CRITICAL SELF-REFLECTIONS ON THE CLASSICAL TEACHING CULTURE IN ENGINEERING

Gion Koch Svedberg

Department of computer science, Malmö University, Sweden

ABSTRACT

The classical teaching culture in engineering is determined by a deep-rooted belief system that becoming an engineer means having to endure the worst three to five years of your life of hard and boring math, useless abstract theories of physics and a couple of project works for which one slaves day and night for months in order to get things to work. In this paradigm, engineering studies are seen as a kind of initiation time, after which the newly examined engineer will be welcomed into the arms of the engineering brotherhood. No wonder that young people do not find such studies very enticing anymore. In a globalized world full of interesting, catchy, fun and state of the art educational programs, an old-fashioned style of teaching culture in engineering seems rather outdated. But unfortunately, from my own experience I know that it isn't. Teachers in engineering at universities tend to teach in the same way as they have experienced during their own studies. This way they preserve and recreate a teaching culture that resists pedagogical reforms despite substantial criticism from all possible sides.

Why is this? What is it about the classical teaching culture in engineering that makes it impossible for any teacher adhering to it to obtain good or effective teaching? The objective of this paper is to use long-established pedagogical research results on teaching and student learning to analyse the classical teaching culture in engineering. A discussion of this analysis leads to three underlying problem areas: different epistemologies between engineering sciences and engineering undergraduate education, the hierarchy between research and teaching, and the style of examination and its impact on student learning. Finally, possible ways of improvements are discussed. It is also shown that the CDIO Initiative is a valid alternative to the classical teaching culture in engineering, as it allows their teachers to improve the quality in teaching and to make it effective.

KEYWORDS

Engineering teaching culture, teaching style, resistance towards reforms, realism and constructivism, contructive alignment, CDIO Standards.

INTRODUCTION

Traditional engineering education on university level seems very difficult to change or even modify. The classical way of how engineering is being taught at many technical universities follows a tradition with only few reforms since its beginning about a century ago.

Most teachers at technical universities teach more or less in the same way as they have been taught themselves. Usually, they see themselves primarily as engineers, researchers or scientists rather than as teachers. In regard to the need for reforms they are primarily concerned about the content in the engineering programs and less about the way the courses are taught or the role they as teachers play for student learning. Most teachers who teach in engineering are very well aware about the importance to follow the latest developments in their respective technical fields by means of research-activities and co-operations with the industry, companies and organizations. But somehow, they do not regard pedagogy and the field of teaching in higher education as a similarly evolving area on its own.

The objective of this paper is to give a self-critical view regarding the classical teaching culture in engineering from my own experience as a student, PhD-student and most of all from teaching over eight years as an engineer and researcher at the department of computer science at Örebro University in Sweden. My own view on teaching has changed dramatically over the years from a more objectivistic outlook on the content of courses towards a more constructivist understanding about student learning. With other words, my sole concerns about *what to teach* in the beginning of my teaching career have over time expanded to include the questions about *how to teach* and, after becoming interested in the research on higher education, now more and more focus on the problem of *how to support student learning*. This paper contains some of my reflections and conclusions gathered during my own pedagogical journey. I am for example convinced today that in order to be able to reform and modernize engineering programs so that they will attract young men and women, the classical teaching culture in engineering will first have to be changed.

Chapter 2 contains a description of the characteristics of the classical teaching culture in engineering as well as some of its criticism. Examples of reforms are mentioned – the so called Bologna process [2] and the CDIO Initiative [3]. Chapter 3 uses the research results on studies of exemplary teaching that Paul Ramsden has grouped into a set of well-known and generally accepted principles for effective teaching in higher education, [1]. These principles are used to analyse the classical teaching culture in engineering and to compare it to the standards adopted by the CDIO Initiative. Chapter 4 discusses some of the underlying causes in the classical teaching culture of engineering that counterwork a number of principles for good teaching. Chapter 5 suggests possible improvements and changes and mentions interesting examples from various universities.

1. CLASSICAL TEACHING CULTURE IN ENGINEERING

2.1 Traditional style of teaching in engineering programs in Sweden

Traditionally, the teaching culture in higher education as practiced in engineering programs in Sweden is characterized by two or more courses read in parallel, which consist of lectures and laborations or exercises. Lectures usually cover the theoretic ground and are taught by professors or associated professors (senior lecturers) to all of the students together. Laboratories are usually carried out in smaller groups (typically around 20 students max) and meant for the students to reach understanding by applying the theory on practical examples, in form of experiments or exercises. Usually, and especially if larger groups of students require several laboratory groups, laboratories are supervised by PhD-students or lecturers and not by the teacher holding the lectures. This teaching model is moreover regarded as

well suited for basic engineering courses, like mathematics, physics or mechanics, which are common at several engineering disciplines during the first year of undergraduate engineering programs. It optimizes the costs by limiting the more expensive teaching hours of a professor and by using cheaper teaching hours for the laboratory hours instead.
This model of differentiating between lectures and practical applications is often even used as the base for allocating teaching resources. In this paradigm, lecture hours, with its higher status, usually count more than laboratory hours. One hour of lecture can for example be multiplied by three to count for the expected amount of time spent by the teacher, while the hours for laboration, exercises or seminars might only be doubled. The two factors three and two are flexibly chosen by the head of the department and can vary in order to divide up the teaching workload among the available teachers.

The main characteristic regarding the style of teaching in this tradition is the view on knowledge as being something objective and absolute, e.g. independent of the teacher or student or their learning context. The role of the teacher is seen to be somebody who is competent and trustworthy to present and explain the knowledge in front of and to the class. It is then up to the students to learn this knowledge so that they can reproduce it in the right way. This transformation of knowledge, selected and presented by the authority of a professor is usually well-defined within the boundaries of the corresponding course. While the laboratories, as part of the course, help students to get a deeper understanding of the knowledge by means of practical application of the theories, the division into different courses creates islands of knowledge that the students find hard to see how they connect. For this reason project-work courses are offered in which the students are expected to solve technical problems by applying the content of all the courses learned so far. It is generally agreed among teaching staff that it is through this kind of applied learning that the students get a deeper understanding of the course material and learn how to think as engineers. Seminars, common in other faculties, such as humanities, pedagogy and philosophy, has almost no tradition in engineering education, at least not in what is referred to as “hard-science” engineering courses.

Traditional assessment in engineering courses follows the division into a theoretical and a practical part. To pass such courses, the students must turn in all exercises and lab-reports and pass a final exam at the end of the course. According to the hierarchy described above, the assessment of the knowledge transferred in lectures by professors or associate professors usually weights more than the practical part (as long as it is not a project-work course). The grade for the final exam with the focus on the theoretical knowledge usually determines the grade for the whole course, while the laboration part is either passed or failed. This outlook on assessment can be seen as the logical result from the traditional view on teaching described above. Since knowledge is seen as something absolute and objective that is presented and transformed to the students, it is up to the students to incorporate it and to show that they have done so at the end of the course. It is then up to the initiated authority (professor or assistant professor) to decide how much of this knowledge each student has incorporated by grading the student’s performance at the final exam. With the professors’ time being so much more valuable than the teachers’ supervising the laboratory work, time for grading is kept to a minimum, typically around half an hour per student and course. This time-limitation usually does not allow for continuous assessments during the course with the exception of short tests in form of automatic graded multiple-choice questions.

2.2 Criticism towards the traditional style of teaching in engineering programs

Criticism regarding the classical teaching culture in engineering as well as the need for reforms have been postulated before. A Swedish study that was ordered by the Swedish parliament and that was partly used to reformulate the official requirements for bachelor and master exams in engineering is the ontology from 1998, called NyIng (new engineer) edited by Linköping University [4]. The report consists of eleven articles that deal with different aspects regarding the work and role of modern engineers. The common understanding of the different articles is that the role and work of engineers has changed dramatically in the past 10 to 20 years whereas education changes much slower. While higher engineering education programs have adapted well to the changes in technology, the newly examined engineers are being criticized for lacking insights about crucial factors that are part of what one can refer to as "engineering professionalism". In the NyIng report, a group of engineers and managers discuss the concept of engineering professionalism and find the following major shortcomings in today's newly examined engineers: communication skills (written and oral), foreign-language skills, team-work, and problem-solving skills of undefined problems under uncertainty.

Some articles in the report are written by well-known people at engineering companies describing the view of these companies about engineering education. Bernt Ericson, chief of research at Ericsson at that time, explains for example his view on higher engineering education in an interview as part of the NyIng report, [5]. Some of his most critical comments are summarized in the following list:

- Focus on "education" where the teacher is the active part should be shifted towards "learning" where the students play the active part. Teachers should become mentors and inspirators instead for holding speeches.
- It is wrong and devastating that newly examined engineers no longer have any intellectual curiosity left. One should be even more inspired to read and learn after studying engineering, not less.
- The setup in which during the first two years students only study basic subjects for the sake of the subjects makes students leave their engineering studies before they are finished. They see no relationship between the different subjects and have no long-time goals for their studies. Young people of today are inpatient, they will see fast results. They lose their interest if they have to put in a lot of time for something they do not see what it is good for.

Bernt Ericsson proposes that engineering studies can be made more meaningful and interesting for young people of today if one re-structures higher engineering studies with focus on projects and concrete, real-world problems. And, if tasks are based on real-world problems, the way of working should also be such. This is why engineering students should work in groups and learn how to present their work to one another. Today's engineers must be able to communicate both within and outside of their discipline. Bernt Ericson as research leader at Ericsson has seen how engineers lack this skill when they for example talk to customers and focus on technical details which are totally uninteresting for the customer who only wants to know how the overall system works. According to Ericson, companies shout after people with interdisciplinary knowledge, who not only are experts in a specialized niche.
At the end of the interview Bernt Ericson repeats once more that engineering studies need to improve their attractiveness and that this means that engineering educational programs must be improved, [5, p101].

2.3 Bologna Process

Parts of the findings in the NyIng-report were used by the Swedish National Agency of Higher Studies ("Högskoleverket") when reforming engineering education at Swedish universities as part of the European coordination of higher studies, called Bologna process [2]. The aim of the Bologna process was to promote and encourage student exchanges between European universities. Besides the harmonization of administrative processes it also propagates a pedagogical framework that is based on John Biggs "constructive alignment" [7,16,17]. Typical for the Bologna process is the shift of focus from the contents in courses towards a description of the learning outcomes for the student completing the course. Learning outcomes are divided into three categories "*Knowledge and understanding*", "*Competence and skills*" and "*Judgement and approach*" with a thought progression from factual knowledge via application to deep understanding. Learning outcomes for engineering

programs are broken down individually by Swedish universities from a set of common goals defined by the Swedish National Agency of Higher Studies. For example, the learning outcomes of engineering programs with professional qualifications (such as Bachelor of science in engineering, for example) is being stipulated in Appendix 2 to the Higher Education Ordinance, System of Qualifications, see [8]. Looking at these common goals, the points listed under “knowledge and understanding” are very much in line with the traditional view on engineering knowledge to be taught. Next to the “hard-science” technical knowledge common in the traditional teaching culture, other requirements have been added under the headings for “competence and skills” and “judgement and approach” which bring to mind the critics about the traditional teaching culture in engineering as mentioned in the preceding paragraph. For traditional engineers, subjects or issues like “interaction between technology and society”, “economically, socially and ecologically sustainable development”, “teamwork and collaboration”, “oral and written presentations”, “social and ethical aspects”, “responsibilities”, “information literacy” and “preparations for life-long learning” are considered to be “soft”-science in contrast to pure engineering “hard”-science topics. When more or less forced to integrate soft-sciences in engineering programs, such courses are often delegated to the humanities and philosophical departments.
The responsible teachers belonging to the traditional teaching culture of engineering programs found these requests for changes put forward to them by means of the Bologna process as rather awkward. Since no one explained to them the underlying pedagogical foundations and thoughts, they reduced the task for pedagogical reforms to technicalities, such as, for example, rephrasing a course syllabus so that old course contents became students’ learning objectives. This is why nowadays Swedish universities require that all of their teaching staff have successfully completed higher educational pedagogical courses. But since teachers adhering to the classical teaching culture in engineering above all see themselves as engineers, researchers or scientist with a primary interest in “hard”-sciences, it is questionable how much of the “soft”-sciences they actually will acknowledge and incorporate in their teaching.

2.4 CDIO Initiative

CDIO stands for “Conceiving - Designing - Implementing – Operating” real-world systems and products, which is postulated by the CDIO Initiative [3] as the context in which engineering education should take place. The CDIO Initiative can be seen as the answer developed at MIT to the open question of how to meet the new demands posed on modern engineers as described in chapter 2.2 and how to modernize engineering university education to account for these changes. Following an engineering problem solving paradigm, a comprehensive understanding of the skills and knowledge needed by modern engineers was first derived together with faculty, alumni, students and the industry. The outcome was documented by Edward F. Crawley in the MIT- CDIO Syllabus, [10]. The next steps were to look at ways to improve the learning of the knowledge and skills. In January 2004, the CDIO Initiative adopted 12 standards that describe CDIO programs, [11]:

> “The 12 CDIO Standards address program philosophy (Standard 1), curriculum development (Standards 2, 3 and 4), design-build experiences and workspaces (Standards 5 and 6), new methods of teaching and learning (Standards 7 and 8), faculty development (Standards 9 and 10), and assessment and evaluation (Standards 11 and 12).” See [11, p1].

With currently more than 50 collaborating institutions in over 20 countries, the CDIO Initiative is becoming more and more of a quasi-standard regarding modernized educational engineering programs. The CDIO Standards were for example used 2005 in a Swedish national evaluation of engineering educational programs by the Swedish National Agency for Higher Education, se [12].

2. ANALYSIS OF THE CLASSICAL TEACHING CULTURE IN ENGINEERING

It is important to be very clear about the fact that there exists no “silver-bullet” or “secret universal recipe” of how to achieve good and effective teaching. However, most teachers and students agree that there exist examples of excellent, high-quality as well as lower quality of teaching. A substantial amount of research investigated the excellent examples of high-quality teaching and came up with a list of properties that can be seen as the characteristics behind “good teaching” [1, p89]. From this list of properties, Paul Ramsden derived 6 main principles that he advocates as the ones to follow in order to improve the quality of teaching. Ramsden clearly points out that there are no universal recipes for good teaching, [6]. But, based on the fact that most examples of good teaching in one way or the other incorporate these principles, they can be seen as a framework of necessary, but not sufficient, criteria for good teaching. This means that incorporating the six principles will improve the quality of teaching but not necessarily result in good teaching. However, neglecting the principles will most likely prevent good teaching as well as the improvement of the quality of teaching.

3.1 Teaching theories and principles behind good teaching

Since most of the teachers, researchers and scientists working at the engineering departments at universities have experienced the traditional teaching model described in chapter 2 as students, this style of teaching seems rather natural to them. It might even be the only style of teaching that they know and therefore carry on. But, different faculties and disciplines follow different teaching traditions. The crucial difference lies in the views about teaching and the teacher’s role. Ramsden for example, describes three distinctive generic ways of understanding the role of the teacher, [1, p109ff]. The foremost common view on the teacher’s role in the traditional teaching culture in engineering as described above is the one that Ramsden describes as the “authoritative transmitter of content, the demonstrator of procedures”. He refers to this style as the *theory one of teaching*. In the *theory two of teaching* focus is on the student’s individual project and less on the teacher. The role of the

Table 1
Summarized overview over Ramsden’s six key principles of effective teaching [1, p93-99]

Principle 1: *Interest and explanation*	A subject should be made interesting, students should find it a pleasure to learn the subject and be willing to work hard for it, complex matters should be explained in an easy and understandable way
Principle 2: *Concern and respect for students and student learning*	Effective university teaching requires respect and consideration for students, generosity and willingness to share and pass on knowledge, contrary to making things hard or to frightening students, keen interest in what it takes to help other people learn, pleasure in teaching, delight in improvising
Principle 3: *Appropriate assessment and feedback*	Quality of feedback on students’ progress is the most relevant question regarding the quality of teaching, teachers should be accessible and be able to question in a deep learning scenario to discover what students really have learned
Principle 4: *Clear goals and intellectual challenge*	Recognizing a cycle of education from a stage of absorbing, discursive, romantic discovery, stage of precision to a stage of generalization and appreciation, control over learning is shared between the teacher and the students, explaining to the students what must be learned in order to achieve understanding instead of ‘covering the ground’
Principle 5: *Independence, control, and engagement*	Give students the perception that they have control over their learning, each student is an individual with his or her own way of learning, provide relevant learning tasks at the right level, instructions are necessary in the beginning, but the goal should be to make students self-sufficient. “Learning should be pleasurable, There is no rule against hard work being fun”, [1, p 98].
Principle 6: *Learning from students*	A teacher should never take the effects on students for granted, should try to diagnose and clarify possible misunderstandings during the scope of the course, see the evaluation of teaching as an integral part of teaching.

teacher is to be a supervisor that helps as the link between theoretical knowledge and practical experience. Project-work courses in engineering programs are usually run in this way. The CDIO-initiative is a good illustration for this style of teaching. Finally, in the *theory three of teaching*, learning is understood as something the *student* does, instead of something that is being *done* to the students. It recognizes that teaching and learning are two sides of the same coin and that the relation between teacher and student is relational and rather complex in which teaching is defined as making learning possible. Ramsden considers this one as the ideal style of teaching that might not always be realizable but definitely worth to endeavour.
Ramsden's six main principles behind "good teaching" (see Table 1) can be seen as dimensions in which to improve the quality of teaching. Using these dimensions in a polarity profile diagram it can be used to illustrate the strengths and weaknesses in teaching. It also allows comparing the traditional teaching culture in engineering as described in chapter 2, to the 12 standards adopted by the CDIO Initiative.

3.2 Polarity profile diagrams comparing the traditional teaching culture in engineering with the CDIO-Standards

In the proposed polarity profile diagrams each principle from Table 1 is represented by an axis pointing outward in the direction of possible quality improvements. Such diagrams can for example be used to document the development of individual teachers over the years by his or her teaching experiences and involvement with pedagogical questions. In the diagram the teachers development will result in an "enlargement" of the figure along the different axes over the years. Since the teaching culture in engineering more or less sets the framework in which teachers and students meet, it becomes interesting to look at a polarity profile diagram for the overall teaching culture in engineering and to compare it to the CDIO Initiative. However, no quantitative analysis has so far been carried out and the following analyses and drawing is purely qualitative and rather subjective.
The traditional style of teaching in engineering programs puts a lot of focus on the first principle. Most teachers at engineering universities find their subjects interesting and are very engaged regarding the content of it. However, the division into theoretical and practical parts, which are not always synchronized, place obstacles in the student's way to deep learning. Student engagement is usually larger in project works due to more integrated learning with a closer interaction between theory and its application as is the case in CDIO programs. Other clear disadvantages of dividing teaching into different parts with different teachers interacting with the students are the resulting difficulties in giving consistent feedback to the student (principle 3), to control the learning in order to achieve understanding (principle 4), or to provide relevant learning tasks at the right level (principle 5). Regarding the concern and respect for students and student learning (principle 2), Ramsden explicitly mentions the teaching traditions at engineering and medicine as examples for putting pressure on lecturers to act in a certain way:

> "The archetypical arrogant professor, secure in the omnipotent possession of boundless knowledge, represents a tradition that dies hard. Certain lecturers, especially new ones, seem to take a delight in trying to imitate him", [1, p 94].

Professors and associated professors who see themselves primarily as scientists or engineers doing research and who hate to teach also tend to run in and out of their lectures with almost no personal interaction with their students. They simply lack interest in and compassion for students or student learning. But since teaching has a much lower status than research, they often don't need to care, and by this way make sure that they will not be asked to teach more than the minimum. At the same time it is very important for teachers to understand the students of today. As John Biggs so well documents on a video on constructive alignment [13] there are at least two types of students. In the video they are called Susan and Robert. Susan represents the ideal, self-going student who, given a list with the course literature, basically learns herself, driven by her own interest. Robert's main

motivation for studying is the piece of paper with the exam at the end of the undergraduate program. While a few decades ago students were a homogenous group of self-learning Susans, the Roberts now are in majority. Focus on the knowledge to be transferred instead on the individual student also results in the overhanging risk of “breakneck attempts to ‘cover the ground’” (principle 4). Everything in the course books is seen as equally important. This is rather understandable, given the fact that only few of the teachers at engineering departments actually ever worked as engineers outside the university. They lack experiences from real-world examples and therefore find it difficult to prioritize.
Ramsden summarizes the consequences of *theory one of teaching* with the following words:

> “All this is rather bad news for the traditional lecture, practical class, and tutorial, as well as for orthodox approaches to the professional curriculum, [...]. It seems that we often encourage poor learning at university through over-stressing individual competition while at the same time using teaching methods that foster passivity and ignore the individual differences between students”, [1, p98].

Learning from students (principle 6), is usually done in the classical teaching culture in engineering by means of course evaluations at the end of the course. If misunderstandings occur during the courses, the students usually find ways to ask the teacher for clarifications.

Figure 1 shows the qualitative profile diagram as a result of this qualitative analysis of the traditional teaching culture in engineering in regard to the six principles. If a principle is an important part of the traditional teaching culture its correspondence was set to *strong*. If a principle is not part at all or counteracted by the classical teaching culture, its correspondence was set to *weak*. Principles that are neither set to *strong* or *weak* are set to *neutral*. In this way, principles 2, 3, 4, 5 have been set to *weak*, principle 6 to *neutral* and principle 1 to *strong*. One can look at the resulting figure in the middle of the diagram as a representation of the framework for good teaching provided by the classical teaching culture. As such, 4 out of 6 principles are not part of the framework. Of course, individual teachers can always “brake” out of this framework and still realize good teaching, but it is interesting to note that if they do, they will to a large part work outside the traditional teaching framework.

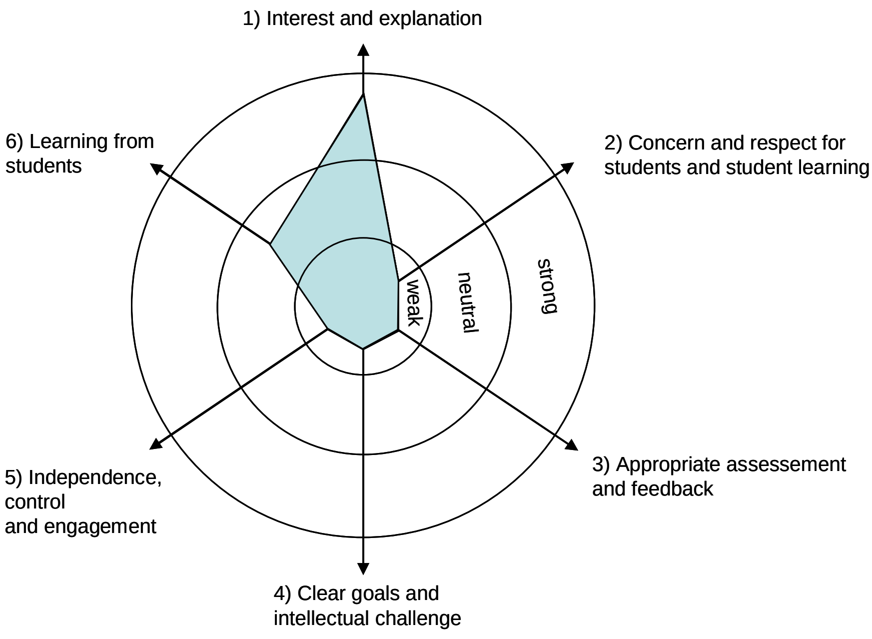

Figure 1. Qualitative profile diagram of the traditional teaching culture in engineering

One of the major goals of the CDIO Initiative is to re-emphasize teaching engineering practice in regard to the teaching of engineering sciences in order to better prepare the graduating students for real-world engineering tasks. This is proposed to happen within a context for engineering education that follows the "*Conceiving – Designing- Implementing – Operating*" model. In this model it is essential that theory and practice are combined and that all the skills needed by a modern engineer are being taught in an integral way. This creates a cultural framework which supports all of Ramsden's key principles as shown in Table 1.

To make the subjects interesting (principle 1) is at the core of the CDIO Initiative. Students have a lot more pleasure to learn and are more willing to work hard in CDIO programs. Several of the CDIO Standards ensure this: the appropriate context for engineering education (Standard 1), the learning outcomes (Standard 2), the curriculum development (Standards 3 and 4), and the design-build experiences, and workspaces (Standards 5 and 6), integrated learning experiences (Standard 7), active learning (Standard 8), and the enhancement of faculty skills (Standards 9 and 10).

Some of the CDIO Standards have a clear student-centred view on teaching, showing concern for the students and trying to make learning interesting and rewarding (principle 2): learning objectives that describe what the students should know and be able to do at the end (Standard 2), an introductory course in the beginning to prepare students (Standard 4), promotion of early success in engineering practice (Standard 5), student-centred workspaces (Standard 6), and active learning methods (Standard 8).

Standard 11 in the CDIO Initiative mentions that effective learning assessment (principle 3) should use a variety of methods according to the learning outcomes. Besides written and oral tests common in the classical teaching culture, the following methods are also mentioned: "observations of student performance, rating scales, student reflections, journals, portfolios, and peer and self-assessment.", [11, p 8]. Combining theory with practice in the CDIO context also generates immediate feedback to the student (principle 3) when realizing that something does not work the way it was intended. The CDIO Initiative is very important in respect to setting clear goals and intellectual challenge (principle 4). Much of its efforts have been spent on the joint agreement between the academic and industrial world regarding the clarification and key-priority of the content of engineering programs. Other important aspects are the focus on integrated and active learning, the design-build experiences, and the enhancement of faculty teaching skills. Hence, CDIO Standards 2, 5, 7, 8 and 10 clearly support this principle.

Since the CDIO Initiative adheres to constructive alignment, knowledge and skills are not regarded as something absolute or objective. Instead, it needs to be constructed in a given context by each individual student. The focus on design-build experiences (Standard 5), learning environments that support hands-on learning (Standard 6), and the process of metacognition (Standard 8) all can be seen to support principle 5.

Learning from students (principle 6) is not directly addressed in an own CDIO Standard, perhaps with the exception of Standard 12 on program evaluation which mentions the need to *gather data from students*. Other standards imply indirectly learning from students. Standard 8, for example, is about active student learning, while Standards 9 & 10 are about the enhancement of teaching faculty.

Together, all CDIO Standards refer to all of the six key principles. Of course this does not mean that all CDIO-engineering programs automatically are superior to more traditional engineering programs. What it means is that the CDIO Standards allow for a framework for good teaching that is larger than the one for traditional teaching in engineering, since it includes all six principles of effective teaching, as figure 2 qualitatively illustrates. It also means that a teacher of CDIO engineering programs can realize good teaching within the CDIO-standards. However, many CDIO-educational programs are probably run by departments which in their structure and organization still adhere to the classical teaching culture in engineering. To operate and maintain CDIO-programs with its full potential in such "stunted" environments probably requires a lot of extra energy.

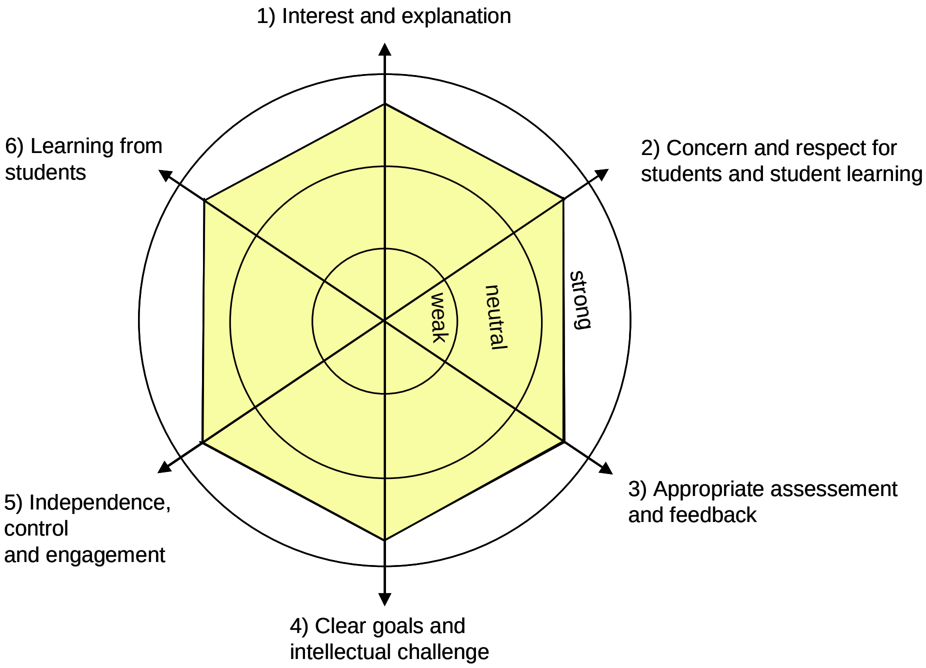

Figure 2. Qualitative profile diagram of the framework for effective teaching possible in CDIO engineering education programs

3. DISCUSSION

The analysis in the preceding chapter indicates that 4 out of 6 principles that research finds necessary (but not sufficient) underlying factors for effective teaching are not really supported within the framework of the classical teaching culture in engineering. With other words: teachers who adhere to the traditional way of teaching in engineering cannot realize effective or good teaching in their courses, no matter what they do! If they want to reach effective teaching they will have to look outside the classical teaching culture. As the example of the CDIO Initiative shows, there are actually more and more engineering programs doing so as well. CDIO does not define how a teacher should be teaching but its Strategies refer to all of the 6 principles of effective teaching so that a teacher actually can implement them in his or her course within the CDIO framework.

Since the classical teaching culture in engineering still is very strong and dominating for most of the engineering programs, the question is how it could be changed to support more of the principles for good teaching. This way, teaching could become more effective within the existing framework and the quality of teaching would improve. Teachers and students would have more fun and learn more. In this chapter, possible underlying key-problems are discussed, e.g. constellations and mind-sets in the traditional teaching culture which counterwork the principles 2, 3, 4 and 5 for effective teaching. The next chapter looks at examples for possible improvements. The key-problems in question are: the hierarchy between research and teaching, focus on teaching as transformation of knowledge from the teacher to the students, and style of examination and its impact on student learning.

4.1 Hierarchy between research and teaching

The structural organization of engineering departments sometimes separates researchers and teachers into two different groups. While the researchers by their working contract are “forced” to teach part-time, the more or less openly declared policy is that researchers shall not be disturbed too much in their research by teaching tasks. Economically it is very costly to pay professors to teach undergraduate courses compared to full-time teachers or PhD-students. This is also why senior researchers often only teach the theoretical part in a course, leaving the practical laboration parts to others. On the other hand, senior lecturers with full-time teaching positions have according to their working-contract the “right” to do research at, for example, 20% of their time. They are formally part of a research group but practically can not attend any meetings because of their high teaching load. They are usually not either included in research proposals since external money should primarily go to pay the wages for researchers who are employed on project bases. The amount of teaching put on senior lecturers usually leaves no time for them to do research.

In Sweden however, the law on higher education clearly stipulates the connection between teaching and the “awareness of current research and development work” for which the teachers must be a guarantee for. The role of universities has traditionally been seen as the place where teaching and research takes place. It is research that forms and stands on the scientific ground upon which university studies are legitimized. It is the connection between research and teaching that provides the level and quality that is expected of university studies. This is why teachers also need to be active researchers.

On the other hand, there is much to gain for researchers being involved in teaching. Teaching is known to be the best form of reaching understanding. To explain complex ideas to undergraduate students is quite a challenge, which, if one succeeds, also benefits one’s own research by providing clarity, priority and simplicity to one’s own mind. Teaching graduate students can be interesting for testing new research ideas. Teaching in the way as proposed by Ramsdens *teaching three theory* is making the researcher attentive and open to other views, the context, other questions as well as to totally new ideas. Effective teaching can be very enriching on a personal and relational level. It helps keeping the right perspective on life as well as preventing oneself from becoming too one-sided on one’s own projects. Baldwin describes in her report on the teaching-research nexus, that “academics have been known to report that being asked to teach a subject in a new area has opened up unexpected lines of inquiry that have led to fruitful new research agendas” [15, p 4].

Finally, only very few researchers will ever get the Nobel-prize or even become internationally successful and well-known professors. This means that full-time teaching positions will be most realistic for most of the ambitious younger researchers who decide to stay and work at a university. Teaching, like any other trade is learned by doing, it should therefore be practiced together with people who have more experience than oneself. This is one of the main reasons why teaching and research is combined at universities; it allows younger and older people to work together and to profit from each other.

Summarizing, one can conclude that the strict division between researchers and teachers potentially lowers the quality of both – the research as well as the teaching carried out at a department.

4.2 View on teaching as transformation of objective knowledge

The view of knowledge as something objective and absolute is very strong in the engineering culture in general. The relationship between hard-science and realism is obvious and even historically deeply rooted. This is probably one of the main reasons why traditional view on teaching at engineering universities is still seen as a transformation of knowledge from the teacher to the students. Ramsden calls this a *theory one teaching* approach which according to research leads to consequences like, for example, students: who are less interested and motivated in their studies, who spend less time than expected studying, who don’t finish their studies in time or quit after the first year, who don’t really understand the fundamental ideas in their subject of studies, who are poor writers and communicators, who learn for the final exams instead for wanting to learn more about what interests them most, and who are not so good at solving unstructured real-world problems. Interestingly enough, these are also very much the observations regarding engineering students mentioned in the interview with Bernt Ericson, research leader at Ericsson, (see chapter 2). It is also characteristic for the *theory one teaching* approach to blame the students for these shortcomings!

In less natural-science and engineering oriented disciplines of science, especially in humanities and pedagogy, knowledge is instead seen as something that is being constructed in a given context, according to constructivism. Students construct the knowledge as part of their learning and dependent on their context. The role of the teacher is to support student learning, which corresponds to the *theory three teaching* approach described by Ramsden. This is more or less what constructive alignment is all about.

4.3 Style of examination and its impact on student learning

As mentioned in chapter 2, the traditional way of examination at least of more technical - and mathematical-oriented courses, are written final exams. This tradition is based on the myth that the final written exam is the best and most just way of examining technical and mathematical knowledge. Most teachers might not at all be aware about the impact of final written exams on student learning if they never have asked students about their learning strategies. Grading only by means of final exams can have devastating effects on students learning. Research confirms that there is clear evidence between different approaches towards assessment and the quality of student learning. In order to enhance student learning, more developed models of assessment should be used, [1, p 186].

4. POSSIBLE IMPROVEMENTS AND CHANGES

The analysis of the classical teaching culture in engineering indicates that there is space for improvements. Three main problem areas were identified in the preceding chapter: The objective of this chapter is to look at possible improvements and changes to each one of these main problems.

5.1 Constructive alignment

With the Bologna process, all European universities adopted constructive alignment as the underlying model of teaching. Even engineering programs were asked to define learning outcomes, describe course activities, and think about assessment for the whole program as well as for single courses. The idea was to create transparency between these parts of teaching which together form the context in which students construct their knowledge, understanding, competence, skills and judgement.

The question that perhaps was not given enough attention is how a research field like engineering sciences that in its core and history belongs to realism can or should be taught according to constructivism. After all, realism and constructivism are in many aspects two rather contradictory epistemologies.

Engineering teachers who, like at Swedish universities, are sent to pedagogical courses need to become aware of this difference. Engineers might need to learn that there exist other epistemologies besides realism. And pedagogy teachers in higher education might need to consider the implications of realism in engineering sciences as well as in society.

At the same time, it is also important to note that the goal of undergraduate studies in engineering is not to educate scientists but engineers. Looking at the requirements for modern engineers and the goals for undergraduate engineering studies as discussed in chapter 2, the role of engineers today is mainly to work together with others in using technology and to solve technical problems within society. If one agrees that technology is an important part of our society and that, as a socio-cultural phenomenon, technology is being developed and used in relation to the values and needs of society (see [18]), one might also agree that the use and development of technology to a high degree is constructivistic.

As a consequence, the socio-cultural aspects of technology and its use should permeate engineering education programs. Not only should the teaching of theory and practical skills go hand in hand, it should also be embedded in a discourse on why or why not certain technologies were developed and used in relation to society. While humanities play an important role in such discussions, engineers have to take the main responsibility for leading them. If they do, they will also see that constructivism actually does play an important part in engineering, and constructive alignment will start to make sense. For the classical teaching culture in engineering, this means that theory and laboration should be taught with relation to project works that can be related to the society we live in. The courses should be given by a single teacher or by a group of equally engaged and prepared teachers. Instead of covering everything in the textbooks, students should be given the possibility and means to try out things for themselves, to chose between different tasks or to provide own examples in the area of their interests. Listening to the students, helping them in their learning so that they can fulfil the course objectives also means that the teaching should continuously be adapted and improved, even during a course, se [19, 20].

A proof that engineering education actually can follow constructive alignment are the CDIO engineering education programs. A closer look at the 12 CDIO Standards [11] shows that they can be grouped together according to the main topics in constructive alignment in the following way:

- Learning outcomes or learning objectives: Standards 2 and 3
- Course activities: Standards 4, 5 and 6
- Assessment: Standard 7

5.2 Assessment used to improve student learning and teaching

If an approach to assessment is chosen that tries to understand the processes and outcomes of student learning in order to improve teaching and student learning during the course, then final exams are questionable and even contradictory. Research shows that final exams can prevent students from deep learning and understanding. Instead, more developed models of assessment should be used. E.g. models, that help to detect misunderstandings early on and that monitor the students' deep learning and understanding. With more elaborated models of assessments students can be helped to learn more effectively, while at the same time giving the teacher feedback which can be used towards improving the quality of teaching.

Engineering education has one very important advantage that many other academic disciplines are lacking: everything that is being taught in engineering can be applied and demonstrated immediately! Engineering is applied science and should therefore be taught that way. The difference between a technician and an academic trained engineer lies in the degree of understanding of the underlying fundamental ideas. Very generally spoken, a technician is expected to learn how to use technology while an engineer should be able to explain and analyze it. Hence, for an engineer deep-learning and understanding is very crucial. This is why another kind of assessment than the one based on final exams should be used. If one looks at engineering working places, a good engineer is known as such without asking him or her to sit in a confined room for a couple of hours at the end of the month and writing answers to questions. Instead, their working situation provides various possibilities to show how much they can, for example when:

- working in interdisciplinary teams together with different engineers and with non-technical personnel,
- interacting directly with customers,
- they need to explain technical systems on different abstraction levels all the way from general overviews to technical details, orally as well as in writing, in different languages,
- they depend on documentations that other engineers have written and when they document their own work, and
- they have to understand and solve technical problems that they have never solved before.

One of the main requirements on engineering education is that it shall prepare the students towards a working life as engineers. A change of assessment models from final exams to something that would help students to become good engineers would therefore be appreciated. For more concrete information how to assess for understanding see for example Ramsden chapter 10 ([1, pg. 176-206]) and Brown and Glasner [9, 21-32].

5.3 Combining research and teaching

Most famous universities in the United States as well as in Europe and other parts in the world show a clear conviction regarding the importance that all of their academic staff including teaches carry out research. While some faculty members do more teaching or research at different times, there is always a common feeling of belonging to the same department. The separation of researchers and teachers at some departments creates two very different organizations in which staff-members no longer know each other and the exchange of ideas is being limited. The main reason for the separation is mostly economical. In Sweden, research has to mainly finance itself by means of external funding while teaching is financed by the state. Both "sides" are asked by the management to keep their budgets in balance which means that teaching researchers have to be paid from the teaching budget.

However, an economical separation of budgets does not necessarily imply an organizational partition. Researchers and teachers can very well work together on common tasks and projects within the same department. After all it is up to the management to determine how they want to organize the department. They could, for example, value the possible financial benefits or the possible synergies in resources of a unified department.

A report by Gabrielle Baldwin from the University of Melbourne illustrates how some universities work consciously towards combining teaching with research, see [15]. Baldin identified in her report nine principles to guide teaching and learning based on the convictions that "at higher education level, you cannot be a good teacher unless you are also a good researcher" and that "research, after all, is a form of learning". The list of identified principles contains the following items, all of which are explained in more detail in Baldwin's report, [15, pg 4]:

- drawing on personal research in designing and teaching courses,
- placing the latest research in the field within its historical context in classroom teaching,
- designing learning activities around contemporary research issues,
- teaching research methods, techniques and skills explicitly within subjects,
- building small-scale research activities into undergraduate assignments,
- involving students in departmental research projects,
- encouraging students to feel part of the research culture of departments,
- infusing teaching with the values of researchers, and
- conducting and drawing on research into student learning to make evidence-based decisions about teaching.

5. CONCLUSIONS

According to research on higher education there are six necessary (but not sufficient) principles for improving the quality of teaching in higher education. An analysis of these principles regarding the classical teaching culture in engineering has shown that 4 of these principles are more or less neglected. This means that teachers adhering to the traditional teaching culture in engineering cannot possibly obtain good or effective teaching.

Underlying reasons were identified in the view of knowledge as something objective and absolute, according to the epistemology of realism common in engineering sciences. Teachers at engineering universities see themselves rather as engineers, researchers or scientists than as teachers. This leads to a conflict between different epistemologies: hard-sciences such as engineering towards soft-sciences such as pedagogy. Research on teaching in higher education belongs to the epistemology of constructivism, where knowledge is regarded as something being constructed by students in their learning context. The role of the teacher becomes more like one of a coach who supports the student's constructive learning, for example by means of clear goals, continuous feedback and transparency between learning objectives, course activities and assessment. This is also known as *constructive alignment* which can be seen as an accepted standard for teaching in higher education today. In Europe, for example, constructive alignment is the underlying pedagogical framework of the so called Bologna process, the coordination of higher studies to promote and encourage student exchanges between European universities. As part of the Bologna process. all universities in Europe, including engineering education programs, were asked to adopt constructive alignment in their teaching. But as long as engineering faculty is “trapped” in realism without the awareness of the epistemological difference between engineering science and engineering education it is questionable if the classical teaching culture in engineering can ever be reformed. Instead, it might be more likely that new alternatives for engineering education, like for example the CDIO Initiative, will attract more and more participating engineering programs. The 12 CDIO Standards refer to and more or less include all of the six main principles for improving the quality of teaching while adapting constructive alignment. This means that teachers in CDIO engineering programs actually are given the chances to obtain good and effective teaching which are lacking in the classical teaching culture in engineering.

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Biographical Information

Gion Koch Svedberg is an associate professor at the department of computer science at Malmo University, Sweden. He got his PhD from the Swiss Federal Institute of Technology in Zurich, and has worked earlier at the department of computer science at Örebro University, Sweden as well as consultant within telecom and automatic control. His scholarly interests are the reform and modernization of undergraduate engineering programs.

Corresponding author

Dr. Gion Koch Svedberg
Computer Science Department
School of Technology, Malmo University
205 06 Malmö, Sweden
+46 40 665 7658
gion.kochsvedberg@mah.se