change is wanted, but the ability to develop the curriculum depends on how well the conditions for change are understood. Whether they are implicit or explicit, it matters what models, concepts, or theory we have. As mentioned previously, concepts can function as lenses for discerning things that may otherwise have gone unnoticed. Similarly, they may also limit our view, because to highlight some aspects is also to relegate others to the background. Thus, models and theories can just as well blunt our perception and misguide our interpretation. In the following, one common view of the university organisation will be severely challenged.

One way of seeing the university is as a factory or machine for education and research. The metaphor suggests an organisation optimised for effective operation, structured along the organisational chart, and designed to coordinate its activities “in a routinized, efficient, reliable and predictable way” (Morgan, 2006). Individual actors are expected to behave in a rational manner, with polices and decisions coordinating and controlling the rational production of services according to stated goals. Perhaps this view is particularly natural to adopt among engineers, due to our strong tendency to see functionalist rationality as the natural guideline for action (Picon, 2004, p. 429). The problem is not that the machine model is necessarily wrong, but that it lacks explanatory power for many aspects of university life, including the experiences
described in the previous chapter. Weick (1976, p. 1) observed that people often find that their experiences in educational organisations “prove intractable to analysis through rational assumptions”, as the rational view simply does not “explain much of what goes on within the organisation”. In particular, the machine model is unproductive when it comes to formulating models for change. In fact, the change strategy that can be derived from this organisational understanding is that change should be mandated from the top and aimed at improving the outputs. But the previous chapter showed precisely the difficulty associated with achieving sustainable change even given top-level decisions, access to resources, and the best intentions with respect to the outcomes of education. These were not sufficient conditions for sustainable change. Thus, there is reason to suspect that a top-down and function-oriented model of the organisation is not useful as a means to inform development, or to make sense of experiences.

An alternative framework will be needed, more appropriate to analyse the university as an organisation and assessing the implications that follow for educational development. In the following, I will construct a theoretical framework describing organisations as embedded in and infused by institutions, meaning social orders, or systems of social beliefs and rules. The institutional perspective was chosen because it helps explain organisational behaviours that defy rational assumptions. The focus on discovering other rationalities, or rather uncovering them, matches the critical research approach of this thesis (cf. Suddaby, 2015). If the machine metaphor focuses on the formal and visible structures, resources, activities and outputs, institutional theory also emphasises the subtler roles played by norms and values, and by culture and identities.

Before introducing institutional theory, it is necessary to disambiguate the term institution. In education it often refers to a higher education institution, a single university or university college. (To make it more complicated for Swedish readers, the word for academic department in our language is also “institution”.) Further, to institutionalise often means making practices routinized and embedded, or institutionalised, in an organisation. This is closer to the meaning in institutional theory.

5.40. 5.1.2. Shattering the machine metaphor
The (neo-)institutional view on organisations challenges the functionalist conception of rationality. In their landmark paper, Meyer and Rowan (1977) argued that: “organizational success depends on factors other than efficient coordination and control of productive activities”. More important for success and survival, they said, is the ability of the organisation to conform to, and become legitimated by, institutions in the environment. It is therefore not merely the production and activities of the organisation that shape formal structures, assessment criteria, vocabularies, and practices, but also the rules and norms of its institutional environment. Two
fundamental problems follow for the organisation, first that institutional rules and norms are often in conflict with each other as they arise from different parts of the environment, and second, that conformity to the institutional rules and norms may be in conflict with efficiency of the production of outputs. In particular when the outputs are difficult to appraise — as they certainly are for universities — legitimacy will depend mainly on conformity with institutional rules. The logic of efficiency is then less crucial than the logic of appropriateness to institutional rules and norms. (While Meyer & Rowan did not use the exact term ‘logic of appropriateness’, they describe the phenomenon (see also March, 1982; March & Olsen, 2004).) Meyer and Rowan further made the point that what really matters is to maintain appearances; the institutional rules are often enacted ritually or ceremonially. Therefore the problem can be stated: “the organisation must struggle to link the requirements of ceremonial elements to technical activities and to link inconsistent ceremonial elements to each other”. Some of the organisational strategies used for absorbing these tensions within organisations are decoupling (minimising disputes and conflicts by avoiding too close integration, more about loose coupling below), preserving ambiguity around goals and outputs (making it hard to evaluate performance), delegation to professionals (individuals are left to work out inconsistencies informally) and maintaining face (through displays of confidence and good faith).

At this point, three key concepts will be elaborated in some detail: loose coupling, isomorphism and legitimacy.

5.41. Loose coupling

Meyer and Rowan (1977) use the term loose coupling to describe how organisations can cope with the two conflicts, between inconsistent rules coming from different parts of the institutional environment, and between institutional rules and the efficiency of the practical activity. These tensions can be reduced through decoupling. Weick (1976) described loose coupling in educational organisations:

“By loose coupling, the author intends to convey the image that coupled events are responsive, but that each event also preserves its own identity and some evidence of its physical or logical separateness… their attachment may be circumscribed, infrequent, weak in its mutual affects, unimportant, and/or slow”.

Noticing that many see loose coupling as a flaw in the organisation, Weick instead takes “a neutral, if not mildly affectionate, stance toward the concept”, and he shows that although it makes matters “modestly predictable”, loose coupling has many advantages. It allows people some autonomy and creativity, makes room for experimentation and development of localised or context-specific solutions. The organisation spends a minimum of resources on coordination and control. Further, the organisation is protected from responding to every change in the environment, and a breakdown in one area need not hit all parts of the organisation. An engineer may make an association to the risks of over-determined systems, and the use of spring-
dampers and firewalls. The integrated curriculum strategy in CDIO can be understood as an effort to achieve a tighter coupling, with coordination between the programme and the courses, and horizontally between courses. This was exemplified by the Mechanical Engineering case at Chalmers described in chapter 2.

We turn to Brunsson (1989) for an example of how loose coupling can be used to uncover organisational behaviour. He addresses the tensions posited by Meyer and Rowan on the concrete level of organisational behaviour. Brunsson makes the case that in order to cope with inconsistent environments, organisations have two structures – one (informal) for producing action and results, and one political for producing ideology for the purpose of legitimation. Brunsson argues that the tensions between these functions make it necessary for the organisation to keep its *talk, decisions and actions* apart, in other words, to keep them loosely coupled. His point is that it could be difficult or prohibitively expensive to actually satisfy inconsistent demands in the actions and production of outputs. Therefore, ideologies are much better suited for handling inconsistencies in the multiple ideas about the organisation, about its environment and about what it should do. In fact, as some problems are insoluble in practice, they are accessible to ideological handling only (pp. 26, 233). The result is double talk where the political organisation deals mainly with ideas, intentions, and wishful thinking, debates insoluble problems, launches reform to inspire hope, and focuses on the future. Brunsson makes the important point that when the political organisation deals with the inconsistencies, it *protects* the action organisation from those tensions. It is far easier to explain and legitimise action and products, i.e. using ideology to make them more appetising, than to turn the ideas into practice:

> “When ideas are to control action, they have to be reduced to the concrete level of action; but when they are to explain action, they can distance themselves from the concrete and become abstract and more inconsistent” (p. 171).

Rather than seeing this “organised hypocrisy” as a problem in the organisation, Brunsson concludes that it is actually a solution for handling the tensions. Nevertheless, he also shows empathy for those who have a functionalist conception of rationality: “it must be very frustrating to believe in the action model” (p.204).

### 5.42. Isomorphism

Isomorphism is interesting for this thesis because, depending on the nature of change, it can be expected to drive or limit change. Meyer and Rowan (1977) state:

> “Independent of their productive efficiency, organizations which exist in highly elaborated institutional environments and succeed in becoming isomorphic with these environments gain the legitimacy and resources needed to survive. […] In such a context an organization can be locked into
isomorphism, ceremonially reflecting the institutional environment in its structure, functionaries, and procedures.”

When DiMaggio and Powell (1983) took a closer look at isomorphism, they referred to the structuration of an organisational field, meaning all relevant organisations that together constitute a recognised area of institutional life (for instance higher education). Whether organisations are in contact or not, and whether they are competing or not, they will shape themselves in response to this common environment, and thereby become more alike (isomorphic). They describe three types of isomorphism pressures:

- **Coercive processes** are those that make an organisation to adapt to rules or structures coming from other organisations on which the organisation depends. For instance, universities within the same legal environment will become more alike.

- **Mimetic processes** are those that make an organisation imitate others, in particular those perceived as most successful and legitimate. This often happens when there is environmental uncertainty, when the relation between means and ends are uncertain, and when goals are ambiguous. For instance, given the uncertainty around online provision of education many universities around the world model their own strategies on those of high-status universities.

- **Normative processes** should be related to pressures from norms and values in society (Deephouse & Suchman, 2008, p. 53) and in particular, in the institutional context. DiMaggio and Powell mention the role of professions in the organisation. The similar background through formal education and continued socialisation in professional networks create categories of individuals who according to DiMaggio and Powell (1983, p. 153) “will tend to view problems in a similar fashion, see the same policies, procedures and structures as normatively sanctioned and legitimated, and approach decisions in much the same way”. While the authors had business managers in mind, they might as well be describing university faculty when they continue:

  “The exchange of information among professionals helps contribute to a commonly recognized hierarchy of status, of center and periphery, that becomes a matrix for information flows and personnel movement across organizations. This status ordering occurs through both formal and informal means.”

It is important to note that while isomorphism makes organisations more alike, this does not necessarily make them more effective. Here, Powell and DiMaggio clearly side up with Meyer and Rowan in often pointing out how pressures are addressed ritually or ceremonially. Practices are adopted whether they really work or not, but if they make organisations appear more legitimate and prestigious they make sense and bring rewards. Again, the logic of appropriateness trumps the logic of effectiveness.
5.43. Legitimacy

Meyer and Rowan (1977) showed how organisations must conform to their institutional environment to achieve the legitimacy and resources they need to survive. Legitimacy can also be applied to groups or individuals within organisations. Suchman (1995) reviewed the literature on organisational legitimacy and offered the definition:

“Legitimacy is a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions” (p. 574).

Some traits captured in this definition are that observed behaviour is evaluated over time (so specific events can be ignored) in relation to the norm system of some social group. Thus there is no such thing as legitimacy in general, it is always viewed through the eyes of some constituents, and further, in relation to some role or practice (legitimacy for what). Four main types of legitimacy can be distinguished (Deephouse & Suchman, 2008; Suchman, 1995):

- **Pragmatic legitimacy** comes from an evaluation based on self-interest, or “what’s in it for me”. The organisation is perceived to produce something of economic, social or political value to the observers.

- **Moral or normative legitimacy** is based on an evaluation whether something is the appropriate thing to do. This can apply to outputs and consequences, techniques and procedures, categories and structures, and whether leaders and representatives are perceived as the right people to do it.

- **Cognitive legitimacy** entails less of an evaluation – it is instead related to whether the organisation is seen as comprehensible and predictable, or even taken-for-granted as necessary or inevitable. This is the most powerful form of legitimacy because it is conferred in the absence of questioning; alternatives become unthinkable.

- **Professional legitimacy** is based on belonging to, or approval by, a professional group, be it on pragmatic, normative or cognitive grounds.

These forms of legitimacy come with slightly different implications. For instance, Suchman (1995) makes a difference between seeking active or passive support, and says:

“To avoid questioning, an organization need only ‘make sense.’ To mobilize affirmative commitments, however, it must also ‘have value’- either substantively, or as a crucial safeguard against impending nonsense.”

Further, he analyses strategies for gaining, maintaining and repairing legitimacy. For this thesis, gaining legitimacy is of most interest. The main strategies for gaining legitimacy are (a) to **conform** to demands in the current environment, (b) to **select** among environments to find a supportive audience, and (c) to **manipulate** the environment to create new audiences and new legitimating beliefs (p. 587).
Other related concepts for social evaluations are status and reputation. Deephouse and Suchman (2008, pp. 60-62) sort out the differences: Legitimacy reflects conformity to social guidelines, and is non-rival. Status reflects the relative position of social groups, with more rivalry between than within groups, and individuals who belong can enjoy the privileges of the group. Reputation is mostly personal, earned based on previous performance, and fundamentally rival (e.g. ranking).

With their contribution, Meyer and Rowan made it impossible to ever see organisations merely as machines again. After this first excursion into the early foundations of institutional theory follows a later and more comprehensive theoretical framework, called institutional logics.

5.44. 5.1.3. The institutional logics perspective

While the focus of this thesis is mainly on the practices within an organisation, it is obvious by now that the external environment of the organisation plays an important role in shaping the internal conditions. Universities are participants in the higher education field, and under influence from the institutional orders in society. In other words, it is necessary to bring society back into the analysis (Friedland & Alford, 1991). The institutional view of organisations has been elaborated and extended into a framework called the institutional logics perspective (Friedland & Alford, 1991; Thornton & Ocasio, 2008; Thornton, Ocasio, & Lounsbury, 2012).

Institutional logics can be succinctly expressed as “the way a particular social world works” (Jackall, cited by Thornton et al., 2012, p. 46), which is remarkably similar to my working definition of organisation in the previous chapter. The more comprehensive definition reads:

“the socially constructed, historical patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality” (Thornton & Ocasio, 2008, p. 101).

From this definition, it is clear that the institutional logics perspective incorporates both the material and normative dimensions. While the early papers (in particular Meyer & Rowan, 1977) provided much-needed insights into the powerful workings of the norm systems, any analysis that neglects the resource environment is incomplete, and here the institutional logics perspective takes a balanced view.

On the highest level, Thornton et al. (2012, p. 73) list seven institutional orders in society: state, market, community, profession, corporation, family and religion. These are the ideal types of institutional logics, each with their own set of norms and sources of legitimacy and authority. On the next level is the institutional field, populated by organisations. The field-level institutional logics often combine several of the societal-level institutions, and different organisations in the field can have different balance between these logics. For instance, the higher education sector is an
institutional field, where some processes are shaped by professional logics (e.g. peer review), and other aspects are shaped by market logics (e.g. technology transfer) or state logics (e.g. degree frameworks). An individual university can have its own instantiation of the field-level logics:

“We assume each institutional field consists of one or more available logics, as well as an array of appropriate collective organizational identities and practices from which individual organizations assemble their particular identities and practices” Thornton et al. (2012, p. 135).

The important implications here are that a university is part of a complex institutional environment that contains contradictions between different societal logics, and that the logics embedded within any particular university will also reflect tensions. This has consequences for practices and identities inside the organisation. In the following some of these aspects are elaborated upon and connected to each other.

5.45. 5.1.4. Practices and identities in the organisation

By connecting the institutional logics to practices, what we do, and identities, how we see ourselves, the theory now becomes very relevant for this thesis. The development of engineering education is precisely an attempt to change one of the practices of the university. It is therefore a key concern how the “old” or “new” curriculum models are related to the institutional logics, how they are related to other practices in the organisation (e.g. research), and how they are related to identities in the organisation.

5.46. Practices

Practices are intimately connected to the institutional logics of the organisation. Thornton et al. (2012) describe “a fundamental duality between logics and practice, where constellations of relatively stable practices provide core manifestations of institutional logics”. All practices will not reflect the institutional logics in the same way, as they may align with different parts of the institutional environment, for instance different sets of uncoordinated constituents. In a complex institutional environment with incoherent demands, we can expect a need to accommodate tensions between practices, as well as within practices, and between institutional rules and the effectiveness of the practice. Some practices are “linked to different logics that coexist relatively independently” (Thornton et al., 2012, p. 139), while others can express hybrids of different logics. This thesis will in particular focus on how the institutional logics of two professions are expressed in the curriculum: the academic profession of the educators, and the engineering profession, which we educate for. Thornton et al. further suggest that practices may be conceptualised as interdependent, so that changes in one practice may have ramifications for other practices in the organisation (p. 141). Here, it is mainly the interdependence of education and research that will be in focus.

In the context of organisational change in higher education, Oliver (1991) combined the institutional and the resource dependence perspectives. Clearly, both normative
and economic rationalities affect the organisation, its practices and identities. Sometimes these forces will coincide so that a practice gains strong support both normatively and materially, while others have more variegated patterns. As already noted in chapter 4, education and research are two practices with quite different resource environments. The resource environment has profound consequences on the inside of organisations. As Pfeffer and Salancik (1978, p. 71) suggested, “organizational environments come to affect organizational actions partly by affecting the distribution of power and influence within the organisation”. We are reminded that both the material and normative dimensions are included in the definition of institutional logics. Thornton et al. (2012, p. 157) note that practices are embedded in economic systems, so that “material resources influence the generation of practices and have partial autonomy from culture and institutions”. They further point out that resource environments are also in turn shaped by institutional logics, e.g. at the societal level.

5.47. Identities

Organisational identity refers to the collective identity of an organisation, as perceived externally or internally. Stensaker (2015) finds that the organisational identity of a university seamlessly connects the past and the future, tradition and modernity, and highlights the values and norms. He also notes that the organisational identity may indicate internal power structures of the university. Given the focus of this thesis, it is however more interesting to consider identities within the organisation. Here, Alvesson distinguishes between the social identity of sub-groups, and self-identity, i.e. how individuals see themselves. Self-identity is linked both to the individual and the collective, and “typically includes elements of social identities, but also more than that, and gives the individual categories more of an individual and rich meaning” (Alvesson, 2012, p. 35). Self-identity can also refer to the identity of the organisation as a whole and to available standardised social identities. Henkel (2005) refers to Bernstein in saying: “identities are strongest and most stable within the context of strong classification, the maintenance of strong boundaries protecting the space between groups, disciplines or discourses”. The classifications of individuals are important in higher education, and university organisations pay much attention to it. Education can be seen as a process where schools and universities handle students through a series of stages, carefully controlling every transition (e.g. admission, examination, degrees), and the classification of academics is no less important (just think of disciplines, titles, appointments and promotions). Meyer and Rowan (1983) find that while educational organisations tend to only loosely coordinate and control their work activity, they do in fact very tightly control the classifications of people. They say: “Education rests on and obtains enormous resources from central institutional rules about what valid education is. These rules define the ritual categories of teacher, student, curricular topic, and type of school” (p. 76). Thus, at least one part of the identity, the belonging in categories, is tightly controlled, as a precondition for awarding freedom in the work they do.
As identities are connected to legitimacy, status, and freedom, it is no wonder that it is often actively adopted and managed. Individuals and groups can engage in identity work, attempting to “rework or alter their identities to make sense of or resolve the tensions they face from competing institutional logics” or to “promote a specific understanding about an identity, link this understanding to specific logics and practices, and work to attract potential adherents to the identity” (Thornton et al., 2012, p. 130). One example, discussed in paper III (Edström, in press, 2017), is the engineering education research movement. The collective efforts to create a recognised discipline can be seen as an active transformation into a more legitimate practice, whose institutional logics offers stronger support than that of education or educational development.

5.48. Interplay between identity and practice

There is a close relationship between practices and identity; we can say that they are co-produced. The tight link is also evident when we consider how status is attached both to identity and practice. In the same way that complex institutional environments can generate conflicting rules, they can generate patterns of differentiated status between organisations, and between different practices and groups within the organisations. Status also affects the relationships with the resource environment. Kodeih and Greenwood (2014, p. 10) note that the high-status actors can be expected to have priority access to the most valuable resources. This applies both to the organisation as a whole (such as when high-status universities attract funding, and the most talented researchers and students) as well as to groups and individuals on the inside. Status can play a role in change, since those that are perceived as successful and legitimate are likely to be imitated by peers – and this applies to organisations (DiMaggio & Powell, 1983) as well as to individuals and groups within the organisation (Deephouse & Suchman, 2008, p. 61). This means that role modelling by high-status actors can be a driver of change. It also means that change may be strongly resisted if it is perceived as a threat to the status of organisations, groups, or individuals.

For this thesis, it is relevant to consider status in relation to different practices and identities in the university. The status difference between teaching and research comes to mind, but there are also implications for the relative standing of other practices, e.g. professional practice, educational development, and educational research. Further, if we now consider the curriculum as an expression of educators’ identity, it is clear that changes will be seen as more or less valuable and meaningful depending on how well they resonate with faculty identity. For instance, some educators will embrace the engineering profession as a part of their identity, and they may therefore have a more positive attitude to integrating professional aspects. Seeing the curriculum as an expression of faculty identity, it is also obvious how the mere proposal for changes can be experienced as an intrusion. In her influential study of
academic identities, Henkel concluded that the discipline and academic freedom were the two things that mattered most, “in many cases the sources of meaning and self-esteem, as well as being what was most valued” (Henkel, 2005, p. 166). The implication is that any change in practices and structures will be strongly resisted if it is perceived to entrench these values. If a reform instead can respect (or even draw on) the core values in faculty identities, it may have a better chance. As Stensaker puts it: “Academic identities can have multiple starting points for either supporting or resisting changes – or both of them simultaneously – in higher education, depending on how the reforms are defined and what their objectives are” (2012, p. 9).

5.49. 5.1.5. Organisational culture: values, beliefs and assumptions

This theoretical excursion followed Thornton et al. (2012, p. 135) in considering how institutional logics are visible in practices and identities. They also influence organisational culture, which according to Alvesson (2012, p. 4) covers aspects like assumptions, beliefs, ideas, rites, rituals, myths, and values. Culture is by no means separate from the material structures and practices in the organisation. It is insufficient to see material structures (such as budget or evaluation systems) as purely “technical” arrangements. Culture is an integrated part of how the social and material structure is constituted through practice (Stensaker et al., 2012, p. 13, citing Knorr Cetina), and the converse must also be true, that culture (and its components) are influenced by the structures and material practices.

Culture is problematic conceptually, because it rests much on taken-for-granted assumptions and is therefore only semi-conscious, and because it can be used to refer to everything and consequently nothing (Alvesson, 2012, p. 39). Merely adding culture as a mystery layer on top of the machine metaphor is simply unhelpful, especially if we embrace the view that culture can be managed as a tool – that things will go our way if we only “set” the right culture (Alvesson, 2012; Stensaker et al., 2012). As Graham noted in her survey of literature on change in engineering education:

“although ‘changing the culture’ is a phrase used in many recent reports on engineering education, the prevailing culture is rarely defined and suggested strategies for cultural change are limited” (Graham, 2012, p. 11).

Similarly, Kogan (1999) laments:

“‘Culture’ has been used to explain the inexplicable... It is a word unreflectively used by organisational reformers who have run out of specifics; they perceive that rationalistic structuring and engineering of process are not enough to move hearts and minds, and that something must be constructed in the areas of values and affect if members of the system are to produce the desired goods”.

Instead of culture, this thesis will use more limited concepts like assumptions, beliefs, and values. Already in chapter 4, values was used to discuss how the organisation was
set up, and to make the point that the capacity for practices requires the presence of matching values in the organisation. The choice seems defensible also in the light of the institutional logics theory. For instance, Friedland (2013, pp. 30-37) refers to Weber’s “value spheres” when he coins the term institutional substances, “the unobservable, but essential, ‘value’ anchoring an institutional logic”. Also, like identity, values bring meanings of internalisation and passion: “[actors are] passionately and expressively oriented to unobservable values they have internalized and in whose unconditional requirements they believe” (ibid.). Values signals that the logic of appropriateness is in play, more than the logic of effectiveness.

5.2. Perspectives on change

5.2.1. Reform as routine – and as producer of hope

We are already familiar with Brunsson, who highlighted that talk and action are decoupled, in order to protect the action organisation from having to deal with inconsistent demands. He continues to discuss the role and function of reform (2009), noting that organisations are often under constant reform, or attempts to change to a desired state through “reorganizations, change projects, rationalization, restructuring… or administrative reforms” (p. 6). The pressures to reform are so strong that it is difficult to maintain autonomy; it takes stronger leadership to avoid reform than to do it. Brunsson emphasises that reform is an attempt to change: “Reform is not equivalent to change. An organization may undergo several reforms and emerge with little change” (p. 6). He argues that reforms are driven by the supply of problems, of solutions, and of forgetfulness:

“Without problems, reforms are difficult to justify; without solutions they cannot be formulated; and without forgetfulness there is a risk that people will be discouraged by the fact that similar reforms have been tried and failed in the past” (p. 14).

These factors are discussed below.

Problems are in plentiful supply. Brunsson’s earlier work (1989) identified the tension between how the organisation presents itself, the talk, and the way it actually works, the action. This “provides an incentive for repentance, for reform” (Brunsson, 2009, p. 93). Another source of problems is actually previous reforms. Sometimes new reforms are launched to target the same set of values because earlier reforms were better at “raising the level of aspiration than at improving the situation” (p. 95). Since organisations are subject to conflicting demands, it may also be “impossible in practical terms to find any balance that could readily be regarded as the right one”. Therefore every solution “is susceptible to criticism for failing to satisfy one or other – or both – of the needs sufficiently”. Thus a reform furthering one side of such a balance may soon create impetus for new reform in the other direction (Brunsson, 2009, p. 95). Sometimes the organisation ends up just oscillating between different
solutions. Incidentally, this phenomenon has been empirically identified for the organisational location of educational development units, which are therefore objects of frequent reorganisations (Edström, 2010, p. 11).

To start reforms, reformers need solutions that are perceived as attractive in comparison to the current reality of the organisation. Coming up with promising ideas is easy:

“If we set a simple, clear, and good reform idea against our knowledge of the current situation with all its slack, ad hoc solutions; and its uncertainties, inconsistencies, conflicts, compromises, and complicated relationships, then there is a good chance that the new solution will appear better” (Brunsson, 2009, p. 97).

Common sources of solutions are consultants and professional reformers, as well as other successful organisations (mimetic isomorphism).

Given that reforms are often repetitions of earlier reforms, organisations need a supply of forgetfulness – it is necessary to forget the content and outcome of previous reforms: “Reforms focus interest on the future rather than the present, and forgetfulness prevents the past disturbing the future” (Brunsson, 2009, p. 99). Personnel turnover promotes forgetfulness, as does the use of consultants, who “can see the organisation with fresh eyes and can thus more easily repeat old mistakes” (p. 99). Just like ideas can be more attractive than reality, reforms tend to look very different before and after they are implemented. What started as simple and attractive principles becomes more complex when it is applied to organisational reality with all its conflicts and practical problems, and “making [the ideas] practicable also makes them much less beautiful” (p. 99). An old reform will therefore seem far less attractive than one that is new and still untried, and it may go unnoticed that they are in essence the same. Reformers will reinforce this, as it is certainly in their interest to sell their reform concept as new and different (p. 149). It is the combination of failed reforms and retained hope that drives new reforms. Brunsson quips: “Reforms tend not to deliver what they promise. But their promises are so good that people are easily lured into trying again” (p. 100).

Unsurprisingly, Brunsson dismisses results of reforms in terms of changing organisational practice – he even mentions how presenting controversial changes as a reform can prevent their implementation. But reform has other uses. Brunsson views hope as a “fundamental, cultural factor in explaining the production and reproduction of reform” (p. 17). Organisations need its members to be hopeful; it certainly works better than despair and apathy (p. 153). Therefore, perhaps the most important function of reform is to create, maintain, and express the hope “that it will be possible to transform ideas and principles into practice” (p. 140). This makes it dangerous to learn from discouraging experiences, since it risks destroying hope. Accordingly, Brunsson identifies some strategies to avoid facing failure. One is to avoid confrontation between the principles and practice – by staying on the level of talk.
(e.g. spending all time developing the reform model in itself) and avoiding practice
(e.g. evaluation focuses on the effects on people’s thinking rather than on their
practices). Another strategy is to focus on the future instead of the present, to
postpone every confrontation with practice (p. 144-146). In addition to hope, other
advantages with reform is to improve the image of the organisation in the eyes of
external audiences, also, the reformers themselves can develop their ability to
represent the organisation. But results can also be negative, when attention is drawn to
problems and reinforcing the perception of failure. And while hope is necessary, it is
precisely by inspiring hope that, “reforms risk increasing the importance of the very
goals which the organization has greatest difficulty in achieving” (p. 101). Brunsson
cautions: “From the point of view of the individual organization there is reason to
avoid these effects, if survival is considered more important than the meeting of high
standards” (ibid.).

5.51. 5.2.2. Institutions as resources for institutional innovation

It is easy to think of institutional norms and rules mostly as limiting the autonomy of
organisations and individual actors, but an important theme throughout literature is
that social systems can be seen as simultaneously constraining and enabling. This is
what Giddens (1984, pp. 25-28) calls the duality of structure. Meyer and Rowan
(1977) made the point that while it is often most beneficial to conform, organisations
can also play active roles in shaping rules and expectations (p. 348). Further, Oliver
(1991) suggested an interesting typology of available coping strategies (table 5.1).

Table 5.1. Strategic Responses to Institutional Processes (Oliver, 1991, p. 152).

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Tactics</th>
<th>Examples</th>
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<tbody>
<tr>
<td>Acquiesce</td>
<td>Habit</td>
<td>Following invisible, taken-for-granted norms</td>
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<tr>
<td></td>
<td>Imitate</td>
<td>Mimicking institutional models</td>
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<tr>
<td></td>
<td>Comply</td>
<td>Obeying rules and accepting norms</td>
</tr>
<tr>
<td>Compromise</td>
<td>Balance</td>
<td>Balancing the expectations of multiple constituents</td>
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<tr>
<td></td>
<td>Pacify</td>
<td>Placating and accommodating institutional elements</td>
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<tr>
<td></td>
<td>Bargain</td>
<td>Negotiating with institutional stakeholders</td>
</tr>
<tr>
<td>Avoid</td>
<td>Conceal</td>
<td>Disguising nonconformity</td>
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<tr>
<td></td>
<td>Buffer</td>
<td>Loosening institutional attachments</td>
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<tr>
<td></td>
<td>Escape</td>
<td>Changing goals, activities, or domains</td>
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<tr>
<td>Defy</td>
<td>Dismiss</td>
<td>Ignoring explicit norms and values</td>
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<td></td>
<td>Challenge</td>
<td>Contesting rules and requirements</td>
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<tr>
<td></td>
<td>Attack</td>
<td>Assaulting the sources of institutional pressure</td>
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<tr>
<td>Manipulate</td>
<td>Co-opt</td>
<td>Importing influential constituents</td>
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<td></td>
<td>Influence</td>
<td>Shaping values and criteria</td>
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<tr>
<td></td>
<td>Control</td>
<td>Dominating institutional constituents and processes</td>
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By focusing on the opportunities, institutional logics can be seen as resources that
can be invoked for the legitimacy of identities and practices. Especially in
organisations with multiple institutional logics, there are opportunities for individuals
and organisations to actively exploit any inconsistencies and contradictions (Thornton
et al., 2012). Studying an organisation with two competing logics, Binder (2007, p. 568) concludes:

“Logics are not purely top-down: real people, in real contexts, with consequential past experiences of their own, play with them, question them, combine them with institutional logics from other domains, take what they can from them, and make them fit their needs.”

Such possibilities are available at all levels, for individuals, for a particular activity or for a whole organisation. Actors and sub-groups can, and do, utilise such opportunities selectively, making the organisation a mosaic of groups, with more or less potential for enabling or resisting change (Greenwood & Hinings, 1996).

Organisations, sub-groups and individuals can draw on institutional innovation in the institutional field. For instance, Thornton et al. (2012) mention how people with experience from different institutional contexts are less likely to take things for granted in their local organisation, and may have capacity to create institutional change (p. 110). While the organisational field is a source of values and norms, it can also supply concrete exemplars of structures and practices available to organisations. As a version of isomorphism, Greenwood and Hinings (1996) discuss how templates, or archetypal patterns, reflect ideas and values in the institutional field, shaping structures and practices. Collective sense-making can support some factors necessary for change in organisations: recognising the weakness of existing arrangements and building the capacity for action, which means having sufficient understanding of the new conceptual destination, the skills and competencies required to function in that new destination, and the ability to manage how to get to that destination (Greenwood & Hinings, 1996, pp. 1039-1040). Greenwood, Suddaby, and Hinings (2002) showed the role of professional associations in legitimating change, by hosting debate, justifying and endorsing new practices. They call this theorization, “the process whereby organizational failings are conceptualized and linked to potential solutions” (p. 58). Associations can also be a suitable locus of theorisation and diffusion. This study also stresses how pragmatic legitimacy matters relatively little in professional contexts, compared to normative legitimacy:

“What matters within a professional context is the demonstrated conformity of innovation with the values embedded in traditional beliefs. It is only when ideas are couched in such a way that they are perceived to be consistent with prevailing values that they appear compelling and legitimate for adoption” (p. 75).

Greenwood, Suddaby, and Hinings note that gaining a shared understanding is a long process: “Models must make the transition from theoretical formulation to social movement to institutional imperative” (ibid, p.60, citing Strang and Meyer). So how can such transitions happen? Thornton et al. (2012, p. 159) refer to field-level vocabularies of practice, defined as “systems of labelled categories used by members of a social collective to make sense of and construct organizing practices”. They explain: “Vocabularies of practice guide attention, decision making, and mobilization,
and provide members of social groups with a sense of their collective identity.” This creates common ground, facilitating sense-making and communication, coordination and collective action. Thornton et al. depict a process involving *cultural entrepreneurs, narratives, and reification*:

“While cultural entrepreneurs following their interests are involved in the formation of narratives that lead to vocabularies of practice, the categories must become reified for the institutional logics to move beyond the level of theory or ideology” (p. 160).

Reification implies that practitioners “must perceive over time that the categories and systems of practices are generated not as direct products of human intervention and agency, but as the natural order of things” (p. 160). In other words, they must achieve cognitive legitimacy – the most subtle and powerful form of legitimacy (Suchman, 1995).

### 5.52. 5.2.3. A note on “change management” literature

Much of the so called change management literature is of limited interest here since it is written within the logic of corporations, entailing an image that power is hierarchically structured and profit is the measure of success – even the raison d’être – for organisations as well as individuals. Numerous books seem written for managers looking for tactics to push, evangelise, and manipulate their subordinates to overcome their supposedly illegitimate resistance (for a similar critique, see Alvesson, 2012, pp. 157-158). In one of the most cited works, Kotter (1996) lists eight necessary phases in a change process and discusses potential failures in relation to each. It is a linear model aimed at senior management to firmly push change top-down in their organisations. Efforts have been made to translate some of the strategies into the university setting (see for instance Froyd, Penberthy, & Watson, 2000), however the model fails to capture the institutional nature of university organisations. Clark (1986, p. 275) notes that we cannot understand educational organisations if we analyse them as companies: “We insist in peering at higher education through glasses that distort, producing images that render more confusing a terrain that is naturally difficult”.

Change models underpinned by such borrowed assumptions are likely ineffective for analysing educational organisations, for formulating strategies, and for engaging the people in them (Kezar, 2001, p. 74). Further, change models intended for corporations will likely interpret the specificities of universities only as obstacles and barriers, failing to draw on them as strengths and resources (Musselin, 2007). Moreover, much of the change management literature comes across as based on a worldview of “us” and “them”. Referring to technological change, Williams (2002) remarks:

“The rhetoric of change management has the effect of trivializing the whole concept of change. […] There are many fault lines in history today, and many of them run right through us. The change agent and the change resister are often the same person” (p. 19).
5.2.4. Change in higher education

In a review of journal articles on how to promote educational change in STEM, Henderson, Beach, and Finkelstein (2011) categorised change strategies based on whether the focus is on individual educators or organisation, and whether the results are predefined or emergent. While they criticize the general level of scholarship of the studies with regards to the use of theory and the robustness of evidence, they still concluded that effective change strategies must (1) be aligned with or seek to change the beliefs of the individuals involved; (2) involve long-term interventions; and (3) take into account the complexity of universities, meaning that it is necessary to first understand the system and then design a compatible strategy. Later, Borrego and Henderson (2014) suggest that the relevant literature on change “is not necessarily accessible to those who need to apply it”, and proceed to present examples of curriculum change strategies according to the framework.

In a large-scale study involving six case studies and in total 187 interviews, Ruth Graham (2012) finds that successful reform is often associated with threats, for instance problems with recruitment, retention, or employability. She also mentions that it often involves faculty with industry experience and/or newly recruited faculty, less invested in the status quo. Such reforms start with a curriculum-wide assessment of goals and a high-level realignment of the curriculum, and Graham finds long-term success associated with “the extent to which the change is embedded into a coherent and interconnected curriculum structure”.

Much literature on change in higher education lists strategies and/or necessary conditions for change. For instance, Ambrose (1987) suggests the critical need for five conditions: 1) vision, 2) skills, 3) incentives, 4) resources and 5) action plan. This model also interestingly identifies the states when any of these elements is missing: 1) confusion, 2) anxiety, 3) resistance, 4) frustration and 5) false starts, respectively. This model is often cited in the context of educational development (de Graaff & Kolmos, 2007; Knoster, Villa, & Thousand, 2000).

Other authors on change in higher education emphasise possibilities of influencing norms and understandings. Dill recommends change strategies focusing less on what we do in higher education, encouraging universities to instead actively influence culture by managing meaning and social integration. The management of meaning includes “the nurturance of myth, the identification of unifying symbols, the ritual observance of symbols, the canonization of exemplars, and the formation of guilds” (Dill, 1982, p. 316). He notes, “if the new staff is socialized at all, it is within the department or field”. The management of social integration is therefore important to counteract faculty orientation toward the individual, discipline-based, career, and build loyalty to the academic enterprise as a whole. To Dill, influencing culture is not only a concern for the top management and administration; instead he attaches importance to peers and collectively organised socialisation mechanisms. Dill later
remarked that attempts to manage the symbolic side of universities are often related to branding, to becoming “world-class” or “entrepreneurial”. These are efforts for external marketing rather than to create “an academic culture that defines, communicates and helps embed the values essential to effective teaching, scholarship and research within universities” (Dill, 2012, p. 229).

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This theoretical framework will now be set to work, to analyse the tensions in the organisation between the academic and the professional aspects of engineering education. This is followed by an analysis of CDIO as institutional innovation.
6. DISCUSSION AND CONCLUSIONS

The overall aim of the thesis is to explore the dual nature of engineering education, simultaneously an ideal and a source of tensions. The objective, then, was in particular to investigate opportunities and challenges in efforts for developing engineering education in relation to this ideal.

This section begins with a depiction of the academic-professional duality and its tensions, drawing on the theoretical framework from the previous chapter. Next follows a discussion of efforts to work towards realising the ideal, in particular in the strategies on different levels in the CDIO initiative. Here, I will also makes some critical reflections regarding the limitations of the CDIO concept. Finally, I reflect on some of the insights that are particularly challenging for the educational development enterprise.

6.1 Seeing the duality in the light of institutional logics

5.54. 6.1.1. Practices

Using the institutional logics theory we will now consider the academic-professional duality in engineering education, the ideal as well as the tensions. We saw that institutional logics – or patterns of material practices, assumptions, values, beliefs and rules – are embedded in the practices within the university, and in the co-produced identities. Different practices may express the institutional logics differently since they align to different parts of the institutional environment, for instance resource environments or uncoordinated stakeholders. The logics embedded within a particular practice can also contain such contradictions.

The dominant practices in higher education – in principle the practices that define a university – are research and education, with intimately related identities for faculty, as researchers and educators. See figure 6.1.

![Figure 6.1. The major practices in higher education and the co-produced faculty identities.](image)
5.55. 6.1.2. Competing logics in engineering education

We begin with the practice that is of primary interest in this thesis, engineering education. My interpretation is that the institutional logics of engineering education expresses two professional logics: the logics of the engineering profession that we educate for, and the logics of the academic profession of the educators. These logics come with slightly different assumptions, beliefs and values regarding the educational mission and the role of the educators. The logic of the engineering profession must reasonably harbour the assumption that the educational mission is about teaching the next generation of engineering professionals. In the logic of the academic profession it could instead be reasonable to see the teaching mission as conveying the theory of their discipline. See Figure 6.2.

![Figure 6.2. Education, a practice expressing two professional logics.](image)

To elaborate some aspects in which the institutional logics of the two professions differ: In the logics of the engineering profession, the educator teaches future professionals. The engineering identity of faculty is strengthened by the fact that most have an engineering degree, and some also have experience of professional practice. Knowledge is relevant if it is useful for engineering practice, and so are the problems and questions that matter in industry and society. Engineering students should prepare for professional practice, i.e. working on real problems in real contexts, which includes a deep working understanding of theory, and the ability to integrate and apply it. In the logics of the academic profession, the educator teaches disciplinary theory. The academic identity of educators is strengthened by the fact that the normal route to a faculty position is through a PhD in one of the disciplines, and a research career. Knowledge is relevant if it is part of the disciplinary canon, and problems and questions are interesting if they have a potential to lead to new discoveries furthering the disciplinary frontier. Engineering students should learn disciplinary theory, and prepare for research education. These factors are summarised in Table 6.1.
Table 6.1. Analysis of the institutional logics of the engineering profession and the academic profession, respectively.

<table>
<thead>
<tr>
<th>Institutional logics</th>
<th>The engineering profession that we educate for</th>
<th>The academic profession of the educators</th>
</tr>
</thead>
<tbody>
<tr>
<td>The role of the educator</td>
<td>Teaching future engineers</td>
<td>Teaching theory</td>
</tr>
<tr>
<td>Relevant knowledge</td>
<td>Knowledge useful for engineering practice</td>
<td>The disciplinary fundamentals</td>
</tr>
<tr>
<td>Interesting problems and questions</td>
<td>Real problems, consequential issues in industry and society</td>
<td>Pure problems, close to the disciplinary frontier</td>
</tr>
<tr>
<td>Students are prepared for</td>
<td>Engineering practice – through deep working knowledge and professional competences</td>
<td>Engineering practice – through theoretical knowledge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Research education – disciplinary depth</td>
</tr>
</tbody>
</table>

This analytic scheme is not meant to set these two sides of education against each other. Instead the point here is that both sides are necessary, and the ideal is that they should be in a meaningful relationship. This is the dual nature of engineering education, the theme of the thesis. That it is an ideal does not however prevent manifestations of the contradictions and tensions between the logics. For instance, the problem discussed in chapter 4 was that some of the values necessary for engineering education are weakly represented in the organisation, e.g. integration, application, and real problems in context. To reformulate it in the language of institutional logics: if the professional logics are weakly represented among the faculty, it is more difficult to satisfy the related aspects in the curriculum. Simply put, the capacity to teach disciplinary theory is strengthened by the academic logics, while the professional logics create capacity for addressing also the other necessary aims of the curriculum.

5.56. 6.1.3. Competing logics in research

I will now proceed to discuss how the research practice can be characterised by a similar tension within its institutional logics. Here, I also draw on the discussion in paper III (Edström, in press, 2017), although it was there related to the aims of the engineering education research field. My suggestion is that two beliefs about the aims of research exist simultaneously: one that research aims to further the discipline, often called knowledge for its own sake, and one that research is guided by a consideration for usefulness in society. See Figure 6.3.

The first belief can be expressed as the university as academia, because in my view, knowledge “for its own sake” quickly translates to the same thing as furthering a discipline. This is because the academic career depends on peer recognition, making disciplines the site that controls the necessary resources for survival. Peer recognition is a sine qua non, since those whose work does not pass this disciplinary quality control will soon be marginalised by a lack of resources. Quite aptly, Gibbons et al. (1994) called disciplines the “homes to which scientists must return for recognition or rewards”. Academic capital comes in hard currencies such as being accepted for
publication, passing a thesis defense, receiving grants and prizes, being appointed and promoted, and selected for commissions. Many of those decisions concern the classification of individuals, which was identified in the theoretical framework as a particularly important component of identity. This helps explain the strong socialisation of faculty into the discipline-based identity and beliefs. The academic pursuit can become very personal:

“A key element for many academics is the narcissism involved in doing and publishing research. The self is invested in the work and research publications function as reinforcers and stabilizers of a sense of self susceptible to the insecurities and vulnerabilities of a profession constantly exposed to assessment and a level of competition where failures greatly outscore successes for most people…” (Alvesson et al., 2017)

Figure 6.3. Two aims of research, with corresponding beliefs.

The second belief, *the university as public service* implies that research is guided by *consideration for use*. The crucial matter becomes how to evaluate the usefulness dimension of the work, and who should be seen as the legitimate judge. It is quite telling that even funding for highly applied research is often dispensed using academic peer review. While there are efforts to make societal impact matter more in the academic career evaluation, it seems seldom conceptualised as a main consideration within research and education, but as a separate third task, service, and the discourse often has a distinctly commercial character (cf. Dill, 2012).

According to the Pasteur’s Quadrant model (see figure 2.2), the two beliefs are not mutually exclusive, because research can simultaneously be directed toward applied goals and lead to significant new understandings. Not least since the resources under academic control are so vital, I suggest that the university as academia belief has stronger support in the institutional logics than does the university as public service. The reason why this matters here is, as I see it, the university as academia is highly consistent with the logics of the academic profession, while the belief in the university as public service has strong similarities with the logics of the engineering profession, for instance the values attached to integration, application, the interest in real problems that are consequential in society and industry, and their real solutions. The core distinction is similar to the description by Williams (2002): “In science, the
fundamental unit of accomplishment remains the discovery; in engineering, the fundamental unit of accomplishment is problem-solving” (p. 44). My conclusion here is that in the research practice, the logics of the academic profession enjoy the strongest support in the institutional environment, both normatively and materially.

5.57. 6.1.4. Interplay between education and research

We have discussed two practices separately, education and research, focusing on some tensions within each practice due to inconsistent demands in the embedded logics. What remains is to consider the interdependence between education and research. There is much educational research and development addressing the relationship – often called the nexus – between research and teaching (for a recent overview see Geschwind, 2015). There are many dimensions to this interdependence, for instance we know that faculty draw on their disciplinary networks in educational matters (Mårtensson, 2014, p. 58). Here, guided by the constraints of my research questions and following the theoretical framework, I will mainly focus on the different conditions for the practices, and the influence by research on the dual nature of engineering education. Now the two figures can be merged, see figure 6.4.

![Figure 6.4. Competing institutional logics in education and research.](image)

Due to inconsistent institutional demands we can, according to the theory, expect tensions between practices, and between institutional rules and the effectiveness of the practice. Further, we can expect patterns of differentiated status between these practices and groups within the organisations.

Seen from outside the university, both education and research enjoy high status. Engineering education is a prominent source of legitimacy for a university, as a supplier of elite professionals to society and industry. The research activity corresponds to the role of the university as producer of new knowledge and is an important source of status and identity, not least for the university international reputation and brand. However, within the university, while there is certainly also status in excellent teaching, the status of research is generally higher than for education. One reason is the career system, where research merits dominate every step (see for instance Geschwind & Broström, 2015). We are reminded of the
imperatives created by the “university as academia” described above. While teaching merits feature increasingly in the hiring and promotion criteria, it seems sufficient (from a career point of view) to be above a threshold level (Graham, 2015). Another reason is the difference in the associated resource environments. Funding for education is distributed internally, most often based on quantitative factors without reward for quality. Research funding varies considerably, between research fields, in terms of availability, and whether the funds afford freedom or come with strings attached. But in contrast to education, research funding is to a large extent sought externally, in competition based on peer review; the rewards for excellence are considerable in terms of resources and prestige. In short, the socialisation and reproduction of the faculty, and the incentives of the resource environment result in a dominance of research. My conclusion is that research has stronger institutional support than education, both normatively and materially. This affects the conditions for education generally, including related matters such as the attention paid to teaching competence, teaching quality, and educational development.

While the imbalance between education and research is important, the specific focus here is the dual nature of engineering education. The duality was conceptualised above as competing logics within the education practice: teaching theory and teaching professionals. Because of the role played by research in shaping the faculty, it will limit and enable what is possible in education. While some research and researchers focus on matters of mainly academic interest, the furthering of a discipline, there are also researchers who work on matters with a more direct consideration for use. Many applied and cross-disciplinary fields, and for instance design related subjects, are closer to professional practice. We can presume that many researchers with such interests have more engineering capital, for instance closer contact with industry (including the public sector), and that they in their role as educators might then find it more natural to take on the role of educating professionals (see also table 6.1).

What I would like to suggest here is that the institutional logics of research, being the dominant practice, strongly influences the institutional logics of the education. Hence, the more the research practice is dominated by the academic logics, over the consideration for use, the more it will tilt the balance in education, in favour of teaching theory, rather than teaching professionals. When the balance is heavily tilted, it will also be difficult to achieve the ideal of a productive relationship between the academic and professional aims.

I have painted a picture here in which research has the primary position in the university organisation, positioning education as a secondary practice. I also argued that the institutional logics of the academic profession have the upper hand not only in research, where disciplinary interests takes priority over considerations for use, but also in education, where teaching theory takes priority over the other aspects of professional preparation. No wonder then that is difficult to make certain kinds of educational changes sustainable, when the primary practice exerts its constant
influence and imprint. This happens through the faculty, whose academic identity is stronger than their engineering identity, because research is the birthplace of new faculty, and it holds the keys to continued survival and success. While the organisation naturally needs to spend considerable attention to its own academic reproduction processes, one may wonder if it has not taken a life of its own, to the point where it fully takes precedence over the educational mission of the university.

6.2. Seeing CDIO in the light of institutional logics

5.58. 6.2.1 CDIO as integration of the academic and professional logics

Above, the dual nature ideal was analysed using an institutional logics perspective, describing how the logics of both the engineering profession and the academic profession are embedded in the engineering education practice, with the associated assumptions about “teaching future professionals” and “teaching theory”, respectively. Despite focusing on them separately, the message was that both are necessary and that the ideal was a productive relationship. In chapter 2, the efforts of the CDIO initiative illustrated the integrated curriculum strategy for realising the ideal on the programme and course level, and in faculty development. Here, these strategies will be discussed in turn.

5.59. Integrated learning on the course level

From a perspective of teaching and learning I will argue that there need not be much tension between the disciplinary theory and the (other) professional competencies. They belong together and give each other meaning – as argued in table 2.1 – and we can devise ways to integrate them in subject courses (discipline-led) as well as project-based courses (problem/project-led). One could say that on a course level the integration strategy works. However, it works under one necessary condition. It works depending on individual faculty and their willingness and ability to unite the theoretical and the professional. It works as long as they are prepared to pay attention also to professionally relevant aspects that are not necessarily part of the teaching traditions of the subject. Some educators, but not all, have the inclination and the competence to do it. Since new faculty members are inducted through the research disciplines, as discussed above, we can expect strong orientation towards disciplinary traditions; this is what they believe education is (cf. Roberts, 1982). We remember that Henkel (2005) identified the discipline and academic freedom as the most important values for faculty, even as keys to meaning and self-esteem. Further, the imbalance between education and research makes it even more precarious to depend on individual faculty. For instance, those who perceive that course development does not further their career may choose the path of least resistance, which means following traditions. Integration can be successful, but as long as such courses are seen as exceptions to the predominant norms, the success is tied to individuals and
hence vulnerable and temporary. I can conclude that the strategy of integration can work on the course level, but only as far as faculty members can support it.

5.60. The integrated curriculum
The defining aspects of CDIO, the standards, describe a process for establishing structures holding the curriculum together, making the programme a joint collegial project, where every course has a function towards the overall goals. This is a reaction to curricula “consisting of disciplinary courses disconnected from each other, and as a whole, loosely coupled to espoused programme goals, professional practice, and student motivation” (Edström & Kolmos, 2014). CDIO development is a way to establish a power base around the programme, necessary to create and uphold the coherent and interconnected curriculum structures identified by Graham (2012) as a key factor associated with successful and sustainable change. The Mechanical Engineering case at Chalmers, in chapter 2, showed the full strength of the integrated curriculum. For instance the modern computational mathematics could be weaved through the programme, strengthening connections between the mathematics and the engineering in several courses where it was appropriate and meaningful. This programme was developed and refined over a long time, by a team of faculty with high legitimacy and the resource system in their hands. It could be seen as a case of tighter coupling between the programme and its courses, creating an uncommon structural capital and agility, which allowed the programme team to proceed to set and reach new goals. There is no doubt that other programmes, despite similar intentions, have failed to achieve this development or to make it sustainable, as mentioned in chapter 4. One reason is that coordination takes some effort. While faculty members expect to work extremely hard to succeed in research, there is a risk that curriculum development initiatives fail to engage the relevant people, as such work is perceived to go unrewarded. When “stronger leadership” is proposed as a solution, it is often based on rationalist assumptions and refers to stronger line management, which fails to recognise the highly institutionalised context. Given that integration and coordination represent almost the counterweight to the core values of discipline and academic freedom, it is not obvious that the faculty is up for any joint efforts in education at all. On the programme level, I conclude that the integrated curriculum can work, but only as far as the faculty capacity for coordination can support it.

5.61. Faculty development level
Could Harvey Brooks have seen the CDIO standards today, he would likely react just like in 1967, when he criticised engineering educators for being obsessed with the curriculum:

“the heart of the problem lies in the character and orientation of the engineering faculty. In the long run the courses and curriculum, and the knowledge and motivations of the students, are bound to reflect the research
interests, the consulting experience, and the values of the faculty” Brooks (1967b).

While the importance of faculty was recognised in the standards on enhancing faculty competence, as a programme development scheme CDIO has had limited influence over faculty appointment and development. There has still been much development in this area, at least in Sweden, where courses on teaching and learning were required together with more attention paid to the evaluation of teaching competence.

If it was perceived as provocative that the needs of education are increasingly taken into account in the appointment and promotion of faculty, it seems even more daring to make suggestions about the research. But the interdependence of education and research does raise the questions about what kind of research could support the educational mission in a university, since the shaping of the faculty is largely under the auspices of the research enterprise, at least in research-led institutions. It could at least be interesting for funding agencies to consider how the research they support helps or hurts the conditions for engineering education. The analysis of institutional logics suggested that research with a consideration for use shares some key aspects with the engineering profession, e.g. the values attached to integration, application, and real problems in context. As Brooks also hinted, and we saw in the life and work of Söderberg (Edström, forthcoming 2018), another promising way to enhance faculty professional engineering competence is through their consultancies.

In the faculty development standards, CDIO did not achieve the same balance in the academic and professional duality as we saw on the course and programme level. A complete conceptualisation would need three standards, one related to teaching competence, and two related to the object of teaching – aligned to the academic and the professional aims, respectively. If CDIO had three standards for faculty competence, related to subject, teaching, and engineering competence here is a parallel in the medical field, where there is an understanding that faculty need scientific, teaching, and clinical competence (see for instance Karolinska Institutet, 2011). The missing faculty competence standard concerns enhancement of faculty competence in the subject. However, this should not be equated only with research competence. It is not enough to know the subject for oneself, it is also necessary to be able to guide others into it, so to technical and scientific knowledge I propose to add the concept pedagogical content knowledge (Shulman, 1987). It refers to “the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction” (p. 8).

When CDIO addresses the need to address what we teach, it constitutes a critique of educational development initiatives, and ways to assess teaching competence in appointments, which are narrowly conceptualised to concern only how we teach. For instance, when the Scholarship of Teaching and Learning movement refers to Boyer’s scholarship of teaching, it is often seen in isolation from the other facets of
If we consider the problems raised in this thesis, it would not be sufficient if all educators overnight became twice as good with regards to the methods of instruction. The education would be better, but if the teaching theory view on education still dominates over teaching professionals, some of the most important aims would still be inadequately addressed. Faculty development is a challenge that needs to consider a wide range of possibilities for shaping a faculty, which collectively has the necessary strengths related to what they teach as well as how they teach.

The CDIO concepts focus on the programme and course level development, but as we saw here the only principles applying to the organisational conditions are those concerning faculty development. This is a limitation, and one possible extension of the CDIO concept would be to focus on the enabling conditions in the organisation, drawing on institutional theory.

5.62. 6.2.2. CDIO as institutional innovation

Wearing the theoretical lenses crafted in the previous chapter, we can see the CDIO initiative as a field-level driver of institutional innovation.

5.63. CDIO as a field level site for institutional innovation

The CDIO community is situated in the organisational field, promoting new logics through collective mobilisation. It can be seen as a site where narratives are crafted and shared, making up certain vocabularies of practice. When the CDIO community shares experiences from different institutional contexts, it also exposes individuals to a wider repertoire of institutional values, practices and identities, which can then also make them less likely to take things for granted in their home environment. Local innovators can invoke CDIO as a legitimate template, to strengthen the legitimacy of their local work, and as a part of their identity. The legitimacy of CDIO is partly mimetic, due to high-status universities among the founders and adopters. Whether it also achieves normative or cognitive legitimacy depends on how well the values and norms that are invoked in CDIO conform to the institutional environment, and the support will likely differ in different parts, for instance in different types of schools.

5.64. CDIO as a compromise strategy

The legitimacy of CDIO will to a large extend depend on the values and norms that are embedded in the analyses connecting problems with solutions, the methods and instruments for action, and communicated in the activities of the CDIO community. Paper III (Edström, in press, 2017) highlighted some significant differences in how the CDIO and PBL communities conceptualise and handle the relationship between disciplinary theory and professional aspects. Although even in PBL universities only half of the curriculum is problem/project-based, the PBL movement is still perceived to fundamentally challenge the role of the disciplines. CDIO takes another strategy,
embracing discipline-led teaching as the major part of the integrated curriculum. When CDIO stresses the need for a deeper working understanding of disciplinary theory, it is a plea fully consistent with the values of both academic and engineering professional logics. The motive is to make the innovation more legitimate, in the sense that it is understandable, consistent with prevailing norms and practices, and less threatening for traditional identities. This is a compromise strategy (cf. Oliver, 1991), balancing different expectations. For instance, CDIO obviously challenges programmes that consist of loosely coupled theoretical courses, but the proposed intervention is not a pure PBL approach. Instead, CDIO takes a middle road, making PBL, with a distinct engineering flavour, a part of the integrated curriculum. As a concept invented by engineering educators specifically for engineering education, CDIO can also to a larger extent invoke an engineering insider identity, as a resource in its institutional entrepreneurship.

5.65. Engineering education development communities and research

Another difference between CDIO and PBL identified in paper II (Edström & Kolmos, 2014) was the role of educational research. There are mature international research communities focused on PBL, with centres and professorships. Research is used to advance the philosophy and create legitimacy for the educational model. One particular emphasis has been to create empirical evidence demonstrating the results obtained through PBL, for instance the quality of the graduates from PBL universities (Kolmos & Bylov, 2016; Kolmos & Koretke, 2017a, 2017b).

In contrast, the CDIO community had paid considerably less attention to research, despite a significant amount of published work. Paper III (Edström, in press, 2017) discusses how engineering education research can become more central to CDIO, an idea that arose after identifying the opportunity in the comparison with PBL. Before making such a move, it was necessary to understand the dynamics of the EER landscape, and find a position that does not abandon the development agenda or compromise the CDIO ethos. Seen through the lens of institutional theory, this can be interpreted as a strategic effort to conform to the values in the institutional environment, to improve legitimacy and access to resources, not least by strengthening the academic identities of the people involved. Taking a cautious approach I would venture so far as to suggest that it is mainly the logic of appropriateness at work, and it remains to be seen if the logic of effectiveness will also apply.

6.3. Wrapping up

5.66. 6.3.1. Conclusions

This thesis argues that the problems with sustainably realising the dual nature ideal in engineering education, i.e. the meaningful relationship between disciplinary theory
and professional aims, lies not at the level of teaching and learning. Both types of learning outcomes are present in the stated aims of engineering curricula, and they can be productively integrated into both subject-based and project-led courses. There are also educational development concepts that readily support such implementation in the curriculum, for instance the CDIO approach. However, whether the productive relationships can be realised and sustained in courses is dependent on individual faculty members. Whether the integration can be realised and sustained on the programme level is further dependent on structures to coordinate the courses, or in other words to coordinate the work of faculty members. This can make implementations vulnerable.

In the words of Alvesson and Kärreman (2011), “the desire to become challenged, surprised, bewildered, and confused may take centre stage in research”. There are in particular two such instances in this thesis. One was the historical excursion, demonstrating the perennial character of the tension. Examining the process by which the engineering curriculum became science-based in the United States showed how change was slow until an “avalanche” of research funding – and the attached status and prestige, both for the university and for the faculty members – changed the character of the faculty, who then in turn changed education to become more theoretical, and in the process, professional values were weakened. This is an interesting case showing the dynamic shift in institutional logics (cf. Thornton & Ocasio, 1999). It also highlights the importance of the resource environment. There is no doubt that the material support for research is still strongest, not least because the resources under academic control are tightly coupled to survival and status for faculty. At least this is true in research-intensive universities, but my impression is that also schools with far less research are to some extent influenced by the same logics, through values, beliefs, assumptions, identities, and status concerns. By triangulating the ideal that Carl Richard Söderberg and CDIO had in common, I concluded that we should let go of the swinging pendulum metaphor, because it depicts a zero-sum balance. Instead of fighting over the amount of disciplinary theory and practice-oriented learning, we should focus on strengthening the meaningful relationships between them in the curriculum. Söderberg as a person combined the theoretical and practical interest, himself embodying the dual nature ideal. This inspired a suggestion that to achieve the duality, we need enough people in the faculty who can simultaneously defend both the academic and the professional values. If too many people stand on one side only, then the zero-sum view, and the ensuing trench wars, may be hard to avoid.

The second bewildering moment came from the accounts of unsustainable change in engineering curricula, leading me to formulate the organisational gravity model. The message was not so much that it is difficult to achieve change, but that even successful change may not be sustainable. (Again: it makes no prediction about the sustainability of change. Instead, it is a sensitising and explanatory model to assist perception and provide conceptual tools with which to discuss experiences.)
important debate within institutional theory has been how to conceptualise both stability and change. The organisational gravity model depicts a flexible response that can also be seen as a protective device, a spring-damper. Curriculum change can be successful, temporarily, but I suggested that certain types of changes – those with weaker support in the institutional logics – are gradually undone when the dominant process makes its continuous imprint on education through its dominance over faculty reproduction, socialisation, resources and incentives, and leadership recruitment. The contribution of this discussion could be to suggest a more dynamic image of stability and change.

The organisational gravity model suggested widening the perspective from curriculum development in itself, to the organisational level. This was also consistent with the historical study. Drawing on an institutional logics perspective, this thesis suggests that the logics of the academic profession seem to have the upper hand in research and, through the faculty, also in education. The result is a double hegemony where the logics of the academic profession are the strongest in both education and research. This weakens the professional preparation, and at the same time the education as a whole – both the theoretical and the professional preparation – is affected by the general disadvantages of education relative to research. The resulting impression is that the academic profession of the educators takes precedence over the engineering profession that we educate for, and this has consequences for the effectiveness of the engineering curricula.

I also suggested that we could understand educational development as efforts to compensate for such values that are obviously necessary for education, but inadequately represented in the organisation. Brunsson made the point that decoupling talk and action can serve to protect the production organisation from incompatible demands. Accordingly, we may consider to what extent educational development belongs to the production organisation or the political organisation, the latter handling insolvable problems mainly through ideology production. I have argued that the academic-professional tension is inherent to engineering education, an insolvable problem caused by conflicting institutional demands. Precisely therefore, it is necessary to have qualified venues for discussing ideals and tensions, and for identifying opportunities for handling the tensions productively in practical situations. Supporting practical development is key, because the tensions will be expressed in the curriculum, one way or the other, whether the implications are understood or not. And even those who subscribe to Brunsson’s refreshing take on reform will understand the value of hope, in helping the organisation carry on in good faith instead of being paralysed by conflict.

Applying the institutional logics analysis, some suggestions were made for strengthening the legitimacy of educational development initiatives. One strategy identified here is to find support in the institutional environment by shaping narratives, conceptual tools, and instruments to define and emphasise common
ground. Another strategy is to integrate engineering education *development and research*, producing work that combines scholarliness with usefulness and relevance for improving engineering education. In this thesis I wanted to bridge engineering education development and research, but without implying that development is the optimistic doing and research the critical thinking. I have taken a critical approach, questioning dominant interests and asking what groups are privileged by the way things work around here, and what groups get short-changed. At the same time I have shown that hopefulness is possible, necessary, and justified.

5.67. 6.3.2. Contribution

The thesis is essentially a case study, using the CDIO approach to represent a particular kind of educational development addressing one of the major issues in professional engineering education, the academic-professional dual nature. It contributes a rich description of this case from several perspectives: analysing strategies for curriculum development and faculty development; comparison with PBL; connection to engineering education research; considerations of unsustainable change; and a historical comparison. This account could stimulate further reflection those who are interested in the nature of professional education, for CDIO practitioners, and for anyone considering reform attempts of any kind.

The main theoretical contribution was to combine a critical approach with a theoretical framework based on institutional theory, to analyse the academic and professional nature of engineering education, and interpreting engineering education development as a case of institutional innovation. The research outcomes helped highlight both challenges and opportunities for engineering education development, uncovering them in a novel way that may reinvigorate such discussions. The research approach is also a contribution to a more critical discussion about engineering education, about engineering education development, and about engineering education research.

Some other fruit were harvested along the way. The thesis contains an attempt to formulate a research agenda in engineering education research, combining usefulness and scholarliness. Further, the organisational gravity model offers us a new view on unsustainable change, and on educational development. Finally, the biography of Carl Richard Söderberg was a contribution in its own right as an historical account, and the comparison of past and present discussions was also an experiment in engineering education research that engages with the past.

5.68. 6.3.3. Future research

Obvious avenues for future research would be to study empirical cases of programme development, in particular using a longitudinal approach to investigate what happens after a reform is considered completed. In the cases of sustainable or unsustainable implementation in curricula – what makes them so? What processes are involved
more specifically to sustain, develop or abandon new practices? How do normative
and material aspects interplay?

It would also be relevant to study how people in the organisation experience and
interpret the tension between academic and professional values. How is the tension
present in educators’ own views on engineering education, or in their own teaching
practice, and in their competence? It would also be interesting to trace how the
tension is enacted in key organisational practices. For instance, how are merits related
to the academic and professional aspects valued in recruiting and promoting faculty?

To further refine this research, it would also be necessary to study differences
between different types of institutions, for instance research-intensive universities and
those with less research. While the experiences referred to in this thesis mainly come
from higher education institutions characterised by significant research, according to
institutional theory the norms, values, and patterns on the field level are likely to
influence also institutions where there is relatively little research.

To extend these findings, a promising alternative is to compare engineering education
with professional education in other fields. What is the relationship between
theoretical knowledge and professional competence in other fields? Do they have
similar ideals and tensions, and how are they conceptualised, debated and handled?
What would a historical comparison show? It would be interesting to see if it matters
how recently the education has come into the university environment, whether parts
of the education takes place in professional environments (such as internships in
schools or teaching hospitals), the professional background and experience of faculty,
how strong the image is of the professional role and destination, and what role is
played by professional organisations and other stakeholders.
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