TEN YEARS OF CDIO – EXPERIENCES FROM A LONG-TERM EDUCATION DEVELOPMENT PROCESS

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ABSTRACT

The paper describes and analyses a long-term education development process – the CDIO-based reform of Chalmers University of Technology's M.Sc. in Mechanical Engineering programme. The initial goals of the reform programme and the changes that it has lead to are reviewed. The results of various kinds of evaluations – CDIO self-evaluations, external evaluations, student and faculty views and costs – are reviewed. A number of critical success factors for sustainable educational development process are identified.

KEYWORDS

CDIO, education development, long-term, critical success factors, mechanical engineering

INTRODUCTION

Education development is sometimes seen as a "project" where a reform is initiated and implemented during a period of a few years. However, one can also argue that the project phase should be seen as merely the start of a long-term development process, and that a large potential for improvement lies in the ability to sustain an enduring improvement process, resembling industrial continuous improvement approaches mastered by leading manufacturing firms such as Toyota.

In this paper, we examine such a case: In 2000, the M.Sc. Mechanical Engineering programme (the "M programme") at Chalmers University of Technology teamed up with programmes from The Royal Institute of Technology (KTH), Linköping University and Massachusetts Institute of Technology to form the Wallenberg CDIO project, which later evolved into the CDIO Initiative, which has many more participating universities [1][2]. This was the starting point for an education development process, which has now lasted for ten years, and comprised many changes including the introduction curricular, pedagogic and learning environment innovations. This reform thus provides a rich empirical base for a study of long-term education development.

Sustainable education reform can be viewed as a strategic process, which according to Lissack and Roos [3] can be maintained by continuously updating descriptions of (a) the current business (who are we and what do we do, our identity), (b) the vision (an image of the desirable future) and, (c) the strategic plan (important sub-goals and actions to reach the desirable future). Persistent changes are further strongly coupled to cultural changes. Such changes require according to Bennich-Björkman [4] agents inside the organisations, a programme for reform or at least some guiding principles, a structural opportunity when the organisation is weak, and changes to the explicit and implicit norms that govern the organisation.

We thus view long term education development as a strategic process governed by a continuously updated strategic plan, actions to realise the strategic plan, and with essential elements of cultural change. The literature on such processes is scarce. One notable exception is Edvardsson Stiwne et alia's [5][6] studies of students from Linköping University's Applied physics and Electrical engineering (Y) programme. They examined changes in student's perceptions of their education and future profession in the context of the Y programme's CDIO reform. However, they did not focus on describing curricular changes in detail nor on how the implementation of educational changes progressed. These aspects are focused in this paper.

Our general aims in this study are to bring forward experiences and knowledge from a long-term education development process. These, in turn, could constitute a base for proposing improvements in education development practice. In particular, the paper aims to:

- Provide a detailed account for a long-term education development process, highlighting aims and goals, changes made in order to reach these, important events, organizational structures, successes, failures, delays etc.
- Evaluate the result: in what way is the programme different and better today? Have the goals and intentions of the initial project been realized? Have the goals changed over time, and if so, how and why? How are the achievements measured? How do different stakeholders view the result?
- Examine how the M programme's development has affected reform of other programmes at Chalmers. What are the catalyst and barriers for spreading educational innovations within a university?
- Identify critical success factors for achieving a sustained programme development process over a long time period.

The remainder of the paper is structured as follows: We will first account for the research approach applied, followed by a description of the current design of the M programme. In a retrospective section, we revisit the starting point for the development: the M programme of 2000. We then account for the process up to the current date and summarise the future development plans for the programme. In the following section, we evaluate the outcomes of the reform. We start by reviewing the goals that were stated in the beginning of the CDIO project and assess ho well they have been fulfilled. Further, qualitative and quantitative evaluation data from CDIO self-evaluations, Swedish National of Higher Education evaluations, interviews with students and faculty as well as costs are reviewed. We then present a list of critical success factors for sustainable education reforms and wrap up the paper with conclusions.

RESEARCH APPROACH

As was stated in the introduction, our general aims in this study are to bring forward experiences and knowledge from a long-term education development process. Education development is a complex activity affected by a great number of dynamic factors and interesting phenomena; we have adopted a qualitative systems approach in the research. This approach requires a detailed documentation of the case and a rigorous data collection, in order to identify underlying factors, to minimise bias, and to increase the transparency of the observations made.

Here, the principle of multiple information sources has been adopted. Various documents have been studied, and individual and group interviews have been carried out to map out the progress, outcomes and perceptions of the process. The documents have included development proposals [7][8], the programme description [9][10][11], course syllabi [12], course evaluations, school year evaluations, budgets, external evaluation reports [13][14], CDIO self-evaluations and a number of papers that have been published during the development process. Two group interviews with students and three group interviews with faculty were carried out (6 student and 13 faculty participants in total).

It should be pointed out that the authors have played central roles in the development process, as dean of education, programme directors, education coordinator and as teachers. There is thus a risk that the results are perceived as biased in a positive direction. To some extent, this is mitigated by the inclusion of evaluation reports by external agencies and interviews with faculty and students in the analysis.

THE M PROGRAMME OF TODAY

This section reviews the current version of the programme, including the programme aim and idea, curriculum, learning environments and management processes. More detailed information can be found in the programme description [10] and at Chalmers' website [12].

The aim of the programme

The M programme aims at developing the knowledge, skills and competence required to participate in and lead the development and design of industrial products, processes and systems for a sustainable society. The programme also prepares for positions in other areas of the society where skills in analysis and processing of complex open-ended problems are of great importance. During the studies, the student shall be able to develop her/his personal qualities and attitudes that will contribute to professional integrity and to a successful professional life.

The programme idea

The vision of the M programme is outlined in the programme idea statement. It states that the vision of the programme is to offer a relevant, stimulating and advanced level engineering education with a holistic view, which emphasizes both engineering fundamentals and practice. The well-being of the students is in focus as well as the students' attractiveness for prospective employers. Programme characteristics are:

- The "main thread" of the programme is a holistic view of product and system lifecycle development and deployment.

- The introductory course of the programme provides a framework for the practice of engineering in product and system building and introduces the students to the engineering profession. The students participate in a small team project in developing a product and producing a prototype. A report is to be presented in writing as well as orally.
- The base of the programme is the fundamentals of mathematics and mechanical engineering with emphasis on common principles. This is achieved by having joint projects and assignments between mathematics and the basic courses in mechanics and strength of materials. The projects include the full view of problem solving, from selecting a model and setting up equations, describing the model to solving equations and simulating and assess quality of the choice of model and accuracy of the solution. The purpose of working with the full view, joint projects and the sequence of courses is that education and learning of a topic shall not be isolated in a specific course.
- Computer based tools for modelling, analyzing and simulation of real designs, products and systems are early introduced and utilized in the programme at an early stage.
- Fundamental engineering courses are introduced early in the curriculum to prepare the students for upcoming Design-Build projects where the assignment is to realize realistic and relevant products and systems. At least one project is included in the curriculum each academic year.
- Development of the students´ teamwork and communication skills is integrated in the courses with a distinct progression throughout the programme.
- Aspects of sustainable development are emphasized, and the focus is on product development and energy supply.
- The fundamentals of the programme together with the elective courses in the third year prepare the student for the concluding two years of study at the master's level in mechanical engineering as well as adjoining areas such as acoustics, industrial economy, mathematics and mechatronics.
- Teaching is partly executed in cooperation with industry through guest lecturers or teachers from industry. Student assignments, project management models and laboratory experiments are designed together with industry.
- The level of the education in the two years of study at the master's level shall prepare for doctoral studies (third cycle).
- The syllabus of the programme is continuously improved in cooperation with teachers, students, and administrators as well as in the advisory board where representatives from industry take part.

Curriculum

The M programme is a five-year programme divided into two cycles in accordance with the Bologna structure. The first cycle consists of three years of full time studies and corresponds to 180 credits (cr) and ends with the degree of Bachelor of Science. The second cycle is a two years (120 credits) international master programme. After completing both cycles the students is awarded the Swedish degree Civilingenjör as well as the degrees of Bachelor and Master of Science. Teaching at the bachelor level is generally in Swedish, while the teaching language in the master programmes is English in order to cater for incoming international students with Bachelor degrees.

The programme plan for the first three years of the M programme is shown in Table 1 (the year is divided into four study periods, quarters of eight weeks). The Design-Build-Test courses are marked grey and jointly taught projects between courses are indicated by grey ellipses.

Table 1
M programme plan for years 1-3

Year 1, Quarter 1	***Quarter 2***	***Quarter 3***	***Quarter 4***
Programming in Matlab 4.5 cr	Calculus in a single variable 7.5 cr	Linear algebra 7.5 cr	Calculus in several variables 7.5 cr
Introductory course in mathematics 7.5 cr	CAD 4.5 cr	Mechanics and statics 7.5 cr	Strength of materials 7.5 cr
Introduction to mechanical engineering 7.5 cr			
Year 2, Quarter 1	***Quarter 2***	***Quarter 3***	***Quarter 4***
Mechanics: Dynamics 7.5 cr	Machine elements 7.5 cr	Thermodynamics and energy technology 7.5 cr	Industrial production and organization 6 cr
		Integrated design and manufacturing 7.5 cr	
Material science 7.5 cr	Material and manufacturing technology 7.5 cr	Sustainable development 4.5 cr	Industrial Economics 4.5 cr
Year 3, Quarter 1	***Quarter 2***	***Quarter 3***	***Quarter 4***
Mechatronics 7.5 cr	Automatic control 7.5 cr	Bachelor diploma project 15 cr	
Fluid mechanics 7.5 cr	Elective 1 7.5 cr	Elective 2 7.5 cr	Mathematical statistics 7.5 cr

The first cycle (first three years) begins with the course Introduction to mechanical engineering, which serves as the introduction to the programme and to the role as a professional mechanical engineer. The course includes a team project. The assignment is to identify, define and solve an everyday problem and design and build a prototype for it. An example is a pizza cart holder for bikes. Lectures and exercises in teamwork and communication are integrated in the course. The students are then introduced to general aspects of communication, report writing and oral presentations. Moreover, an introduction to sustainable development is given and the link to product development and material selection is discussed.

Matlab is the general programming and simulation tool in the programme. The mathematical education is computationally oriented and focussed on engineering applications. It combines traditional symbolic mathematics with computational mathematics and programming in Matlab. Engineering applications are explored in computational exercises taught jointly with the courses in Mechanics and Strength of materials. Fundamental engineering courses such as Mechanics, Strength of materials, Materials and Machine elements are introduced early in the curriculum to prepare the students for upcoming design-build-test projects. In particular, the Finite Element Method is taught and used in the courses Calculus in several variables and Strength of materials.

In the second year the students' communication and teamwork skills are strengthened and practiced together with project management in the design-build-test project course Integrated design and manufacturing. The project task is taken from the industry. Relevant analyses are carried out using principles, knowledge and methods learnt in fundamental engineering courses.

The third step in the training of communicative and team work abilities is implemented at the end of the third year when the students complete their Bachelor thesis projects involving team work, report writing and presentations. Moreover, a minor course in theory and science methodology is integrated in the Bachelor diploma project.

The M programme students can choose between 14 different master programmes for the degree of Civilingenjör. Eight of the 14 approved master programmes are organized in close connection to the first cycle of the Mechanical engineering programme. This means that the programme management is responsible for content, level, quality, budget and study environment of both the first and the second cycle. The approved master programs are listed in Table 2. All master programmes include at least one team project. The master programmes admit both domestic and international students holding Bachelor degrees in mechanical engineering or similar.

Table 2
Master programmes approved for the degree of Civilingenjör in Mechanical engineering

Master programmes belonging to the M programme	**Other Master programmes approved by the M programme**
Advanced engineering materials	Engineering mathematics
Solid and fluid mechanics	Management and economics of innovation
Automotive engineering	Nuclear engineering
Industrial ecology	Quality and operations management
Production engineering	Sound and vibration
Product development	Supply chain management
Naval architecture	System, control and mechatronics
Sustainable energy systems	

Learning environment

The M programme has its own prototype laboratory and workshop. It consists of fully equipped metal and wood workshops, a mechatronics lab and a paper working area. The lab and workshop are fundamental resources used throughout the M program. The students build physical models or prototypes of their own designs, e.g., from the simple first year projects in the introductory course and the industrial solutions in the second year course Integrated design and manufacturing to a complete racing car in the fourth year Formula student course. All M programme students take a basic course in safety and handling of basic tools since it is required to be allowed to work in the workshop. More advanced workshop courses in, e.g. welding, operating of NC machinery, metal and wood shaping, are offered to the students. After taking these courses the students get licensed to operate the facilities in the workshop. The students are also allowed to use the workshop for private work during after school hours, and there is a student run organization, which is joined by those who are particularly interested in that.

The students together with the programme management have re-built and furnished the study hall and the cafeteria “Bulten”. The study hall is built and furnished to create a stimulating environment for studying and for social activities. It is very much appreciated by the students and frequently used from early in the morning to late in the evening.

Programme management

At Chalmers, a buyer-supplier setup is applied for managing the education. The programme thus "buys" courses from several departments to compose a programme. The departments are suppliers of courses. The head commissions courses from the departments through an agreement with the vice head of the delivering department. In the agreement, content, pedagogy and budget are specified. The most important reason for this "buyer-supplier" organization is to ensure that the multidisciplinary programmes are well composed and unified. The organisational structure further enables the programmes to optimize goals and content to meet the demands of the society rather than departmental considerations. Another reason is to separate the departmental economics from the economy of the programme.

The head of the M programme is responsible for the programme, including budget, overall planning and quality of the programme, as well as the study environment and the safety and health of the students. The goals of the programme are established through a continuous process lead by the head of the programme in collaboration with the advisory board, students and teachers**.** The students are very active in the running and the development of the program. The views of the students are considered very important. The program management and the students meet regularly.

Quality assurance system

The programme's quality assurance system follows a plan-do-check-act cycle. In short, the cycle consists of the following actions:

Plan: Establish programme description and course plans, Outline and confirm links between courses, outline cooperation and common projects between courses. Advisory board meetings, teacher meetings, student-program management meetings are the fora for discussing these issues.

Do: Teaching, learning and assessment in courses and projects.

Check: Course evaluations, class evaluations, follow-up of course delivery agreement, alumni survey, CDIO-self evaluation and benchmarking of the program, student results follow-up, study environment health and safety review and study social environment review are used to evaluate the state of the programme.

Act: Revision of the programme description and course plans, update course delivery agreement for next academic year

Each academic year starts with a meeting with the teachers, programme management team and student representatives. The agenda consists of last academic year experiences and feedback from each quality system, e.g. course evaluations, class follow-ups, students' results self-assessment, benchmarking and follow-ups of the annual agreement with the departments. The programme description is discussed and established. Links between courses and cooperation between courses are outlined and confirmed.

The major body for programme development issues is the advisory board of the programme, which consists of representatives from industry, students, Chalmers teachers and administrators connected to the programme. Meetings with the advisory board are held two to three times per semester. All strategic questions are discussed in detail at the meetings. Further, the programme content and the achievements of the students are discussed and analyzed regularly. A standing item at the meetings is the students' view on the education and the study environment.

An essential tool in the quality assurance system is the programme description. The programme has a CDIO-centred integrated programme description [9]. The programme description framework can be described as a template for programme development. It captures the programme aim, idea, goals, plan and it is shown in what courses the goals are fulfilled in a programme design matrix. The development of the programme description is the most important tool for the unification of the programme as well as for the design of courses and teaching activities. It generates a common terminology and helps to shift the emphasis on programme development discussion from specific courses towards high-level issues such as programme purpose, goals, idea and the teaching/learning of generic skills. Suggested changes can be put in relation to the goals of the programme.

The programme's quality assurance system further comprises a set of planning and evaluation tools including the agreements between programmes and department on courses deliveries, which specify course content, pedagogic, assessment, labs, etc. as well as course budgets are specified, course evaluations, alumni surveys, and CDIO self-evaluations.

THE TIME-LINE

Following this account for the current state of the M programme, this section provides a chronological report of the development, starting from the programme as it looked ten years ago and the initial goals for the CDIO adoption. We will then discuss the main events during the process, ending with future development plans. Figure 1 is referred to throughout.

Starting position

The development that is discussed in this paper started in January 2000 at a meeting at the Royal Institute of Technology (KTH) in Stockholm, Sweden. At the meeting, representatives from MIT, Chalmers, KTH and Linköping University outlined an application for funding of an education development project with CDIO as the basic idea [7].

Chalmers' M programme had then just graduated the first students from an earlier programme revision – M2000 – that aimed to prepare students for the requirements on engineers of 2000. Educational changes introduced in that revision included several project courses, engineering science already in year one and new profiles at the master level. Design was given a more prominent role in the education. However, the end results of the design projects were, with some small-scale experiments as exceptions, limited to paper and computer prototypes. We did not have the means to run design-build-test projects that went all the way from need to manufactured product, certainly not in classes with 150 students.

We were thus initially attracted by the CDIO idea because we thought that design-build-test projects was "the" missing element in our programme, the element that if included would lift the programme from good to great. Over time CDIO has evolved to a more comprehensive concept, but in 2000 we considered design-build-test experiences as it most distinguishing feature.

Main phases & events

The development can roughly be divided into three phases: CDIO planning, CDIO basic development & piloting, CDIO implementation & further development, see Figure 1.

<u>CDIO planning</u>

This first phase lasted from early 2000 to mid 2001. It comprised initial planning and culminated in an external review that was a requirement for the final approval of the major part of the funding.

During the CDIO planning phase, we stated an initial set of goals for the project, concretized the CDIO concept, made stakeholder surveys [15], and benchmarked our programmes against the CDIO syllabus [16]. We also introduced design-build-test experiences on a small scale. These were essential for demonstrating the CDIO concept to our faculty, and to achieve some short-term wins that are important for a successful change process [17].

<u>CDIO basic development & piloting</u>

The phase of the development lasted from mid 2001 to Fall 2004. During the period CDIO learning experiences and workspaces were developed and successively deployed into the programme. Major efforts included the design and construction of the prototyping lab, the design-build-test learning experiences that use it, and planned learning sequences for integrated learning of teamwork and communication. Early results included design-build-test projects in for the first [18] and second year of studies [19].

In 2002, Chalmers decided to adopt a Bologna-inspired 3+2 education structure, with the last two years consisting of Master programmes taught in English. The reform brought on changes also in the Bachelor part of the programme. As a consequence, the transition to a CDIO and 3+2-based programme became tightly coupled. The new education structure was introduced in 2004. Students from this cohort are the first M programme students that followed a “complete” (but not “final”) CDIO programme.

By 2004, the programme had the basic tenets for running a CDIO programme in place: the learning environment, the key courses, the staffing.

<u>CDIO implementation and further development</u>

In the next period (2004-2008), the M programme implemented, evaluated and refined the basic elements of its CDIO concept. Simultaneously, a number of development activities were carried out: a mathematics course emphasizing modelling and simulation using MATLAB [20], a planned learning sequence for sustainability [21], a further developed 2nd year design-build-test project course, refined programme goals [9], a new bachelor thesis project course [22], and education in English on the master level.

During this period, the M programme was twice evaluated by the Swedish National Agency for Higher Education. The first evaluation was the 2005 national evaluation of all of Sweden’s Civilingenjör programmes [13]. The second was an evaluation of appointment as a Centre of Excellent Quality in Higher Education in 2008 [14].

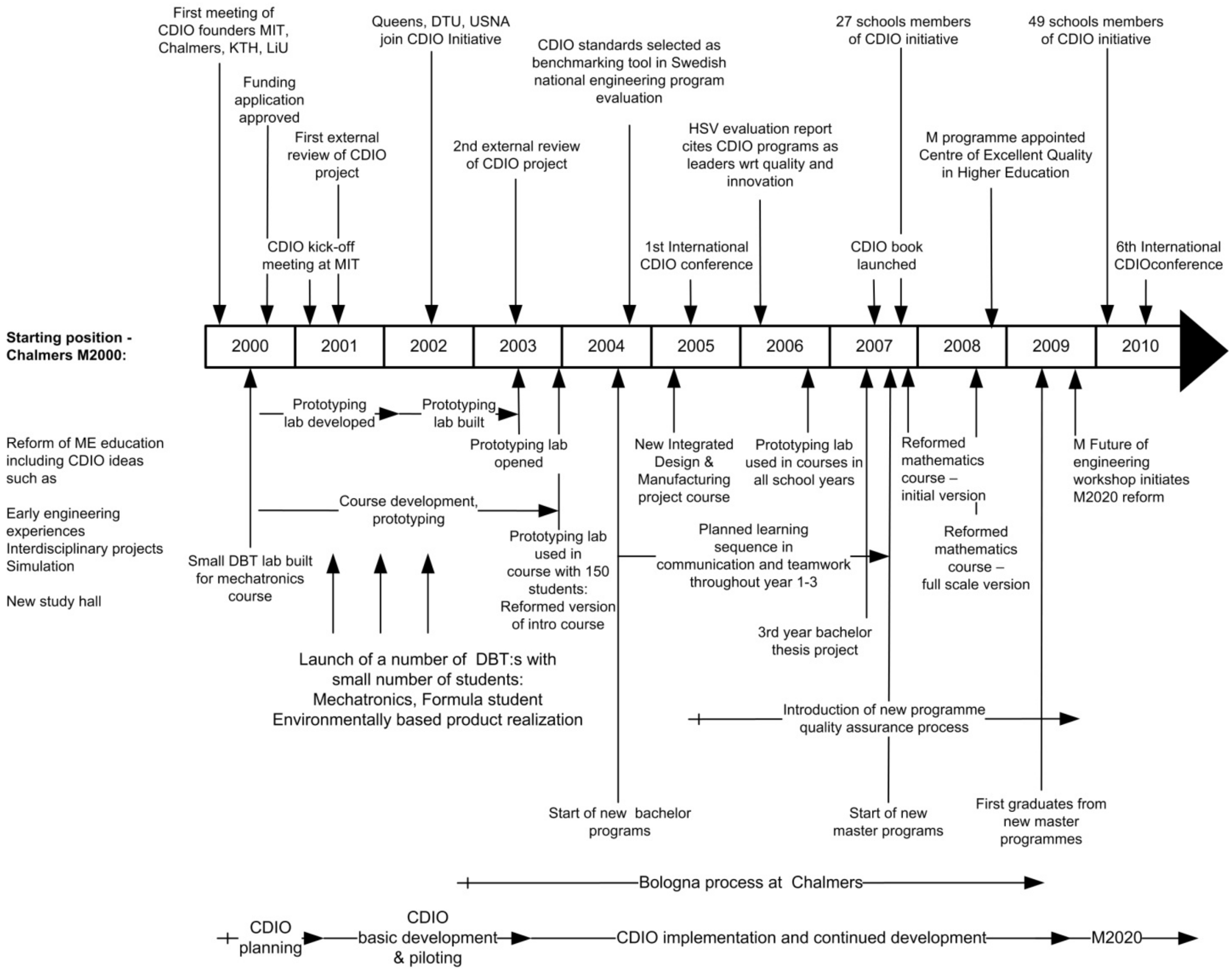

Figure 1. Time-lime for Chalmers M programme evolution.

During this phase, ideas from CDIO were to some extent spread to other Chalmers' programmes. For example, the adaptation to the Bologna process at our university meant the start of 44 Master programmes and it was agreed upon that the CDIO model provided structured tools applicable for programme development and for writing programme descriptions. The programmes were required to write detailed programme goals, and to use programme design matrices were also created to demonstrate that the programmes addressed their goals [23]. This adoption essentially focused on CDIO as a tool for systematic programme development. Some programmes embraced the content components of CDIO, e.g., design-build-test projects courses, whilst others chose not to.

Recently, Chalmers' Computer, IT and Electronic engineering programmes started a reform of their programmes and much of the pedagogical concept that they have chosen to introduce is inspired by CDIO, and by the M programme.

In parallel with the completion of the CDIO implementation, the programme realized that it needed to find new challenges and improvement ideas, in order to continue a positive development. It was decided to create a new vision for the programme based on the requirements on engineers graduating in 2020.

Future plans for the M programme – M2020

As a result of the recognition as Centre of Excellence in Higher Education 2008 [14], the M programme was given an opportunity by the Chalmers' presidency to further develop. To set up the direction for the developments the program management together with the advisory board arranged a two-day workshop *Shaping the Future of Mechanical Engineering Education at Chalmers* to discuss the requirements on an M engineer graduating in 2020 and to create a road map for the program [24]. The workshop comprised expertise in engineering education from academia, industry, trade and government from Asia, Europe and North America together with teachers and students from Chalmers.

The panel suggested directions for the long-term program content and stated that teaching methods need to be reformed. The programme vision needs to be updated to match the requirements on an engineer graduating in 2020. The role of the teacher will be transferred to more of leading a dialogue with students than a traditional lecture giving traditional lectures. The panel argued the need to make the education more efficient and to use interactive learning and assessment to a larger extent. The curriculum needs to be more flexible in order to accommodate changes. New technologies and materials (e.g., micro/nano, bioengineering, IT) must be included in the curriculum and used in design-build-test projects. The process of integration of sustainability issues in the curriculum needs to be continued and extended. The projects based education needs to be further developed to include more training of creative abilities, innovation and entrepreneurship. The process of integration of sustainability issues in the curriculum needs to be continued and extended. The panel concluded that the engineers of 2020 need to be broadly educated with specialists skills within an narrow field and be able to take leadership in the transfer to a more sustainable society. Further, they need to be well prepared for the global labour market and the global competition.

The work with the long-term development of the program is running as an active project with strong involvement of the advisory board and the students. An international review committee is appointed to monitor the program's progress and to provide advice and feedback,

In the short term, the program develops according to a continuously improvement philosophy based on CDIO. Intellectual properties rights will be regarded as a generic competence taught in integrated fashion in the project courses. A new CAD course will be launched next semester. The course includes a complete design chain, from sketching, 3D modelling, drawing and creating data as the basis for rapid prototyping to produce a physical model. The material science and manufacturing technology courses are being re-designed. The new courses will have a product focus and thus be more integrated in the program. The sustainable development education is strengthened through a separate course that includes more about materials selection and lifecycle analysis. The course will be strongly connected to the second year Integrated Design and Manufacturing project course. Further a plan for more distinct integration of sustainability issues is under development. The mathematical education is continuously improved and the cooperation between fundamental mechanical engineering courses is strengthened. Next semester will the first year mathematical course use a virtual learning environment for training, exercises and tests. The emphasis is thus made on individual work of the students complemented by teaching support in computer labs.

EVALUATION

In this section, we summarise data from a number of evaluations that the programme has undergone during the period.

The original goals and their fulfilment

As described above, the programme began its CDIO reform in 2000-2001 with planning and some pilot experiments. The bases for these activities were two: The first was the then-current state of the programme where the M2000 reform had led to the introduction of early engineering experiences and more projects and new profiles. The second basis was the CDIO concept as it was described at the time. In the original project proposal from 2000 [7], the three basic goals of CDIO are identified along with four areas that need to be addressed in order to meet these goals: curriculum, pedagogy, assessment and workshops. In the proposal, some sub-areas to the four main areas are identified, but the only codified element of the CDIO model that existed at the time was the CDIO syllabus [25].

The original goals for the M programme reflected the opportunities in the CDIO project (with its large initial amount of funding) to realize certain ideas of the M2000 reform that were not realizable then due to financial constraints. Focused goals included the introduction of design-build-test learning experiences and the physical infrastructure to support them. Table 3 summarises the CDIO “model” of 2000 and the M programme’s planned efforts to realize the goals, as described in the original proposal [7] and a follow-up proposal [8], and the achievements to date.

From Table 3, and the description of the programme’s evolution since 2000, it can be noted that many of the original goals have been met and are now key features of the programme, including design-build-test experiences, the prototyping lab, and early engineering experiences.

Some original goals have not been met, notably some that related to technology. The IDE studio was envisaged as a state-of-the-art virtual engineering lab, enabling video-conferencing collaboration between geographically distributed student teams. However, the technology was not mature when the studio was opened (2003) and the experiments were not successful. The studio was subsequently closed. We also failed to find teacher who were interested in applying the electronic system for in-class feedback in their courses. The system was therefore not acquired.

Some goals have been realized but took longer time than planned. These include the construction of the prototyping lab and the reform of the mathematics. The first was due to a rent conflict between Chalmers and its landlord. The second was due to that we first failed to find a mathematics teacher who was interested in reforming the mathematics courses.

It is further noticeable that several elements have been added to the CDIO reform (noted as accomplishments for which the mid-column box is empty): These include key features of the M programme today that have been implemented after 2000 (e.g., the systematic programme design, integrated learning of communication and teamwork, sustainability, programmatic assessment) were poorly visible both in the CDIO model anno 2000 and in the M programme’s plan of that date. An important factor is that the knowledge and skills needed to develop these elements have emerged as a result of CDIO project, rather than planned from the start.

Table 3
An early version of CDIO "model", the initial goals of the M programme, and the main achievements during the process

CDIO model 2000	**Initial M programme goals**	**Main accomplishments**
Curriculum - CDIO syllabus - Early engineering experiences - Disciplinary linkages - Design build experiences - CDIO skills education	Benchmark goals and curriculum against CDIO syllabus	Benchmarking reported in [15] and [16]
	Develop sequence of design-build experiences	Design-build-test learning experience sequence stretching through all year developed
	Develop course in systems engineering	Not accomplished
	Early engineering experiences	Reformed introductory course
	Link courses in mathematics and engineering science	Collaboration between courses in mathematics, mechanics and strength of materials
		Systematic approach for programme goal-setting and design developed and applied [23]
		Own computation oriented mathematical education with focus on applications developed [20]
Teaching & learning methods - Concrete and hands on learning - Problem formulation - Active learning - Feedback - Pedagogic scholarship - Faculty skills	Introduce mud cards techniques	In use in some courses
	Study teaching & learning in large groups	Accomplished
	Develop courses for faculty in CDIO skills	Courses in group dynamics and project work model arranged
	Active, problem formulation focused learning of mathematics	Matlab introduced, accepted and used as general simulation tool
		Planned learning sequence for integrated learning of communication and teamwork
		Integrated learning of sustainability
Assessment - Clear and measurable disciplinary goals - CDIO skills assessment - Creative skills assessment - Programmatic assessment	Develop methods for assessing creative skills	Creative aspects are assessed in design-build-test projects but no common method has been adopted
		A comprehensive programme quality assurance system has been developed and introduced
		The programme advisory board has taken a very active role in programme development and follow-up
		Programming courses with final examination on-line in computer lab
Workshop - Browsing laboratories - Sharing of research laboratories - System/product realization labs	Develop physical prototyping lab	Achieved, and used in many courses
	Develop IDE studio	Studio was built but failed to meet expectations
	Utilize electronic system for in-class feedback	Not accomplished

The effects of the reform programme and indications of its quality are also evidenced in high-level success indicators such as:

- The industry is contacting the programme for cooperation as well as for hiring students
- The highest number of first priority applicants of all mechanical engineering programmes in Sweden
- Comparatively low number of student drop outs from the program
- Comparatively high rate of completed degrees
- Teachers interested in pedagogy, course development and reforming education are looking to the programme and are eager to teach and participate in the development of the program
- Recognitions for high quality from alumni, industry, universities all over the world, the engineering union as well as the employers' associations
- The high and recognized quality of the proposed solutions in project courses including the reports and presentations

Internal evaluations

Below, we will discuss results from the internal quantitative evaluations that we have conducted during the period: a set of CDIO self-evaluations and an alumni survey.

<u>CDIO self-evaluation evolution</u>

Throughout the period, the CDIO self-evaluation tool ([1], chapter 9) has been used regularly to monitor, guide and visualize the evolution of the programme.

A CDIO self-evaluation implies a valuation of the programme's status vs. fulfilling the twelve CDIO standards. A five-level rating scale ranging from 0-4 is used. A "0" implies that there is no implementation of the standard, whilst a "4" implies that there is a complete programme-level plan for the standard, that it is comprehensively implemented and programme and course level, and that the implementation has been evaluated and improved.

Table 4
Progress of M programme CDIO self-evaluations during the period 2000-2010

Standard		2000	2003	2005	2008	2010
1	CDIO as context	2	2	4	4	4
2	CDIO syllabus outcomes	1	1	2	4	4
3	Integrated curriculum	2	2	3	4	4
4	Integration to engineering	3	4	4	4	4
5	Design-build experiences	1	3	4	4	4
6	CDIO workspaces	1	3	4	4	4
7	Integrated learning experiences	2	2	3	4	4
8	Active learning	1	1	3	3	4
9	Enhancement of faculty CDIO skills	1	1	2	2	2
10	Enhancement of faculty teaching skills	1	2	2	3	3
11	CDIO skills assessment	2	2	3	3	3
12	CDIO programme evaluation	1	2	3	4	4
Average		1.5	2.1	3.1	3.6	3.7

The ratings for the M programme at different points in time are shown in Table 4. Initially, the programme's fulfilment of the CDIO standards was low. For many of the standards, the rating was "1", which should be interpreted as that some experiments and pilots were already on-going, but there had not been a systematic attempt to adapt a set of principles for education design. The highest rating was given for standard 5 – Introduction to engineering. Such a course had been developed as part of the M2000 reform programme.

In the first few years, a major focus was the development and implementation of a set of design-build-test learning experiences and the prototyping lab, as is indicated in the higher ratings for standards 4-6 from 2003. In the period 2003-2005 there was an additional focus on integrated learning of communication and teamwork skills. Programme context, goals and quality system were implemented in 2005-2008. During the last period of the chart (2008-2010) assessment of CDIO skills has been focused.

The chart also highlights some areas in which the programme has not been able to reach the requirements for a "4" rating – essentially standards 9 and 10. The standards relate to faculty competence. In the buyer-seller system that Chalmers applies, faculty competence is the responsibility of the departments. The programmes thus have limited powers to influence hiring and promotion.

One of the programme's major development efforts during recent years is the implementation of a set of computer-based mathematics courses. This effort has been substantial but only influences the "active learning" standard (8). This aspect, and the circumstance that the standards only have five levels and thus the rating tends to plane out even though improvements are still made indicate the need to complement the CDIO standards self-evaluation with other methods if the method is to fulfil its purpose, i.e. to guide and visualize the evolution of a programme.

Alumni survey

If a CDIO-based programme is effective, the results should ultimately be discernable in alumni surveys that students complete some years after graduation. A fundamental problem with using alumni surveys to evaluate education reform is the time lag. The first M programme students who have gone through a "complete" CDIO programme graduated in 2009, and Chalmers will not survey their views on their education until 2012. Below, we will discuss data from Chalmers' alumni survey from 2009 that was sent to students who graduated in 2006 [26]. In our case, students take on average 5.7 years to complete their degree. This means that many students who graduated in 2006 commenced their studies prior to the CDIO project. However, as CDIO learning experiences have been phased in across all years of the programme, they will have undergone at least a partial CDIO programme. It is therefore likely that they have been affected by the CDIO programme, and it is relevant to examine if any measurable effects can be found in the alumni survey.

Chalmers' alumni survey comprises about 40 questions related to the background of the respondent, first job, current job, the importance of the respondent's education for the job, the respondent's views on his/her education, and a self-evaluation of his/her knowledge and skills in the areas of the education. On an overall level, the alumni survey shows that Chalmers' graduates are satisfied with their education and that their employability is very good. As strong points of their Chalmers experience, they typically point to specific courses, along with the breadth of the education. As areas in which Chalmers can improve, the survey respondents point out contacts with employers and teacher's pedagogical competence.

Tables 5 and 6 present some of the alumni survey data where the responses from graduates from the M programme are compared with those from the average from all of Chalmers Civilingenjör degree programmes. Table 5 shows the responses to a question in which the respondents were asked to provide a self-evaluation of their knowledge and skills related to a number of goals for the education. Table 6 shows how satisfied the graduates were with their Chalmers education. A scale ranging from 1-10 is used. For many of the attributes, the M graduates are similar to those of other Chalmers graduates. However, there are some dimensions for which the differences are significant including teamwork, communication, contact with employers, and to some degree design. These are dimensions that are targeted by the CDIO approach.

It remains to see if these differences are robust over time. An uncertain factor is how the overall experience of a CDIO programme can be discerned in the presence of major external variations, e.g., the business climate. However, the results from our alumni survey are principally similar to those from other CDIO programme-level evaluations, for example Linköping University's longitudinal survey of the CDIO project and their Y programme [6]. The alumni survey further provides a basis for evaluating if the goals of the CDIO reform are relevant by alumni. This seems to be the case: When asked "What can Chalmers improve?", the most frequent answer is "contacts with industry". When asked if they missed something in their education, the most common subjects are economics, project management, organization and leadership. At the same time, when asked what could be removed to make place for other subject, the most common answer is "nothing". This is a clear illustration of the need for dual learning, where subject knowledge and professional skills are co-developed. From Table 5, it seems that the M programme is able to strengthen the learning of professional skills (teamwork, communication, design) without compromising the learning of subject knowledge (mathematics, science and disciplinary knowledge). Again, it must be emphasized that the data is still very preliminary and given by graduates from a partial CDIO programme.

Table 5
Self-evaluation of alumni's knowledge and skills
(Only a subset of the surveyed knowledge/skills is displayed. Discipline-specific knowledge refers to engineering knowledge in the discipline of the programme, e.g. electrical engineering)

Knowledge/skill	**Mechanical engineering graduates**	**Average for all Chalmers Civilingenjör graduates**
Mathematics	7.1	6.9
Science	7.1	6.9
Discipline-specific knowledge	7.7	7.4
Design	7.2	6.8
Teamwork	7.7	7.1
Communication	7.5	7.0

Table 6
Alumni survey respondent's evaluation of their Chalmers education

Attribute	**Mechanical engineering graduates**	**Average for all Chalmers Civilingenjör graduates**
Overall satisfaction	7.8	7.6
Employability	8.6	8.3
Contacts with industry	5.4	4.5

Faculty perceptions - Catalysts and barriers for spreading CDIO to other programmes

In order to identify faculty perceptions of CDIO, loosely structured group interviews were performed with three groups of faculty:

- Members of Chalmers' university-wide pedagogy committee. These persons have not taken part in our reform, but have a strong interest in pedagogy.
- Leaders from the group that are currently reforming Chalmers' Computer, IT and Electronic engineering programmes. This basic ideas of this reform are CDIO-inspired, but the design of the programmes is not finalized at this time.
- Faculty members from the mechanical engineering programme who had taken part in the CDIO reform and are active teachers in the programme.

All interviewees were queried about their perceptions of CDIO and asked to point out catalysts and barriers for its adaptation.

A common response from all interviewees was that the perceived focus of CDIO on the professional role of engineers is the most important catalyst for its adaptation. "- *CDIO forces us to reflect on what the respective profession looks like*".

Further, the interviewees emphasized the value of the strong structure of CDIO, pointing out that even though they had projects of industrial relevance and a pedagogical aim before, CDIO helped substantially with process and structure issues; e.g. creating an organized set of learning objectives and providing a language for faculty to communicate about the programme and its goals and content. The pedagogy committee members pointed out that the structure of strategy of CDIO facilitates the integration of learning of generic competences in the curriculum.

The programme leaders from the programmes currently under revision appreciated the notion of CDIO as a toolbox of relatively independent parts, from which certain parts could be picked and adapted, whilst others were not chosen.

The pedagogy committee members, however, also pointed out that the strong structure could have negative associations, implying a top-down programme design that would constrain the autonomy of individual faculty members. However, the programme leaders did not see this as such a barrier. These contrasting statements reflect a critical issue in successful programme development – the need to have a strong programme level to be able to integrate non-disciplinary knowledge and skills in the curriculum, but also the need to provide the faculty with a sense of ownership of the programme.

Another barrier for the adaptation of CDIO is constituted by the interpretation of the CDIO concept in the disciplinary context of the programme. The pedagogy committee members, in particular, pointed out that when an idea is labelled, like CDIO is, there is a strong risk for introducing a variety of misconceptions. It can be brought together under the expression "CDIO of what?". The definition of "the product" of the programme can be difficult to agree on as well as the conceive-design-implement-operate process. There is a barrier in reaching agreement on this fundamental viewpoint of the education: Programmes with a strong emphasis on preparing for a research career may have serious objections towards the forwarded position of "design" that has motivated much of the CDIO reform. The mechanical engineering faculty interviewed had also experienced this ambivalence towards CDIO. For product development and automotive CDIO was more or less tailor-made and did not infer a need to change attitude. However, there were faculty who disliked CDIO from the start, especially those who wanted to emphasize the specialist role and competence of the graduating engineers higher than generalist skills needed to view their subject in a new manner.

The general opinion of the interviewed mechanical engineering faculty was that faculty was as a whole content with the reform. In particular, the reform was appealing for those who were interested in pedagogy. For example, the Standards raised the pedagogical awareness. "- *I learned that it was about what the students do, not what I do*". They suggested that students of today act much more engineering oriented.

The mechanical engineering faculty suggested that the main barrier for the CDIO reform was that teachers needed to work in a new manner, differing from their earlier experiences. "- *But our faculty have not been working engineers, that is probably a reason why they are hesitant*".

They further identified a number of pedagogic challenges: e.g., regarding how to act in project based courses; to differ between success in learning and success in project task*: – "they work so hard in the project that they do not even buy or read the course literature".* They concluded the discussion by agreeing that many barriers were linked to pedagogical improvements known to be difficult already, but the CDIO reform had officially problematized the issues. –*"Before you did your written exams and was content with that".*

The results from the faculty interviews can be summarized as follows:

Catalysts for CDIO adaptation:

- An engineering concept with the profession as the core focus for the education
- The structured education concept
- The strategies for integrating generic competences into the education
- The toolbox, CDIO contains many parts that can be used independently

Barriers for CDIO adaptation:

- The structured CDIO education concept implies a stronger programme level and a top-down perspective
- Interpretation and translation issues. CDIO is a comprehensive model with risks for differing perceptions and misconceptions
- Programmes and faculty members that are strongly oriented towards preparing for a research career or an analytical profession may feel that CDIO lacks appreciation of analysis.
- CDIO involves significant changes for both teachers and students.

Student experiences and perceptions

A structured group interview with six (four male and two female) third year students at the M programme was performed. The interview was focussed on evidence of CDIO, general and professional skills.

In general the students were very satisfied with the M program. This is also verified by a recent survey about the study environment. About 95 % of the students declared that they were very satisfied or satisfied and less than 5% declared that they were not so satisfied or not satisfied at all. They pointed out that an environment conducive to studies and social activities are of highest importance for a successful programme.

The students related CDIO strongly to the design-build-test project courses and the fact that they make use of their fundamental skills and competences in mathematics and mechanics. The students found the project courses important, relevant and stimulating. They stated that the courses add realism to the education and that they train their creative abilities in a natural manner. Further, the courses connect theory to practice and enforce the students to utilize and practice knowledge and skills from earlier fundamental engineering courses

The students strongly appreciated the strong link and progression between the courses but pointed that if one course fails, the consequences in following courses may be severe. The students also pointed out that the strong focus on project courses and the continuous assessment and grading in the courses make the students work very hard and sometimes to hard. They may put less effort on the course taught in parallel and experience high pressure and stress.

The students expressed that they are well trained in and prepared for work in teams. In multidisciplinary projects with students from other engineering programmes they have noticed that they are much better prepared to work in teams. Consequently, they had noticed that M students take leading roles in such projects. The students expressed strong confidence in their report writing skills and considered it as a natural component in the learning process.

The students considered it natural to use the computer and programming in the basic course of mathematics. The students showed a very positive and constructive approach to mathematics. The students further stated that they had had use for all mathematics taught in later courses and projects. They appreciated the training in solving more open general problems rather than repeating known solutions to very specific problems. They strongly felt that the M programme's mathematical education prepared them better for studying advanced level M courses as well as for their professional careers as engineers. They saw their mathematical education as a natural part of their CDIO based mechanical engineering education.

The students expressed strong support for the continuous improvements philosophy of the program and the strong and active student involvement.

Finally, the students showed much self-confidence and had high expectations on their upcoming master's programmes. They strongly believed that the CDIO based M programme have prepared them well for work as a professional engineers as well as for research studies within the field of their specialization. Further, they think that their employability is very strong because of the CDIO-based education.

Costs

A typical issue in the investigation of a CDIO-based education is that of cost. There are concerns that a CDIO-based education is prohibitively expensive, both in terms of initial investment costs and in terms of operating costs. Indeed, a CDIO programme requires certain learning environments and some courses will be more teacher-intensive and thus more expensive. However, earlier research has indicated that there is a wide range in costs for design-build-test project courses, from 1.0 to 1.8 of that of an average course at the institution in question [27]. In our case, we had the benefit of external financial support for a major part of the initial investments. Investments after the first five-year period and operating costs through the whole period have been financed via our regular budget through redistribution of money.

<u>Investment costs</u>

The investments in the Chalmers M programme case can be split into physical infrastructure and programme and course development. The physical infrastructure investments were mainly to (a) a prototyping lab and (b) a "study hall" for individual and group studies. The latter was not technically part of the CDIO project but is included here as it fills a role that otherwise would have been important for the CDIO project to address, namely that of socializing workspaces for students [28]. Table 7 summarises our investment costs.

<u>Operating costs</u>

The operating costs for the prototyping lab and the more teacher-intensive CDIO courses have throughout been covered by the programme's ordinary budget. These costs can for 2010 be estimated to 4.3 MSEK for the prototyping lab and 1.2 MSEK redistributed money to teacher-intensive courses, totalling 5.3 MSEK per year. These costs need to be related to the overall budget for the programme. The programme has about 1100 full-time students. For each student, the Swedish government pays approximately 91,000 SEK. Chalmers total income for the programme is thus about 100 MSEK. From this amount, about 30 % is allocated to central costs (administration, IT, certain facilities costs etc). The programme thus has about 70 MSEK at its' disposal to buy courses from departments. In conclusion, the programme finances its CDIO workspaces and activities by re-distributing about 8 % of its total budget, as compared to a programme that would not contain any CDIO elements at all.

Table 7
Investment costs for CDIO reform of Chalmers mechanical engineering programme.
All numbers are in MSEK. 1 SEK = 0.139 USD / 0.103 EUR (March 26, 2010).

Time period	**Physical infrastructure**		**Programme and course development**	**Total**
	Prototyping lab	**Study hall**		
Period 1 (2000-2005)	9.8	10	7.2	27
Period 2 (2006-2010)	1.5	-	3.1	4.6
Total	21.3		10.3	31.6
Average	2.1		1.03	3.16

External evaluations

In 2005/2006 the Swedish National Agency for Higher Education (HSV) evaluated all Swedish five-year engineering programmes (Civilingenjör programmes) [13]. The evaluation was based on the CDIO principles. The National Agency concluded that CDIO is a favourable model for engineering education and a tool for developing and reforming educational programmes. The evaluation process consisted of a self-assessment and a site visit. The M programme was highly appreciated in the evaluation. In particular, the work with the CDIO based program description with the connection between the programme goals and the learning outcomes of the courses and the integration of general engineering skills were recognized as outstanding and inspiring.

In 2008 universities and other institutions for higher education in Sweden were invited to apply to the Swedish Agency for Higher Education for recognition as Centre of Excellence in Higher Education. Internally, the presidency at Chalmers pointed out its M programme to apply for the recognition, which resulted in an application from the programme [11].

The applications were evaluated by an international expert panel. Following the evaluation three applications were chosen by the National Agency for detailed assessments and site visits. In conformity with the expert panel's proposal, the National Agency appointed the M programme as Centre of Excellence in Higher Education 2008 [14]. The National Agency and the expert panel appreciated in particular:

- The Chalmers ''buyer-supplier'' organization,
- The strong and devoted management team and advisory board,
- The study environment,
- The elaborate quality assurance system,
- The strong teaching and the support of the students' learning processes,
- The strong involvement of the students in the running and development of the program,
- The integrated curriculum structured around learning outcomes and competences with emphasis on professional skills as well as fundamentals (CDIO) and,
- The close links to industry and research.

Finally they conclude that over time, the concepts of integration, a holistic view, and system as well as process thinking have become best practice through a focus on design-build-test projects following the CDIO model and the combination of this with the organisational structure and systematic quality system.

Discussion

This section has brought together the evaluation data that we have gathered over the period. We can argue that the main goals of the reform have been met, but perhaps more importantly, that new goals have emerged during the process. The sources for these new goals are both a more in-depth understanding of the CDIO concept and internally initiated initiatives, such as mathematics reform and sustainability. The emergence of new goals and elements during the process is characteristic for a sustained education reform, characterised by continuous improvement over a long time period. The views from government agencies, faculty and students provide support for a claim that the programmes holds a high quality, has evolved positively over the period, and that it has influenced other programmes at Chalmers. Some barriers to adaptation of CDIO are also identified.

CRITICAL SUCCESS FACTORS FOR SUSTAINABLE EDUCATION REFORM

This section aims to synthesize our experiences and proposes a set of critical success factors for sustained education development. A critical success factor (CSF) is the term for an element that is necessary for an organization or project to achieve its mission [29]. The set is based on the lessons that we have learned over time combined with recommendations from the literature, including Kotter [17], Crawley et al. [1], chapter 8 and Lissack and Roos [3]. The critical success factors are summarised in Figure 1. Let us now discuss these starting from the top.

Clear purpose, goals and strategy. A programme needs an identified purpose in order to be able to elaborate clear goals and to be able to create and communicate strategies for addressing those goals. A CDIO programme has a stated purpose in educating future engineers who can take leading roles in the conception, design, implementation and operation of products, processes and systems. Clear purposes, goals and strategies are also essential for shaping and discussing the identity of the programme.

Ability to continuously set new challenging goals. However, clear goals are not enough to drive a sustained education development process. Initial goals will at some point be met, and the programme will need to find new goals to direct a continued development. This is particularly challenging for a successful programme, where there is no crisis that can be used to motivate a change. Aspirational goals need to be set. This is in line with Lissack and Roos [3], who argue that a good strategic process is cyclic, continuously revising goals and actions. The ability to set new goals also hinges on openness to the outside world as a source for ideas and benchmark.

Strong programme level. Given the goals and strategy, the next step is system-level design. An engineering programme needs to form a coherent whole and address goals for disciplinary knowledge as well as generic skills. A strong programme level is essential for designing in multidisciplinary topics in the programme, and for resolving conflicts between different disciplines. A strong programme level is also essential for monitoring the programme as a whole.

Well-defined and motivated changes. A programme will during a long-term development process undergo many changes, as is illustrated by the M programme. One by one, these changes need to be well-defined, delimited and anchored in the overall strategy.

A purposeful quality assurance system. A quality assurance (QA) system that monitors and guides the development of the programme is essential. The QA system further needs to be designed so that it measures the intended development. For CDIO programmes, the CDIO standards self-evaluation tool is a central part of the QA system. However, it needs to be complemented with other tools in order to obtain a comprehensive view.

Continuity and multi-year perspective. Many of the changes implemented in the M programme have taken three years or more to design, implement and refine. Long-term change processes require a degree of stability with respect to rules, organisation and staffing. The programme management and the faculty involved need to be aware of the time perspective of the change and not to view the effort as a one-off, nor their engagement as short-term. Over time, the faculty involved in the M programme have also come together as an effective cross-departmental team. This facilitates the introduction of new education innovations that require collaboration between courses and a willingness to take responsibility for programme goals that lie outside of the disciplinary aims for a specific course.

Faculty competence development. Many of the educational changes implemented in the M programme rely on faculty competence that was not available in the start of the project. New and changed faculty competence needs range from the professional (ability to run design-build-test projects) to the multidisciplinary (sustainable development) to the pedagogical (active learning methods). In this context, there is a risk that the reform becomes dependent on a few teachers with critical competence. If one of those teachers leaves the university, there may be no one left who can take on the course. A comprehensive plan for faculty professional competence will provide more teachers to take responsibility for, for example, integration of sustainability aspects in the courses, making the programme less vulnerable.

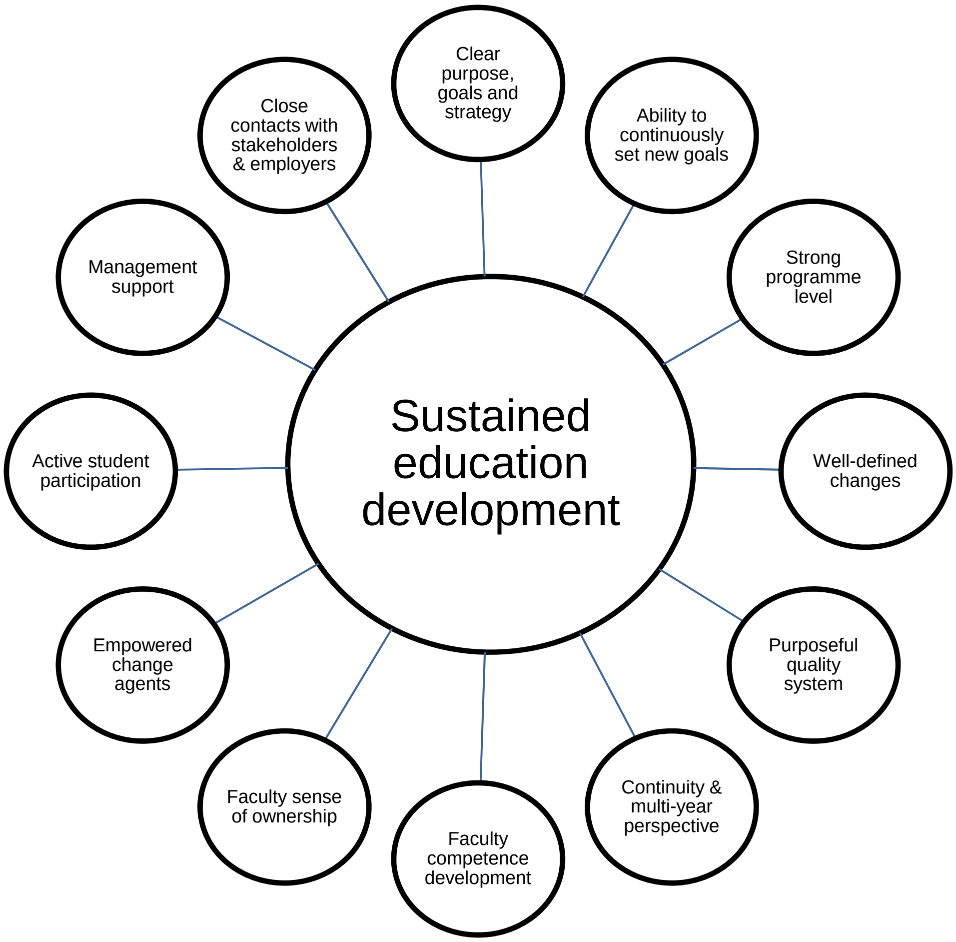

Figure 1. Critical success factors for sustainable education reform.

Faculty sense of ownership of the programme. We highlighted the importance of a strong programme level above. However, this needs to go hand in hand with endowing the faculty with a strong sense of ownership of the programme. There is little that a programme manager can achieve without support from faculty: Enthusiastic individuals can realize small, specific changes but long-term changes that are implemented across the programme require broad support.

Empowered change agents. The programme manager needs to be empowered to drive the change process. Elements of this empowerment include funding for development efforts, moral support from management, and the mandate to decide on certain changes. On an individual level, some faculty will take the lead and will be more willing to experiment with their courses. They must be supported in several ways, not least financially and given time to develop their teaching.

Active student participation. Active student participation is essential for education reform, not only as users and evaluators of proposed and implemented changes. Students are only sources for educational innovations that faculty might not come up with: In our case, the Study Hall was originally a student proposal for an improved learning space. Students can also require that an innovation that they are exposed to in one course is picked up by other course. Further, the cultural element of education reform is not limited to changing faculty attitudes. The students of a programme also tend to form a culture with a strong ethos with conceptions of what the programme is about that can be very challenging to change [30].

Management support. Education reform requires programme-level changes and cannot be carried out only on a course level [1]. The programme head will need to balance demands from different disciplines. This can cause conflict. The programme head needs support from management to drive changes in these circumstances. Reform will further require some investments. Allocating money to investments in education development is a key responsibility of university management. University management also needs to understand the time perspective of education change.

Close contacts with stakeholders & employers. Finally, sustained education reforms is very much dependent on influences from the outside. Close contacts with employers will challenge as well as support the education, if it is responsive to employer’s needs. Other stakeholders such as accreditation agencies pose other requirements. In the CDIO Initiative, the collaboration with other universities has provided a continuous source of ideas, perspectives and benchmarks.

CONCLUSIONS

This paper has summarised and evaluated Chalmers University of Technology’s M programme’s evolution during a ten-year period when it has developed, implemented and refined a CDIO-based education.

During the period, the programme has introduced a large number of educational innovations. Some of the educational innovations were driven by goals set in the beginning of the period, but others have been driven by insights gained and external factors during the process.

Internal evaluations such as CDIO self-evaluations, alumni surveys and student interviews and external evaluations such as those conducted by the Swedish National Agency for Higher Education verify that the programme has developed positively during the period and holds a high quality.

The CDIO model has provided the programme with a number of strategies and tools that have been essential for this development: a clear vision and strategy, the professional role of engineers as the focus of the education, a toolbox of adaptable learning experiences, and a quality assurance system that has guided the process. Through working with CDIO, the programme has also established a structure and working practice that has facilitated the introduction of other educational innovations, e.g. in the area of sustainable development.

The approaches developed by the M programme have been spread to other Chalmers programmes in two different ways: Some programmes are adopting CDIO as an idea and are using it to shape their programme goals and content. More broadly, CDIO is adopted as a toolkit. CDIO tools are used to document and communicate programme goals, ideas and structure also for non-CDIO programmes. The main driving factors behind these adoptions are the programme-level thinking of CDIO, its focus on the professional role of engineers, and its applicability as a strategy for integrating learning of generic competences in a programme.

However, CDIO is also challenged by certain barriers to its implementation including its perceived top-down focus and difficulties in interpreting the CDIO concept in certain disciplinary fields and for programmes with a strong research orientation. Lacking faculty competence in and experience of practical engineering work is also pointed out as a barrier to CDIO adoption.

Finally, the paper proposes a set of critical success factors for sustainable education development.

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