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A MODEL FOR THE DEVELOPMENT OF A CDIO BASED CURRICULUM IN ELECTRICAL ENGINEERING

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ABSTRACT

This paper deals with a model providing a structured method for engineering curriculum design. The model is developed to show the major influencers on the curriculum design and the relations between the influencers. These influencers are identified as the engineering science, the business environment, the university environment, and the teachers and students. Each of them and their influence on the curriculum is described and the sources of information about the influencers are discussed. The CDIO syllabus has been defined as part of the basis for the Bachelor of Engineering programs at the Technical University of Denmark and this gives a strong direct impact of the university environment on the resulting curriculum in electrical engineering. The resulting Bachelor of Engineering curriculum is presented and it is discussed how it complies with the model for curriculum development. The main conclusion and recommendation is that a conscious use of the model presented in the paper can structure and improve the curriculum development in a way leading to a well founded and well structured curriculum.

KEYWORDS

Curriculum development, program development, electrical engineering, CDIO.

INTRODUCTION

The development of engineering curricula is influenced by many factors. One very important consideration is the history of the curriculum. Often curricula are developed in an incremental way by introducing changes to already existing programs in a more or less systematic way. However, sometimes it may be advantageous to revisit the curriculum development and take a fresh view on the impact of different factors influencing the development. The CDIO Syllabus described in [1] is an example of an approach to a global view on the curriculum development. It defines a set of general goals for the engineering education and it provides a method for the definition of the detailed content through the involvement of focus groups representing different stakeholders. Another model describing major influencers on curriculum development is presented in [2]. This model was developed with special emphasis on curriculum development for programs dealing with nanoelectronics and Microsystems. In this paper we discuss a generalization of the model from [2] and we show the application of the model to the development of a curriculum in electrical engineering. The model is an attempt to capture the most important influencers on curriculum development in a structured way while keeping the model simple enough to be useful in practice without requiring comprehensive analysis work. The model has a direct parallel to organizational development as described by Leavitt in [3]. Leavitt's model for development of organizational changes contains four interrelated influencers: The tasks to be undertaken by the organization, the technology, the structure of the organization, and the people in the organization. Likewise we consider four interrelated influencers concerning curriculum development: The business environment where the student are employed, the engineering science forming the basis for the engineering disciplines to be included in the curriculum, the university environment which forms the framework for the educational programs, and the teachers and student involved in the programs. A fundamental feature of the model is that changes in one of the influencers will affect not only the curriculum but also the other influencers. Thus, for example, a development in the engineering science has an obvious impact on the subjects and courses to include in the curriculum but it also has an impact on the teachers and students and on the industry. These relations are there, no matter whether you make use of them or not. A conscious exploitation of the interdependencies can lead to a better curriculum development than a curriculum development based only on a subset of the influencers.

THE MODEL

The development model is shown in a generic form in fig. 1. Central to the model is the curriculum development. The four ellipses around the curriculum development illustrate the major influencers on the development and the arrows illustrate that all elements in the model depend on each other. The model as illustrated in fig. 1 is a generic model for the development of engineering curricula. With modest modifications it can also be applied to the development of curricula in other fields than engineering. In the following we apply the model to electrical engineering curricula using the CDIO syllabus as a concept for the program.

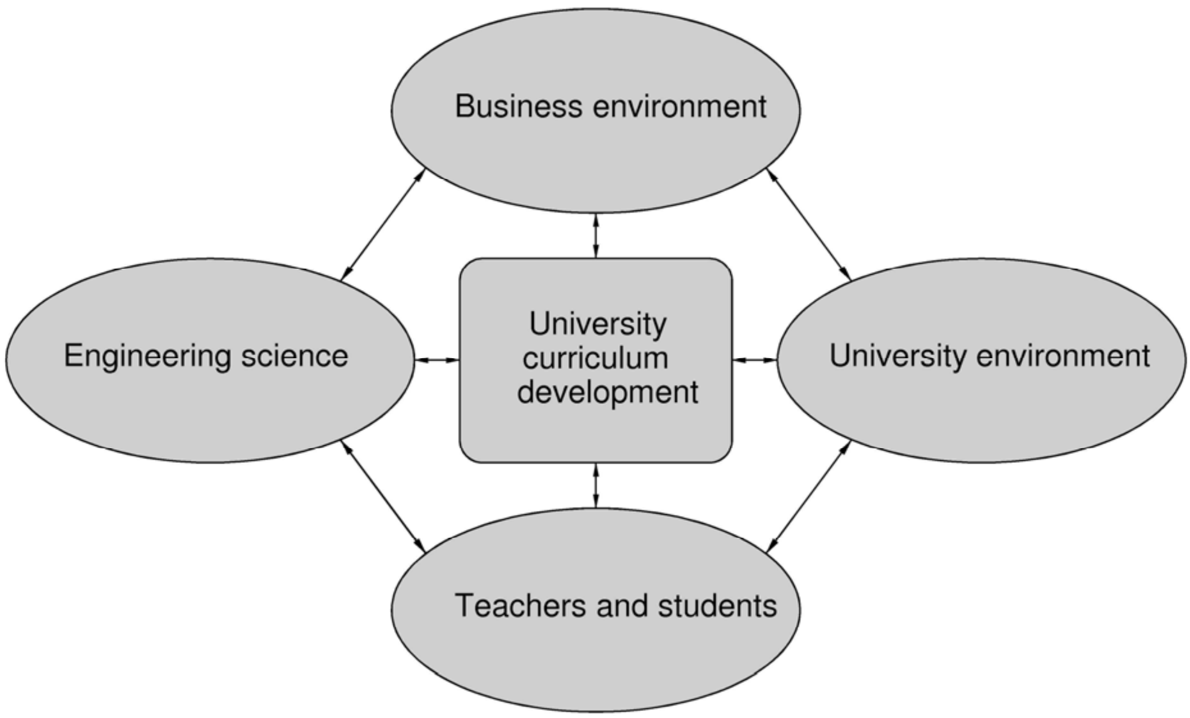

Figure 1. Major influencers on university curriculum development

Engineering Science

Science forms the basis for engineering. New discoveries and developments in physics, mathematics and computer science lead to engineering possibilities in electrical engineering. A well known method for predicting the engineering advances to expect in the foreseeable future is the development of roadmaps. Perhaps the most important roadmap for electronics is the International Technology Roadmap for Semiconductors [4,5]. This roadmap predicts the technology evolution during the coming 10 years and deals with many aspects of electrical and electronics engineering. Fundamental to the predictions is Moore's law [6] which states that the number of components on a chip doubles roughly every 24 months. This increase is obtained in different ways: smaller device geometries, larger chips, novel devices. More specifically, the roadmap deals with three different development tracks:

- *More Moore*. This track describes the direct extrapolation of existing CMOS technology using smaller device geometries. The impact of the scaling is that systems of giga-scale complexity measured in terms of number of components on a chip or in a package can be manufactured, using standard CMOS technologies. The scaling of device geometries is expected to reach a fundamental limit within the next decade.
- *More than Moore*: This track describes a development towards a technology combination between standard CMOS and different forms of microelectromechanical devices (MEMS), RF circuits, analog circuits, bio-devices, chemical devices, etc. The impact is that Microsystems/nanosystems become feasible through this technology fusion.
- *Beyond CMOS*: This track describes a development of new nanoelectronics devices. When the possibilities for device scaling in traditional CMOS become exhausted within the next decade, new devices are needed in order to continue the increase in number of components on a chip.

The three different tracks point towards different curricula: As discussed in [2], the 'More Moore' track points towards programs in computer engineering where the main challenge is how to utilize the increased complexity in larger systems. Of course, this track also requires development of technology engineering but the development of nanoscale CMOS processes takes place mostly in the Far East or in the USA and certainly not in Denmark.

The 'More than Moore' track points towards programs in electrical engineering where the skills of an electrical engineer can be utilized in the design of systems and product using different kinds of electronic devices.

The 'Beyond CMOS' track points towards programs in physics engineering since the main challenge in this track still is the development of novel physical device structures which can replace today's CMOS transistors. A considerable amount of further research and development is needed before new devices are established as the devices for future electronics engineering.

One of the consequences of the development described by Moore's law is that computing and signal processing electronics hardware has become much more powerful and that many development tasks have been changed from dedicated, specific hardware development to software development using generic hardware platforms. Thus, the role of engineering has changed and the balance between hardware development and software development is continually evolving. Likewise, the balance between analog and digital electronics is evolving with as many functions as possible being transferred to the digital domain where design automation is easier and where hardware platforms can be reused through the development of application specific software. Examples of these trends are seen for instance in the development of mobile phones and smart phones where the software content of the phone is what determines the functions of the phone. Also in fields such as audio amplifiers, digital signal processing and digital amplifiers have taken over from previous times' analog designs.

Business Environment

This part of the model deals with the job market that the engineering students are educated for. In an international perspective, the evolution of the engineering science has had a profound impact on the industrial job sector. Much of the electronic design has shifted from hardware to software and much of the hardware design has shifted from design with discrete components (transistors, resistors, small-scale IC's, etc) to integrated circuit design. The volume manufacturing of integrated circuit design is moving away from Europe and being concentrated in the Far East. The manufacturing facilities for modern integrated circuits are so costly that only a few, large multinational companies can afford to follow track on the development of new CMOS processes with even smaller dimensions [7]. Also, manufacturing and assembly of electronic systems based on printed circuit boards and various electronic subsystems are being outsourced to countries with a lower level of labour cost than in Europe.

From a Danish perspective, this means that the job market for electronics engineers has the following characteristic: There are no really large companies, there are no companies in mass consumer markets, there are no companies in semiconductors. Rather, the Danish electronics companies are small and medium-sized enterprises (SME's) in professional markets and OEM markets. They typically deal with niche products and in some niches Danish companies have a substantial part of the world market (hearing aids, wind mills, different types of biomedical equipment). Denmark has a large and innovative energy sector and also a large and innovative health sector. Also, Denmark has many start-up companies dealing with electronics. Examples are found in power electronics and in audio systems where companies emerge, based on engineering competences in the 'More than Moore' track, e.g. in developing new piezo-electric based power systems or new MEMS-based microphone systems. The engineers needed in start-up companies require competencies including conception of products, design and implementation and practical application and operation of products. Thus, the CDIO concept is very well suited for start-up companies.

University Environment

On a global scale, several important developments can be seen in the university structure. One is the adoption of the Bologna model for the university programs [8], i.e. three-years undergraduate (bachelor) programs, followed by graduate programs, in many countries consisting of two-years master programs and three-years PhD-programs. This leads to a harmonization of the university programs, paving the way to easier exchange of students and courses between universities. Another is an increasing internationalization with more programs at master level and PhD level being offered in English.

The vast development of new engineering fields and possibilities has the implication that few – if any – universities can offer programs in all fields of engineering. This leads to a specialization among universities. Some universities have very strong programs in e.g. electronics while others have their particular strengths in other fields, e.g. chemical engineering. Specialized programs such as arctic technology can only be found in few places. However, students are becoming more mobile and the development of a common structure for the educational programs facilitates student exchange between universities. Therefore it makes sense to establish alliances between universities with matching or complementary competences so that joint programs can be developed in fields not fully covered by a single university. This is an important step towards building educational networks.

In addition to the international trends described above, local policies, rules and regulations influence the development of educational programs. The Technical University of Denmark (DTU) offers Bachelor of Engineering programs (B.Eng.) based on a ministerial order from 2002 [9]. This order defines the B.Eng. programs as programs comprising 210 ECTS credits (corresponding to 3½ years) and with the aim of qualifying the students for professional engineering jobs. Also, DTU offers Bachelor of Science programs (B.Sc.) and Master of

Science programs (M.Sc.) based on another ministerial order [10]. The B.Sc. programs are primarily aimed at providing a basis for further studies in the M.Sc. programs and, thus, the B.Sc. programs differentiate themselves from the B.Eng. programs. Only the B.Sc. and M.Sc. programs follow the Bologna model. The policy of DTU dictates that the bachelor programs are taught in Danish, basically aiming only at Danish-speaking students, whereas the master programs are English, aiming at international students. Of course, this creates some limitations concerning the educational networks which can be implemented. Presently, the international dimension is much stronger in the B.Sc./M.Sc. program line. Another declared policy of DTU is that the CDIO syllabus is used for all of the B.Eng. programs but not necessarily for the B.Sc. and M.Sc. programs. A practical implication of this university policy is that the B. Eng. curriculum in electrical engineering is directly aimed at providing engineers for the professional Danish electronics industry with top-class abilities in design and development of electronic systems, whereas the B.Sc./M.Sc. curriculum in electrical engineering aims broader, also at an international job market and at jobs in research and development. Each of the programs is headed by a program coordinator who is also the driving force in the development of the curriculum within the general framework defined by the ministerial orders and the policy of the university.

Teachers and Students

Teachers and students play a decisive role in the developments of a curriculum. The curriculum has to be able to attract students with a relevant background from upper secondary school programs. Teachers with an interest in the subjects included in the curriculum have to be available. Also, teaching facilities, classrooms and laboratory workspace must be available.

In Denmark, the recruitment of students to engineering comes mostly from the STX program (Gymnasium) which has a focus on general education and on general study preparation and from the HTX program (higher technical examination program) which has an emphasis on subjects within the technics and natural sciences. Annually, about 25,000 students complete the STX or HTX program. From these, about 540 chose a B.Eng. program at DTU and from these, about 80 select the electrical engineering program which takes in students both in September and in January. This is an intake which is large enough to provide a good study environment and teamwork among the students while still being manageable for the laboratory workspace available.

A major influencer on the contents of the curriculum is the professional interest of the teachers. At DTU there is a common corps of teachers for all the educational programs, implying that teachers in all of the programs, including the B.Eng. programs, are active researchers. This gives a link to the engineering science and implies that most teachers have a strong interest in research. Many teachers also maintain strong links to industry, providing the necessary background for cooperation with industry about thesis work and trainee service.

DESIGN OF THE CURRICULUM IN ELECTRICAL ENGINEERING

One of the challenges in the curriculum design is to take into account each of the influencers in the model above in a systematic way. The model helps in structuring the process and in pointing out the relations between the influencers but it is necessary to acquire a sufficient amount of information about the influencers in order to take them into due consideration.

Several sources of information are available. Concerning the engineering science, an important source of information is the systematic overview of development trends given in roadmaps like the International Technology Roadmap for Semiconductors [4,5] but also the general knowledge about current and future research topics gathered from the active researchers at DTU is a valuable input to the curriculum development.

Concerning the business environment the CDIO Syllabus [1] suggests an involvement of focus groups including a group of industrial representatives (in addition to groups including faculty, current students and alumni). At DTU each department has an advisory board with representatives from industry and the contents of the B.Eng. curriculum in electrical engineering has been discussed with the advisory board of the Department of Electrical Engineering. Information about the business environment is also accessible from sources including the Danish Society of Engineers and professional organizations such as the Confederation of Danish Industry and DI ITEK (the Danish ICT and electronics federation for it, telecommunications, electronics and communication enterprises). A valuable source of information is also the direct contact to industry which many teachers have on a professional basis.

Concerning the university environment, the information needed for the curriculum development is available from internal sources (about university policies, etc) and from the public organizations defining the framework for the curricula, in particular the Ministry of Education and the Ministry of Science, Technology and Innovation.

Concerning students, teachers and teaching facilities, facts and figures are available from internal sources with numbers for student intake, faculty staff, workspace facilities, etc. and from external sources (Ministry of Education) concerning the students' background from their upper secondary education.

All of this information has to be gathered by the program coordinator and formulated into a proposal for a curriculum which is then discussed in a study planning committee involving teachers and students and in the formal bodies of the university (department study committee, inter departmental program committees) before being reviewed and finally approved by the Dean of Education.

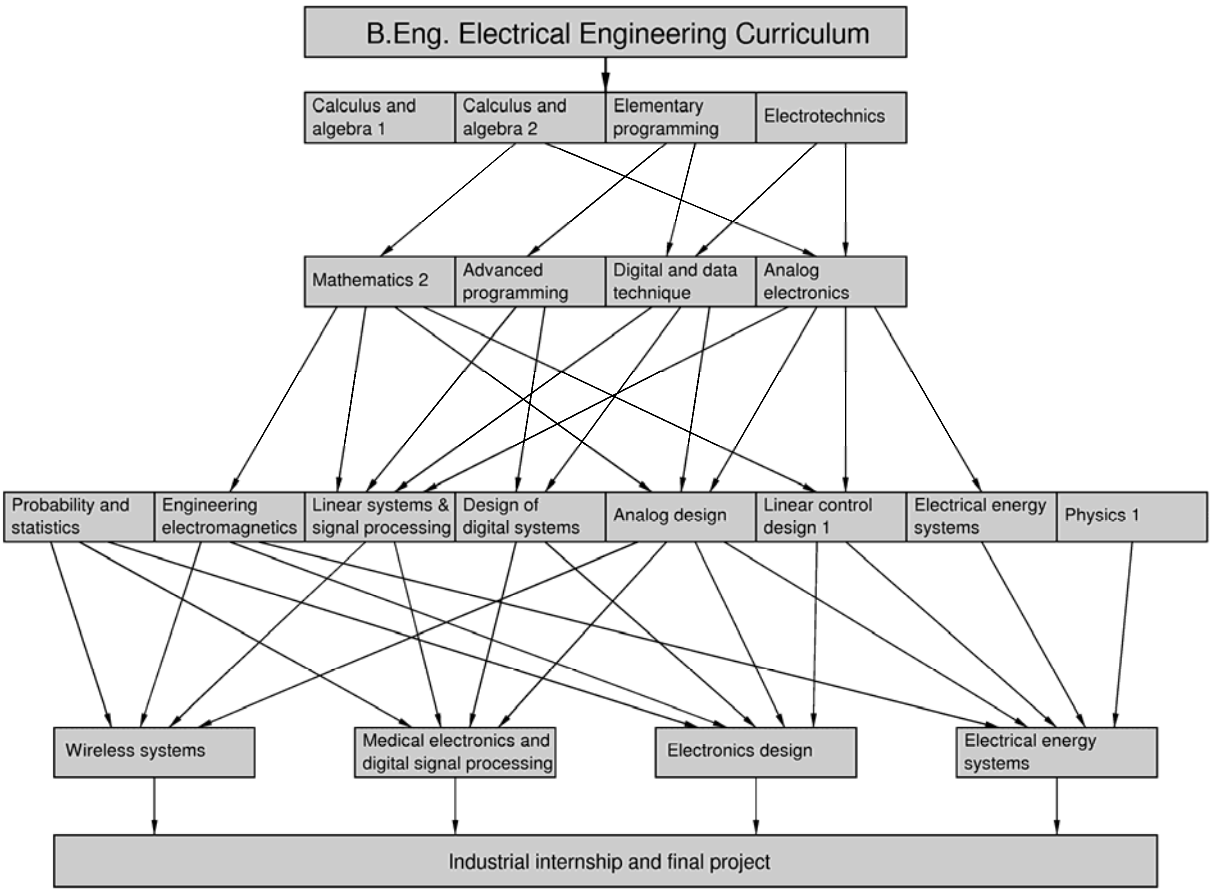

Figure 2. Bachelor of Engineering program for electrical engineering

The outcome of this process concerning the CDIO based B.Eng. curriculum in electrical engineering is shown in fig. 2. A detailed description of the curriculum and how it fits to the CDIO requirements is given in [11]. Here we will relate some features of the study plan to the model described above.

Technical knowledge: The technical knowledge included in the program is a combination of scientific knowledge and core engineering fundamentals in mathematics, physics and computer engineering (programming) and of engineering fundamentals and advanced topics in electrical engineering. The core engineering fundamentals are common to several B.Eng. programs. Thus, their content and definition is strongly related to the educational policy of DTU with departments in mathematics and physics being responsible for these courses, rather than the engineering departments. The engineering fundamentals and advanced topics in electrical engineering are defined by the engineering departments, primarily Department of Electrical Engineering. In the engineering fundamentals, emphasis is on analog and digital electronics, electromagnetics, signal processing and electrical energy systems. Approximately the same effort is devoted to analog and digital electronics. This may at first glance seem strange (in conflict with the general trend in engineering science) but it is a reflection of the teachers' interest, the kind of job functions (often in SME's working in the 'More than Moore' domain), and of the fact that another B.Eng. program is offered by DTU with an emphasis on computer engineering and digital systems. The other engineering fundamentals have been selected such that they support the advanced topics offered in wireless systems, medical electronics and electrical energy systems. These advanced topics have been selected because of a combination of a strong interest and background from the teachers and an industrial base in the Danish industry.

Personal and professional skills: When coming to personal and professional skills, the framework of the CDIO syllabus comes into play. DTU has developed a 'Handbook for CDIO in the B.Eng. programs at DTU' [12]. This handbook gives guidelines concerning how to formulate learning objectives for the courses in such a way that the professional skills are developed through a progression in the technical knowledge. Also, guidelines for the definition of projects are given in the handbook. This is an example of the influence of the university environment on the specific curriculum development, firstly through the adoption of the CDIO concept at DTU on the basis of international university trends, and secondly through the implementation guidelines described in the handbook. In order to combine this university influence with influence from industry, an investigation of industry attitude towards the skills defined in the CDIO syllabus was conducted before launching the CDIO based B.Eng. programs. The results of this investigation indicate an emphasis from industry on the professional skills [13]

Interpersonal skills: Also the interpersonal skills are treated in the CDIO handbook [12] and, thus, serve as an example of the strong influence of the university environment on the curriculum development. The impact of the other influencers in the model in fig. 1 is less pronounced, but it is a general trend in both engineering science and industry that results are increasingly achieved through teamwork requiring interpersonal skills, rather than through the work of individuals. This trend is also seen among the teachers where teams of teachers are assigned to parts of the educational program rather than individual teachers. The teamwork among the teachers also serves as a cultural structuring element in the educational program [11].

Conceiving and engineering skills: These skills are generic engineering skills (not specific electrical engineering skills) dealing with systems design and implementation. In the CDIO syllabus, a very strong emphasis is put on these skills (Conceive – Design – Implement – Operate) which is fully in line with the trend in electrical engineering science where systems are becoming more important for the electrical engineer than circuits, and it is also in line with the Danish business environment where systems, typically for the professional customer, is a common product. Again, the university policy of DTU has dictated that the conceiving and engineering skills should be incorporated into the educational programs through the CDIO syllabus as described in the DTU CDIO handbook [12].

CONCLUSIONS AND RECOMMENDATIONS

A model describing four important influencers on curriculum development has been developed and described. The model operates with the following influencers: Engineering science, business environment, university environment, and teachers and students. The influencers are related in such a way that changes in one of the influencers also affect the others, so they cannot be treated independently. A deliberate exploitation of the relations between the influencers can lead to a better curriculum development than a curriculum development based only on a subset of the influencers. The model is used for the development of the CDIO based curriculum in electrical engineering at DTU. The fact that DTU has chosen the CDIO syllabus as the basis for the B.Eng. programs directly gives a very strong impact from the university environment on the curriculum development, but the CDIO syllabus already takes into account some of the stakeholders in the engineering programs, industrial representatives, the teachers, the students, and former students. In this way, the other influencers in the model are also incorporated into the curriculum development, not only directly but also indirectly through the CDIO syllabus.

The resulting B.Eng. program in electrical engineering is shown and it is concluded that this program has been developed taking both the CDIO syllabus and the characteristics of the Danish business environment and the characteristics of the DTU faculty into account.

The overall recommendation is that a conscious use of the model described in the present paper can structure and improve the curriculum development in a way leading to a well founded and well structured curriculum.

REFERENCES

[1] Crawley E. F., “The CDIO Syllabus”, Massachusetts Institute of Technology, 2001. Available from http://www.cdio.org/files/CDIO_Syllabus_Report.pdf. [Accessed 8 April 2011].

[2] Bruun E. and Nielsen I., “A model for the development of university curricula in nanoelectronics”, European Journal of Engineering Education, Vol. 35, No. 6, December 2010, pp 655-666.

[3] Leavitt H. J., “Applied Organizational Change in Industry: Structural, Technological and Humanistic Approaches”, in Handbook of Organizations, ed. by J.G. March. Rand McNally, Chicago, 1965, pp 1144-1170.

[4] International Technology Roadmap for Semiconductors, 2009 Edition, Executive Summary, Available from: http://www.itrs.net/Links/2009ITRS/2009Chapters_2009Tables/2009_ExecSum.pdf. [Accessed 8 April 2011].

[5] International Technology Roadmap for Semiconductors, 2010 Update Overview, Available from: http://www.itrs.net/Links/2010ITRS/2010Update/ToPost/2010_Update_Overview.pdf. [Accessed 8 April 2011].

[6] Moore G.E., “Cramming more components onto integrated circuits“, Electronics, Vol. 38, No. 4, 19 April 1965, pp 114-117. Available from: http://download.intel.com/research/silicon/moorespaper.pdf. [Accessed 8 April 2011].

[7] Rupp, K. and Selberherr, S., “The Economic Limit to Moore’s Law“, Proceedings of the IEEE, Vol. 98, No. 3, March 2010, pp 351-353.

[8] Confederation of EU Rectors' Conferences, "The Bologna Declaration on the European space for higher education: an explanation", 2000. Available from: http://ec.europa.eu/education/policies/educ/bologna/bologna.pdf. [Accessed 8 April 2011].

[9] Undervisningsministeriet, "Bekendtgørelse om diplomingeniøruddannelsen", BEK nr. 527, 21 June 2002. Available from: https://www.retsinformation.dk/Forms/R0710.aspx?id=23949. [Accessed 8 April 2011].

[10] Ministeriet for Videnskab, Teknologi og Udvikling, "Bekendtgørelse om bachelor- og kandidatuddannelser ved universiteterne (uddannelsesbekendtgørelsen)", BEK nr. 814, 29 June 2010. Available from: https://www.retsinformation.dk/Forms/R0710.aspx?id=132698. [Accessed 8 April 2011].

[11] Kjærgaard, C., Brauer, P. and Andersen, J.C., "CDIO as the educational and cultural structuring element in the DTU B.Eng. in Electronics education", Proc. 7th International CDIO Conf., Copenhagen, June 2011.

[12] Danmarks Tekniske Universitet, "Håndbog for CDIO på DTU's diplomingeniøruddannelser", 2009. Available from: http://www.dtu.dk/upload/administrationen%20-%20101/aus/cdio/cdio_håndbog_endelig.pdf. [Accessed 8 April 2011].

[13] Danmarks Tekniske Universitet, "Undersøgelser af industriens behov". Available from: http://www.dtu.dk/Uddannelse/Diplomingenioer/Hvorfor%20skal%20jeg%20v%C3%A6lge%20diplomingeni%C3%B8r/CDIO/Hvorfra_kender_vi_industriens_behov.aspx. [Accessed 8 April 2011].

Biographical Information

Erik Bruun received the M.Sc. degree and the Ph.D. degree in electrical engineering from the Technical University of Denmark (DTU) in 1974 and 1980, respectively. In 1980 he received the B.Com. degree (HD) from the Copenhagen School of Commerce (now Copenhagen Business School). In 2000 he also received the dr. techn. degree from DTU. Since 1989 he has been a Professor at the Department of Electrical Engineering, DTU. Erik Bruun is currently involved in research concerning analog integrated circuits and systems and he is involved in teaching of analog electronics at both undergraduate level and graduate level.

Claus Kjærgaard received the B.Eng. (hon.) in electronics engineering from the Danish Engineering Academy 1984. In 1984 he joined the Danish Engineering Academy, which is now part of DTU. He is currently an Associate Professor at the Department of Electrical Engineering, DTU. For many years his research was focused on reliability of repairable electronic systems. During the last 10 years his work has been focused on teaching and developing courses and study plans in the field of analog electronics and hybrid microelectronics and on research in these fields. In 2006 he received the reward as best teacher in the B.Eng. educational programs at DTU. Since 2005 he has been head of studies for the B.Eng. program in electronics and has been responsible for the implementation of CDIO in this program.

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