EXECUTIVE SUMMARY: A PHD THESIS WITH A CDIO THEME

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ABSTRACT

In December 2017, the author defended the doctoral thesis titled "*Exploring the dual nature of engineering education: Opportunities and challenges in integrating the academic and professional aspects in the curriculum*". In this paper, the thesis is summarised with the interests of the CDIO community in mind, providing guidance for those who might want to read selected parts. In the title, the term *dual nature* suggests that engineering education is both academic, emphasising theory in a range of subjects, and professional, preparing students for engineering practice. Ideally, these aspects are also in a meaningful relationship in the curriculum. However, this duality is also a source of tensions. This is the theme, explored in the context of engineering education development, in particular the CDIO approach. First, micro-cases on programme and course level illustrate how the dual nature ideal is pursued in the *integrated curriculum*. This is followed by two critical accounts, which suggest widening the perspective from curriculum development per se, to the organisational conditions. The first is a historical excursion, comparing the views of Carl Richard Söderberg (1895-1979) with CDIO, showing significant similarities in ideals, arguments, and strategies. The second is an effort to make sense of experiences of unsustainable change, resulting in a model, called "organisational gravity", used to explain the stability of programmes. As an implication, two change strategies are suggested, with different availability, risks, resource demands, and sustainability of results. Finally, the tensions between the academic and professional aspects are located in the university organisation. Refuting a rationalist view, the institutional logics perspective is used to analyse the tensions within engineering education. It is suggested that the logics of the academic profession dominates over the logics of the engineering profession, hence favouring "teaching theory" over "teaching professionals". The integrated curriculum strategy depends on educators' ability to unite theoretical and professional aspects in courses, and on the collegial capacity for coordination.

KEYWORDS

professional education, dual nature, engineering education development, the CDIO Initiative, PBL, engineering education research, Carl Richard Söderberg, organisational gravity, institutional logics, Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

INTRODUCTION

Title, Theme and Research Questions

The overall theme addressed in this thesis (Edström, 2017a) 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 professional aspects are not merely two 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. The full title of the thesis is: *Exploring the dual nature of engineering education: Opportunities and challenges in integrating the academic and professional aspects in the curriculum.*

The investigation starts by focusing on the approaches and strategies used to develop engineering education towards the dual nature ideal. The relationship between disciplinary and professional aims is a key issue in many reform initiatives, represented by the CDIO approach as the main case (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014). Two critical accounts then suggest widening the perspective from curriculum development per se, to the organisational conditions. The first takes a historic perspective, comparing the past and present discussion. The second considers some of the underlying challenges for this kind of educational change, by discussing experiences of unsuccessful change. Finally, the strategies and challenges will be related to organisational matters.

These interests correspond to the following research questions:

- *What approaches and change strategies can be identified in major engineering education development communities?*
- *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?*
- *What challenges apply to the sustainability of educational development in engineering programmes?*
- *How can we understand those challenges in relation to the university organisation as a context for the change?*

The Context is Development

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. The term *development* already implies a normative stance, as it usually refers to deliberate change to the better. Development is therefore like a vector; it has a direction as a part of its definition. The direction can be seen as an agenda, somebody's agenda, which means that also agency and interests are implied. In the discussion about what development is desirable in engineering education, 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."

The thesis also draws on the author's personal experiences in engineering education development, within the CDIO Initiative and other contexts. Maintaining the credibility of this research is not about pretending to be neutral and objective, since such a position might not even exist, but about being aware of, and openly disclose, the personal perspective. For instance, depicting the dual nature of engineering education as an ideal and making it sound natural and reasonable, as was just done above, is to take a normative stance. While most people would agree, there *are* also other positions possible. The fact that accreditations and qualification frameworks mandate the ideal does not make it neutral; it is still a value statement. 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).

EFFORTS TO INTEGRATE ACADEMIC AND PROFESSIONAL AIMS

Chapter 2 of the thesis can be read as an introduction to CDIO. It explores the CDIO approach as a major attempt to develop curricula according to the dual nature ideal.

The Integrated Curriculum

The starting point of the CDIO Initiative 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 few decades (Crawley, 2001). It is also a critique of "poorly designed curricula, at worst 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, p. 549). The aim is to develop programs for better educating students in developing and deploying technology (or, unpacking the CDIO acronym, conceiving, designing, implementing, and operating technical products, processes and systems). However, while advocating enhancement of professional competence, the first aim of CDIO implementation is still a deeper *working* understanding of disciplinary fundamentals, since this also constitutes a critical preparation for practice. The strategy formulated by the CDIO community is to integrate disciplinary theory and (other) professional aims through curriculum development, on the programme level, on the course level, and in faculty development (Crawley et al., 2014). The objective is to achieve an *integrated curriculum*.

Micro Case: The Mechanical Engineering programme at Chalmers

This case illustrates the programme level focus in CDIO (Standards 1, 2, 3, and 12). At Chalmers, the CDIO methodology is used to keep the programmes unified, although they consist of courses from several departments and disciplines. The programmes commission courses from the departments. Every year, the programme leaders review the course evaluations, and negotiate next year's course offering in a dialogue with the vice head of the delivering department. While this is a collegial dialogue, the programme controls the budget, approves the course syllabus documents, and is the recipient of course evaluations. The Mechanical Engineering programme has created conditions for systematically leading, planning and developing the programme, and for *constantly setting new goals* (Malmqvist, Bankel, Enelund, Gustafsson, & Knutson Wedel, 2010). Skills such as communication, teamwork, and ethics are integrated in several courses with progression throughout the years. They have also repeatedly demonstrated how the curriculum can be further developed through a relatively agile process.

One particularly interesting development is the integration of computational mathematics, aiming to modernize the mathematical content while also strengthening the connection between engineering and mathematics. The rationale was that students need to learn to solve more general, real-world problems, and spend less time "*solving oversimplified problems that can be expressed analytically and with solutions that are already known in advance*" (Enelund, Larsson, & Malmqvist, 2011). A guiding principle was that students should work on the complete problem, from identification and formulation, modelling, simulation, visualization, evaluation. Instead of framing this as a task for mathematics teachers to solve within the mathematics courses, the programme approach was applied, and creating connections to mathematics in engineering subjects was at least as important as making connections to engineering in mathematics. Interventions include new math courses where computational tools are used, new teaching materials, integrating relevant mathematics topics in fundamental engineering courses (e.g. mechanics and control theory), as well as cross-cutting exercises, assignments and team projects shared between the engineering courses and mathematics courses. Similarly, the integration of sustainable development demonstrates how the programme approach enables systematic integration of important cross-cutting topics in several courses, linked to overall programme learning outcomes and ensuring progression (Enelund, Knutson Wedel, Lundqvist, & Malmqvist, 2013).

Course level development

In Mechanical Engineering, the programme-level planning went hand in hand with programme-driven course development, to address the learning objectives that were assigned to courses. Standard 7, 8 and 11 constitute a course design model corresponding to constructive alignment: the learning objectives, learning activities, and assessment should be aligned (Biggs & Tang, 2011). Hence, the integration between disciplinary knowledge and professional skills should apply in all these components.

What sets CDIO apart from other concepts for engineering education development is the recognition of contributions of both discipline-led and problem/project-led approaches. Table 1 shows some arguments for why both logics are necessary, and how they can form a productive relationship.

Table 1. The need for both discipline-led and problem/practice-led learning.
Adapted from Edström and Kolmos (2014).

Discipline-led learning is necessary for:	**Problem/practice-led learning is necessary for:**
▪ Creating well-structured knowledge bases ▪ Understanding the relations between evidence/theory, and model/reality ▪ Methods to further the knowledge frontier **…while also connecting with problems and practice:** ▪ Deep working understanding (ability to apply) ▪ Seeing the knowledge through the lens of problems ▪ Interconnecting the disciplines ▪ Integrating skills, e.g. communication and collaboration	▪ Integration and application, synthesis ▪ Open-ended problems, with ambiguity, trade-offs ▪ Problems in context, including human, societal, ethical, economical, legal, etc. aspects ▪ Practicing professional work modes ▪ Design – in Theodore von Kármán's words: "Scientists discover the world that exists; engineers create the world that never was" (NSF, 2013) **…while also connecting with disciplinary knowledge:** ▪ Discovering how disciplinary knowledge is used ▪ Reinforcing disciplinary understanding ▪ Creating a motivational context

Together with subject courses, project-based learning is an essential component in the CDIO curriculum (Edström & Kolmos, 2014). In particular, Standard 5 implies a sequence of projects in which the students work on real problems, learning through the development and deployment of products, processes or systems, in working modes resembling engineering practice. The hands-on engineering should start early (Standard 4) and progress through the programme. This is a reaction to curricula where the first years are filled with basic theoretical subjects, and 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).

On the course level, two cases, one a subject course and the other a design project course, are presented to illustrate CDIO educational development.

Micro Case: Improving student learning in a subject course

This case (Edström & Hellström, forthcoming) demonstrates how 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). This shows that the synergy between disciplinary and professional aims can be realised on the course level. The intervention, called student-led exercises, aims to improve learning in problem-solving sessions. Instead of the teacher demonstrating calculations on the board (which is considered "normal" at KTH), students are randomly selected to present their solutions, prepared in advance. This teaching method was implemented in two sites, at KTH in a *Semiconductor Devices* course, and at the University of Oslo in the very large first-semester *Introduction to Chemistry*. The implementations provided different insights. Based on quantitative data in the form of course results, qualitative data in the form of student interviews, and teacher reflections over the experiences, the results at KTH indicated improved understanding and motivation, while the most consequential result in Oslo was a significant decrease in dropouts.

Micro Case: Improving student learning in a project course

This case describes a master level design project course at the Vehicle Engineering department at KTH. Student groups build things like a solar powered aircraft, an autonomous underwater glider, or an electric single-hydrofoil vehicle for play (for video clips, see Kuttenkeuler, 2017). The reflections and experiences are reported in conferences (Edström, El Gaidi, Hallström, & Kuttenkeuler, 2005; Edström, Hallström, & Kuttenkeuler, 2011; Hallström, Kuttenkeuler, & Edström, 2007) and a book chapter (Hallström, Kuttenkeuler, Niewoehner, & Young, 2014). The case demonstrates 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. It shows how this learning activity, including individual grading of student learning, can be sustainable from a teaching perspective. This makes it a proof-of-concept for project-based learning which is not necessarily very expensive or requires high teaching effort.

The course design and teaching philosophy are guided by some key principles. For one thing, *teachers do not stand between the students and the problems*. In other words, students are directly exposed to real problems in the project work. Another principle is that the *students own the project*. The teachers' role is to coach the engineering process, but not to drive it, and *never suggest solutions*. Hence, students are not protected from mistakes, contradictions or confusion, and the project results will reflect the proficiency of the students, not of the teachers, because *learning is prioritised* over the product performance. A related principle is that *the project sets the logic*. This means that teachers refrain from unnecessarily making decisions. 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. Hence, details like the page count or the deadline, follow as *consequences of its function*, not from what the teacher wants. When students let go of the teacher orientation and start becoming project-oriented, their work becomes more meaningful, and easier. When teachers refrain from managing (and micro managing) the project, it also makes the course more sustainable in terms of teacher time.

Faculty Development

The cases clearly indicate new demands on the teacher competence, regarding what to teach (Standard 9), and how to design the learning activities and assessment (Standard 10). The development of the integrated curriculum is enabled and limited by faculty teaching competence and faculty engineering competence. On the course level, the integration strategy works, but it *depends on the individual faculty* and their willingness and ability to unite the theoretical and the professional. It works to the extent that they are prepared to attend also to professionally relevant aspects that are not necessarily part of the teaching traditions of the subject. On the programme level, CDIO devises a process for establishing structures to hold the curriculum together, making the programme a joint collegial project, where every course has an explicit function towards the programme goals. The integrated curriculum works, but it *depends on the faculty capacity for coordination.* One particular challenge with recommending faculty development as part of a programme-centred development concept is that although it is an important condition for success, perhaps the most critical, it is a domain in which the programme may lack influence. This is also where least progress is reported by CDIO implementers (Malmqvist, Hugo, & Kjellberg, 2015).

ENGAGING WITH THE PAST

Chapter 3 of the thesis (see also Edström, 2018) makes a historical excursion to problematize the theme.

Perhaps a historical innocence makes it easier to take on this kind of work with optimism, but to be self-critical: we sometimes act as if the problems we work on were discovered in our time, and we devise solutions as if nobody has suggested or tried them before. Comparing past and present discussions will show not only how the issue has a long history, but also that many of the arguments and proposed strategies for addressing it remain very similar across time.

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. He 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. An “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. Many observers, including prominent proponents of the science-based curriculum, felt that the baby had been thrown out with the bath water.

This was the background against which the life and work of Carl Richard Söderberg (1895-1979) is traced, focusing on his views of engineering education. He emigrated from Sweden to the US for an illustrious industrial career. In 1938, he became a professor at MIT, and eventually ending his career as Dean of Engineering. While he was a proponent for a more science-based curriculum, his rationale was related to solving real professional problems, and he would come to criticise the distancing of engineering education from engineering practice. Comparing Söderberg's views to CDIO shows the persistence of the issue, as many of Söderberg's ideals, arguments, and proposed strategies are fully recognisable in the current discussion. Further, Söderberg and CDIO share the ideal of mutually supporting professional and disciplinary preparation, implying that the tension should not be a zero-sum game. The paths to this ideal were different, however, as Söderberg wanted to integrate theoretical aspects to improve an overly practical education, while CDIO is about improving an overly theoretical education by integrating also other necessary professional aspects. Söderberg and CDIO both recognise the dual nature of engineering education, and refuse to single out one side over the other. 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. 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. 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.

It makes a point to focus on Söderberg as a person, because he so clearly combined the practical and theoretical interests, himself embodying the dual nature of engineering. This may suggest that to achieve the integrated curriculum, enough people in the faculty must be able to simultaneously defend both academic and professional values. The binary view, associated 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 these demands seem daunting, we can look around our faculty and say: "*We have such people; we can have more*" (MIT, 1949, p. 93).

MAKING SENSE OF UNSUSTAINABLE CHANGE

Coming back much nearer the present time, chapter 4 in the thesis provides another critical perspective, by considering experiences of unsustainable change.

In 2011, the author had been discussing experiences of engineering education development with educators, programme managers, deans, and educational developers for over a decade. A pattern began to emerge when some colleagues confided that even in projects that were considered highly successful, the results were smaller than intended, and further, that change was not sustainable, in that engineering programmes tended to revert "back to normal". They reported that they felt a need to constantly work hard just to sustain the change. Otherwise, when their attention turned to other matters, the new practices would wither away and the programme revert. The poor sustainability of change had evidently come as a surprise. There was a remarkably common theme in their stories, but what was it and how could it be understood? It also felt novel, as it was not part of the normal discourse about change in the educational development community. 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, what is it that makes it "normal"? Why is this more stable than other states?

Organisational gravity

The lack of concepts to describe the phenomenon indicated a need for theorizing. The result was a model connecting the educational programme with the organisational characteristics of the organisation:

> 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).

The model postulates that the ground state for educational programmes is to simply reflect the organisation. It should then be possible to analyse what type of educational development could be harder to achieve and sustain, and what types should be easier. For instance, the model can explain why engineering curricula often consist of subject courses that reflect the organisational boundaries of the university: Even when cross-disciplinary learning activities are considered desirable for the education, they seem harder to form and sustain across organisational boundaries. Many practical issues need to be resolved, with different cost centres and administrative classifications. Crosscutting collaboration involves extra work to establish and maintain, and they are vulnerable since they often rely more on personal connections. It is consistent with the model that programmes consist mainly of courses corresponding to the administrative territories of the organisational chart. The organizational boundaries, often the same as the disciplinary boundaries, tend to be reflected in the courses of the programme.

The model can also explain why it is hard to integrate learning outcomes related to professional practice: To provide professional preparation, the university needs strengths related to integration and application of knowledge, to 'real' engineering problems, which require integration, interpretation of the context, and judgement and creativity in conceiving and implementing solutions. But when hiring and promoting faculty, disciplinary research merits are more valued, often associated with reduction, analysis, and increasing specialisation. Hence, the faculty, collectively, have relatively little professional engineering experience and researchers may see problems that do not map to the disciplines as outside their perceived responsibility. This is why it takes special effort in a discipline-based organisation to create programmes that address learning outcomes related to professional engineering practice. It is consistent with the model that some of the most desired learning outcomes are difficult to address in the education, because their representation in the organisation is too weak. To conclude, *values that are not sufficiently represented in the* *setup of the organisation are harder to implement sustainably in programmes*. Unfortunately, this applies to some of the most important learning outcomes in engineering education.

The organisational gravity model describes how the 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*" (Edström, 2011). Different factors interplay and influence each other, and in particular, some factors can enable or limit change in others. Internal factors are influenced by the external, and soft and hard factors shape each other – "*the symbolic takes part in creating the real*" (Dahler-Larsen, 1998, p. 54).

Two change strategies

Derived directly from the model is the idea 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* means *adding some kind of extra energy* to move the educational programme to a more desirable state, away from just reflecting the organisation. The extra energy, or force, can take many forms: as funding, leadership, attention, alliances, evaluations, lobbying, personal energy, etc. This strategy is available to all actors; everyone can apply their own force. The disadvantage is that it must be *continuously applied*, to prevent the programme from reverting. It is therefore potentially not very resource-efficient. This is not to say that the force strategy does not work, but it works like agriculture: new seeds must be sown every year. This understanding can inform expectations regarding results and their sustainability, and remind us to plan for a continuous supply of resources. The drawback is that the force strategy risks straining 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, since they do such work that – by definition – does not build a career in the organisation.

The *system strategy* means *changing the characteristics of the organisation* to enable a more desired stable state for the education. This is not only about changing *what we do* in the education, but also *who we are* as an organisation, because the values needed for the educational mission must be present. In other words: *to sustainably change the education it is not sufficient to change the education*. To accommodate professional education, values related to integration and application (cf. Boyer, 1990) must also be sufficiently represented in the organisation. The system strategy is less available, because fewer actors have access to the most important shaping mechanisms, such as career systems and funding systems. These systems also change rather seldom. The advantage is that even small changes, for instance in the requirements for appointment and promotion, 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 curriculum in the right direction.

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

HOW THINGS WORK AROUND HERE – THE ORGANISATIONAL PERSPECTIVE

The historical turn and the organisational gravity model have in different ways problematized engineering education development. Chapter 5 in the thesis follows up on the suspicions that were generated, that the crux of the matter lies in the relation between the nature of change and the setup of the organisation.

The University is Not a Machine

Our mental concepts and theories can function as lenses for perceiving and interpreting things that may otherwise have gone unnoticed, or they may limit our view, because by highlighting some aspects they will also relegate others to the background. A technical university is dominated by engineers, who, according to Picon (2004, p. 429), have a strong tendency for functionalist rationality. A suitable metaphor for the organisation would then be a machine, suggesting 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, p. 13). This view is not necessarily wrong, but it lacks explanatory power for many aspects of university life. We note for instance that the experiences of unsustainable change (described above) came as a surprise to the informants. In particular, the machine metaphor is unproductive when it comes to formulating models for change. In fact, the only 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 experiences above showed that top-level decisions, access to resources, and the best intentions with respect to the outcomes of education were not sufficient conditions for sustainable change. Thus, a top-down and function-oriented model of the organisation is not sufficient to inform development, or make sense of experiences. In the following, an alternative framework will be assembled, more appropriate for analysing the university as an organisation and for assessing the implications for educational development.

The Institutional Logics Perspective

The following draws on theory which describes organisations as embedded in and infused by *institutional logics* (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 seems similar to the working definition suggested above: "*how things work around here*" (Edström, 2011). If the machine metaphor focuses on formal and visible structures, resources, activities and outputs, the institutional logics perspective *also* emphasises the subtler roles played by norms, values, beliefs, assumptions, culture, and identities.

On the highest level, Thornton et al. (2012, p. 73) list seven ideal types of institutional logics in society: *state, market, community, profession, corporation, family, and religion*, each with their own set of norms, and sources of legitimacy and authority. On the next level is the institutional field, where combinations of the societal logics are at play. For instance, in the higher education sector, some practices are shaped by professional logics (e.g. peer review), while other aspects are shaped by market logics (e.g. technology transfer) or state logics (e.g. degree frameworks). In a complex institutional environment with incoherent demands, there may be tensions between different logics, leading also to tensions between the logics embedded within any particular university.

Practices and identities

Practices are intimately connected to the institutional logics of the organisation. There is "*a fundamental duality between logics and practice, where constellations of relatively stable practices provide core manifestations of institutional logics*" (Thornton et al., 2012). Practices may reflect the institutional logics differently, as they align with different parts of the institutional environment, for instance uncoordinated constituents. This can create tensions *between practices*, *within practices*, and between institutional rules and the *effectiveness* of the practice. Further, practices may be conceptualised as interdependent, so that changes in one practice may have ramifications for other practices in the organisation (p. 141). Here, the interdependence of education and research will be in focus.

There is also a close relationship between practices and *identities*; we can say that they are co-produced. The availability of standardised social identities in higher education also has great importance for identity. The classifications of individuals are important, and in fact, education can be seen as a process where students pass through a series of stages, every transition carefully controlled, e.g. admission, examination, degrees. The classification of academics is no less important; just think of disciplines, titles, appointments and promotions. The tight link between identity and practice is also evident when we consider how *status* is attached to both. Complex institutional environments 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 and high-status actors have priority access to the most valuable resources.

Identity and Status in Curriculum Change

Since engineering education development is precisely an attempt to change one of the practices of the university, the theory now becomes very relevant. It connects the practices inside the organisation, *what we do,* and the identities, *how we see ourselves,* to institutional logics. It is a key concern how the "old" or "new" curriculum models relate to the institutional logics, to other practices – to research in particular – and to identities in the organisation. If we consider the curriculum also as an expression of educators' identity, it is clear that changes can be seen as more or less valuable and meaningful, or improper and threatening.

Status plays an important role. Change may be strongly resisted if it is perceived as a threat to the status of organisations, groups, or individuals. Status can however also further change, since those that are perceived as successful and legitimate are role models 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).

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). If the curriculum is an expression of faculty identity, any changes in practices and structures will obviously be strongly resisted if they are perceived to threaten these values. Considering the main strategy in CDIO programme development, two problematic tensions can be identified. First, the strategy to integrate professional aspects in courses differs from the traditions of the discipline. Then, the need for coordination across the curriculum can be seen to limit academic freedom. A reform that can draw on core values in faculty identities may instead have an advantage.

DISCUSSION

Chapter 6 of the thesis considers the academic-professional duality and its tensions, in the light of the theoretical framework from the previous chapter.

Analysing the Dual Nature Ideal

We saw that institutional logics – patterns of material practices, assumptions, values, beliefs, and rules – are embedded in the practices and identities within the university. In complex institutional environments, the logics embedded within a particular practice can contain contradictions. The proposition here is that the engineering curriculum expresses the institutional logics of two professions: *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 reasonably assumes 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 1.

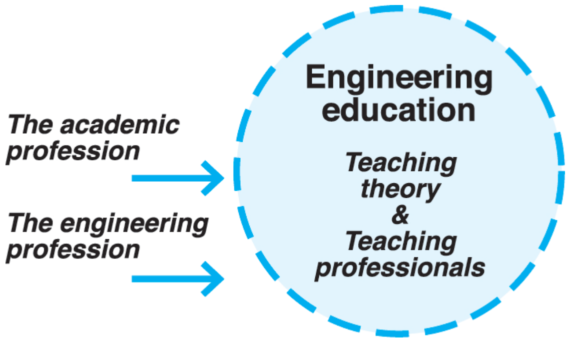

Figure 1. Engineering education, a practice expressing two professional logics.

Some aspects in which the institutional logics of the two professions differ are elaborated in Table 2. The analytic scheme is not meant to set these two sides of education against each other. For instance, when we consider what knowledge is seen as relevant (see Table 2, row 3) there is no doubt that disciplinary fundamentals are useful for engineering practice. But when they are taught with the approach of the academic profession, the main emphasis is often on deriving or proving the theory, most often going through the subjects one at a time. In contrast, when disciplinary fundamentals are taught with the approach of the engineering profession, emphasis is on achieving a working understanding, i.e. the competence in using theory from many disciplines in the context of real problems. The point here is precisely that *both sides are necessary*, and according to the dual nature ideal, they should also be in a *meaningful relationship*.

As another example, we consider what problems and questions are seen as interesting (see Table 2, row 4). We want students to be *problem-oriented*, considering how to solve consequential social and economic problems in society, but we also want them to be *discipline-oriented*, to think in terms of new technology looking for applications – and they should ideally be able to combine these two perspectives.

Table 2. Analysis of the institutional logics of the engineering profession and the academic profession, respectively.

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

The ideal to combine these perspectives in education does not prevent manifestations of contradictions and tensions between the logics. For instance, the cases of unsuccessful change suggested that some of the values necessary for engineering education are weakly represented in the organisation. In the language of institutional logics: when the professional logics are weakly represented among the faculty, it is more difficult to satisfy the related aspects in the curriculum. Similarly, in an organisation where the academic profession is weakly represented, it would be difficult to satisfy the aims in the right-hand column of Table 2. 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.

Competing logics in research

The other practice in the technical university, research, can be characterised by a similar tension within its institutional logics, where two beliefs about the aims of research exist simultaneously: one that research aims to further knowledge for its own sake, and one that research is guided by a consideration for usefulness in society.

The first belief can be expressed as *the university as academia*. Knowledge "for its own sake" quickly translates to the same thing as furthering a discipline, because the academic career depends on peer recognition, making disciplines the site that controls the necessary resources for survival. Peer approval is a *sine qua non,* since those whose work does not pass this disciplinary quality control will be marginalised by the 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, being appointed and promoted, receiving grants and prizes, and being selected for commissions. Many of academic decisions concern classifications of individuals, which is a particularly important component of identity, and in the career system, research merits dominate every step. All this helps explain the strong socialisation of faculty into the discipline-based identity and beliefs.

The second belief, *the university as public service* implies that research is guided by *consideration for use*. The challenge is how to evaluate the usefulness dimension of the work, and who should be seen as the legitimate judge. It is quite suggestive that even funding for highly applied research is often dispensed based on academic peer review. See Figure 2.

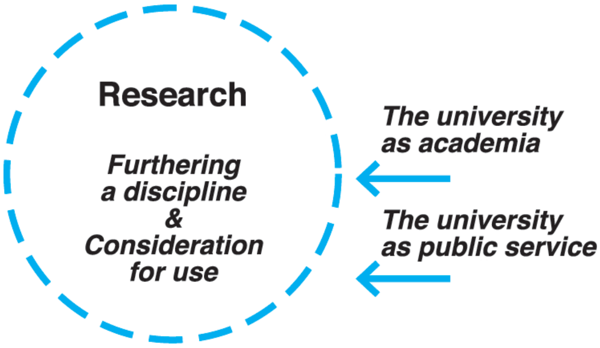

Figure 2. Two aims of research, with corresponding beliefs.

Given that the resources under academic control are so vital, the proposition here is that "university as academia" has stronger support in the institutional logics than does the "university as public service". While the former is highly consistent with the logics of the academic profession, the latter 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. These two beliefs are not mutually exclusive, as research can simultaneously be directed toward applied goals and lead to significant new understandings (Brooks, 1967; Edström, 2017b; Stokes, 1997). There is, however, still a core distinction, 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). The 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.

Interplay between education and research

Education and research have so far been discussed separately, focusing on some tensions *within* each practice due to inconsistent demands in the embedded logics. What remains is to consider their *interdependence.* The two figures can be merged, see figure 3. The focus here are the different conditions for the practices, and how research influences engineering education. The theoretical framework can tell us that, due to inconsistent institutional demands, we can expect patterns of *differentiated status* between these practices and between groups within the organisations. We can further expect tensions *between* practices, and between institutional rules and the *effectiveness* of the practice.

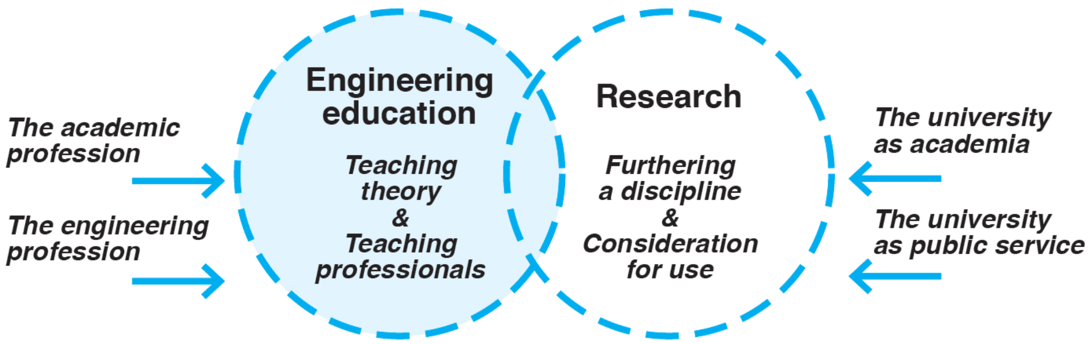

Figure 3. Competing institutional logics in education and research.

Seeing the university from the outside, engineering education and research both enjoy high status. However, within the university, while there is certainly status in excellent teaching, the status of research is generally even higher. We also remember the imperatives created by the "university as academia" described above. While teaching merits feature increasingly in the hiring and promotion criteria, from a career point of view it seems sufficient to be above a threshold level (Graham, 2015). Another reason is the different resource environments. Education funding is distributed internally, 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 often sought externally and 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. In conclusion, *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.

The focus here is the dual nature of engineering education, which was conceptualised above as competing logics within the education practice: teaching theory and teaching professionals. But because of the crucial role played by research in shaping the faculty, the suggestion here is that the institutional logics of research, being the dominant practice, strongly influences the institutional logics of the education, because it is shaping the faculty. Hence, *the more the research practice is dominated by the academic logics*, over the consideration for use*, the more it will tilt the balance also in education, in favour of teaching theory*, rather than teaching professionals. If the balance is heavily tilted, it will also be difficult to achieve the ideal of a productive relationship between the academic and professional aims.

In the picture painted here, research has the primary position in the university organisation, positioning education as a secondary practice. The institutional logics of the academic profession have the upper hand not only in research, where disciplinary interests take priority over considerations for use, but also in education, where teaching theory takes priority over the other aspects of professional preparation. No wonder then, if it is difficult to make certain kinds of educational changes sustainable, when the primary practice exerts its constant influence. This happens through the faculty, whose academic identity is stronger than their engineering identity, because research is the birthplace of new faculty, and it also 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.

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