TOWARDS CDIO-BASED B. ENG. STUDIES AT THE TECHNICAL UNIVERSITY OF DENMARK

Jens Sparsø **Peder Klit** **Michael May** **Gunnar Mohr** **Martin E. Vigild**

Technical University of Denmark

Abstract

The Technical University of Denmark is introducing CDIO as the basis for all of its 8 B.Eng. study programs. A task force has developed a roadmap for the process, and defined common goals and guidelines for the future CDIO-based study programs. The paper reports on this process and highlights areas where the context or the approach differs from that of previous adopters of CDIO.

1. Introduction and background

The Technical University of Denmark (DTU) offers a set of 5 year "Bologna style" B.Sc + M.Sc. studies and a set of 3 ½ year B.Eng. studies. The former are traditional university studies emphasizing a foundation in research and science, and the latter put more emphasis on applied engineering.

In the past, the B.Eng. studies were offered by the Engineering Academy of Denmark (DIA) which was an independent school within DTU. DIA had 4 quite autonomous divisions corresponding to the four classic engineering disciplines (mechanical, chemical, electrical and civil engineering). Each division had its own faculty and its own building where all teaching took place. In combination with the fixed study plans, this created a very coherent and effective learning environment which facilitated coordination across courses and semesters. The faculty consisted of full-time teachers without research obligations, and industrial experience was considered important when recruiting new staff. Altogether this means that many of the elements which characterize a CDIO-based study program have always been characteristics of DTU's B. Eng. studies, albeit not formally documented to nearly the same extent as the CDIO standards [1] and CDIO syllabus [2].

In the year 1994 DIA was merged into DTU; first as four departments, and from 2003 its faculty was merged into the relevant DTU departments, where the culture is that of a traditional research-active faculty. One of the reasons behind this change was to ensure the necessary professional and scientific basis which is required to maintain up-to-date high quality teaching in the future. The merge also created a couple of challenges. After the merge one big group of faculty has been teaching courses in both the 3 ½ year B.Eng study program, the 3 year B.Sc. study program, the 2 year M.Sc. study program and the 3 year Ph.D. program. As a result, the dedicated culture which existed around each of the B.Eng. studies has been lost, and the emphasis on engineering practice has weakened.

At DTU we see the combination of CDIO and a faculty of research active professors, as a way to maintain what has always been the hallmark of DTU's B.Eng. studies: emphasis on applied engineering *and* an up-to-date and high level of professionalism. More specifically, we see CDIO as: (1) a way to capture and express some of the important characteristics of the B. Eng. studies, (2) as a framework for future development and improvement of the studies, and (3) as a way to structure, plan and assess learning outcomes. Finally, having just passed a round of accreditations focusing on procedures and adherence to curricular regulations we also believe CDIO will provide a valuable means towards handling future accreditations and certification of actual content of the studies, should this be necessary.

Based on observations like these, DTU's management (the rector, the deans of studies, and the board of governors) decided to introduce CDIO as the teaching context for all of DTU's B.Eng. studies from 2008. The decision is even stated as one of the deliverables in DTU's contract with the Ministry of Science, Technology and Innovation for 2006-08. To initiate this process, a task force was formed in the late summer of 2006. Its mission was to develop a roadmap for the process, and to define common goals and guidelines for the future CDIO-based study programs. This work was finished in March 2007, and the resulting plan of action [3] was approved by DTU's management.

Following this, the individual B.Eng. study program directors and the relevant departments will implement the necessary changes to the individual B. Eng. study programs. According to the plan, the new CDIO-based study programs will be launched in the fall semester of 2008.

As the decision has been made by DTU's management, and because it involves all 8 B.Eng.-studies, the process of introducing CDIO is somewhat different from that reported by some of the early adopters of CDIO. In most of the previously reported cases the process has been driven by a few enthusiastic individuals, whose effort has focused on a single study program [4] or much more frequently, a single course [5,6,7]. Our endeavor is to implement a management decision and reform all the B.Eng. study programs, and we are fortunate to be able to leverage previous experience and resources developed by the pioneering CDIO-partners.

In the following sections we will elaborate more on these issues. Section 2 describes the B.Eng. study programs. Section 3 describes a couple of ongoing activities which overlap with the CDIO-process, and which we are leveraging to help motivate the introduction of CDIO. Section 4 reviews the initial efforts of the CDIO-task force. The resulting plan of action defines six specific tasks which – when completed – will result CDIO being fully implemented. These six tasks are briefly presented in section 5. Following this section 6 outlines the work which is scheduled for the coming academic year (2007/08), i.e. the detailed development of the individual CDIO-based B.Eng. studies. Finally section 7 concludes the paper.

2. The B.Eng. studies at DTU

DTU has always offered a 5 year masters level engineering degree. The B.Eng. studies at DTU dates back to 1957 where the Engineering Academy of Denmark (DIA) was established as an independent school within DTU. The mission of the new DIA was to offer a shorter 3 ½ year engineering degree; still based on a solid theoretical foundation but with more emphasis on applied engineering. In this way it was a supplement to the engineering programs offered by today's engineering colleges. As of today, DTU offers the 8 B.Eng. study programs listed in table 1. The total yearly intake is 470 students and currently a total of 1700 students are enrolled.

Table 1: Current B. Eng. study programs and past departments.

Current B.Eng. study programs	**Original B. Eng. Studies (Departments up to 2003)**
Arctic technology	Civil engineering
Civil and structural engineering	
Architectural engineering	
Electrical and electronic engineering	Electrical engineering
IT engineering	
Mechanical Engineering: • Mechanics • Production management	Mechanical engineering
Chemical engineering and biotechnology	Chemical engineering
Technology and Economy • Chemistry and business economy • Internet technology and business economy	*New study programs from 2006*

The B. Eng. studies follow a quite fixed curriculum structure which enables carefully planned coordination among courses. The present curricula include many projects and design-build experiences, and a one semester engineering training where students work in companies and organizations outside DTU. Figure 1 shows the structure of a generic 3 ½ year B.Eng. study program.

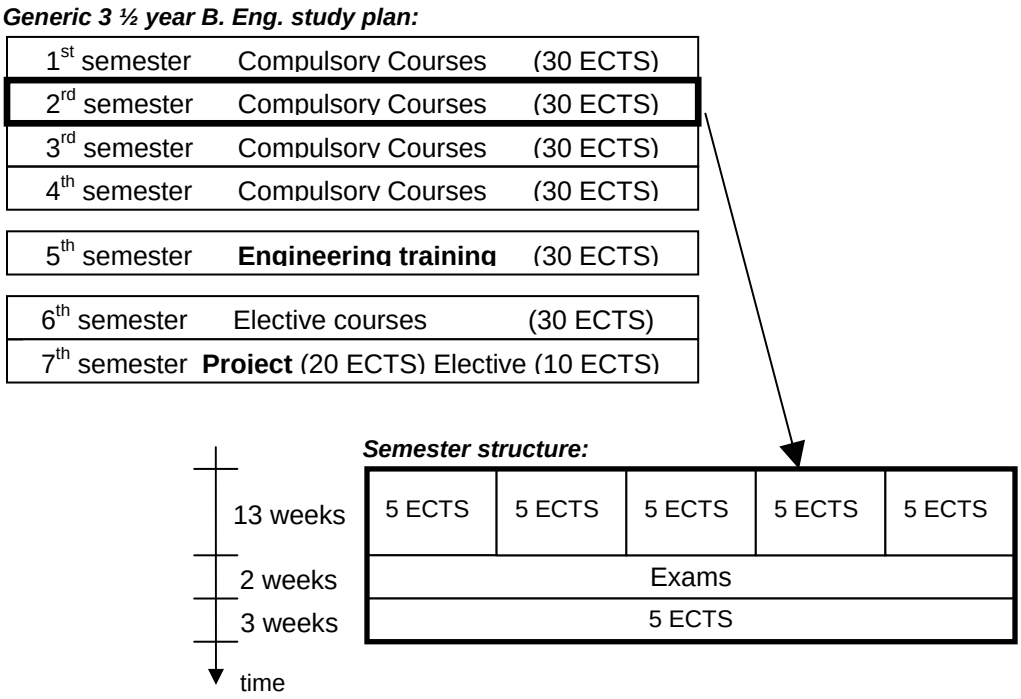

Figure 1. Structure of the 3 ½ year B. Eng. study.

Course credit points are given in the European Credit Transfer and Accumulation System (ECTS). Details vary slightly across the 8 B.Eng. study programs: The first 4 semesters consist entirely of compulsory courses, and in several cases some of the following courses are compulsory as well. The engineering training is in the5th semester except for the IT Engineering program and Electrical and Electronics Engineering program where it is in the 6th semester and normally linked with the final project in the 7th semester.

The semester structure includes a 3-week full-time block, figure 1. It can be an independent 5 ECTS course or it can be part of a larger 10-15 ECTS course. In our experience the latter form supports CDIO-style design-build activities very well: the 13-week lecture period is well suited for Conceive-Design activities and the 3-week period is well suited for Implement-Operate activities. In the IT engineering study (which the first author is involved in) 4 of the first 5 semesters has such a 10 ECTS course extending into the 3-week period and use the time periods as just described.

3. Activities running parallel to the CDIO effort.

Independently of the CDIO-process a number of activities focusing on learning objectives are taking place at DTU. The CDIO process has been able to leverage from these and will continue to do so. Also, and perhaps more importantly, these efforts help us motivate CDIO by explaining and stressing that CDIO can be seen as a larger and unifying context for these efforts.

Firstly, based on a requirement from the Danish Ministry of Education, a so-called *competence description* has been developed for every B.Eng. and B.Sc. line of study at DTU. Examples are found in [8]. A competence description is a 1-sheet double-sided document which in bullet-form defines:

- The general profile of a B.Eng. candidate (common to all B.Eng. candidates).
- Intellectual competences (common to all B.Eng. candidates).
- Technical competences (common to all B.Eng. candidates)
- Technical competences specific for the individual study programs.

There is obviously some relation to the CDIO-syllabus. The 3rd and 4th bullets in the above list matches CDIO syllabus category 1 and the 1st 2nd and 3rd bullets relate to CDIO syllabus categories 2, 3 and 4. The competence descriptions were discussed and iterated at several department–wide meetings involving all faculty members.

Secondly, a new grading scale is currently being introduced in all Danish high schools and all institutions of higher education. The new grading scale has 7-steps and it is directly comparable with the European ECTS-scale (A, B, C, D, E, FX, F), and as such similar to the American scale. This scale is supposed to be common for all EU countries to ensure student mobility, as agreed in the Bologna Treaty. An important difference to the old grading scale which has been used in Denmark for the past 40 years, is that the new 7-step scale is *absolute;* students are evaluated against a set of learning objectives. At DTU the new grading scale will be used from the fall semester of 2007, and at the time of writing this paper all faculty members are involved in the process of defining learning outcomes for the different courses. Each course description is required to state 8-12 learning outcomes, and these are to be expressed using active verbs corresponding to the levels in the modified Bloom-based taxonomy being used at DTU, figure 2 [9].

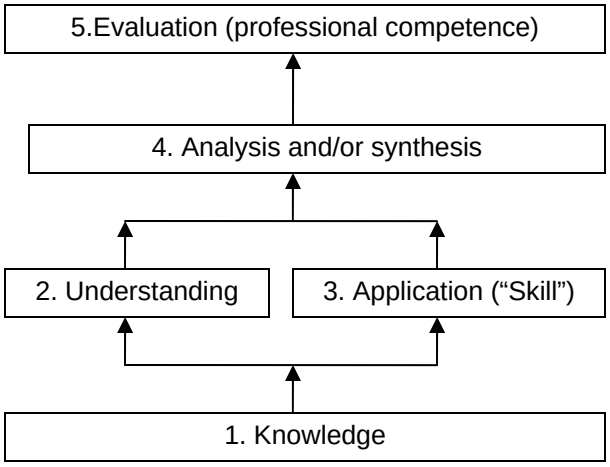

Figure 2: DTU's modified Bloom-based taxonomy.

With a total of 1100 courses offered by DTU this work represents a huge effort which is supported by written instructions, departmental meetings, workshops and courses, feedback from study-program-directors and iterations of the learning objectives.

At the time of writing this paper, the CDIO-process is about to enter a phase where all faculty members will be involved. The above mentioned two activities overlap directly with the effort of developing a CDIO-syllabus for each B.Eng. study and contribute to the fulfillment of the CDIO standards.

4. Stakeholder surveys and adaptation of the CDIO syllabus.

The CDIO task force started its work in September 2006 with the mission to write a plan of action detailing the different tasks and steps towards the final goal: CDIO fully adopted in all 8 B.Eng. study programs from the fall semester 2008. The first discussions were obviously somewhat hesitant: The CDIO standards address a wide range of fundamental issues, and the CDIO web-site provides a substantial (perhaps even overwhelming) amount of material and resources. During a sequence of 12 meetings, which took place over a 6 month period, things shaped up and the plan of action described in section 5 was completed in mid March 2007 and subsequently approved by DTU's management.

Our first discussions were concerned with the CDIO-syllabus and the stakeholder surveys.

In the process of translating the CDIO syllabus into Danish and adopting it to the B.Eng. studies we felt a need to limit the extent of the syllabus, in order to emphasize overview and clarity over detail and comprehensiveness. We deliberately omitted CDIO category 1 which we feel is the responsibility of relevant faculty and study program directors. The resulting *DTU-syllabus* [3, appendix A2] includes only first and second level content within CDIO categories 2, 3 and 4. For each of the sub-categories 2.1 through 4.6 it lists 2-5 learning objectives. This document fits on 2 pages making it useful for communicating CDIO-concepts to a broader audience. We anticipate that more detailed and comprehensive syllabi may emerge over the next 1-2 years; but in a bottom-up process driven by the study program directors and the faculty involved in implementing

CDIO. As mentioned elsewhere, the introduction of the new 7-step grading scale has cased all of DTU-faculty to be involved in writing course-level learning objectives during the spring of 2007. We expect that the major part of the DTU faculty will construct objectives which primarily relate to category 1 of the CDIO syllabus and that categories 2, 3 and 4 are covered in a more scattered and arbitrary way. Thus, we anticipate considerable discussion, iteration and improvement of these learning objectives over the next 1-2 years. There will obviously be considerable synergy between this development of the learning objectives, and the above mentioned refinement of the CDIO syllabus for the B.Eng. studies.

Any syllabus should obviously be based on stakeholder requirements and interests. We acknowledge that this very important, and to start with we anticipated a significant effort. Our initial plan was to address the advisory boards of the departments involved in the B.Eng. studies, and to interview a panel of relatively newly graduated candidates (1 year and 5 years). When discussing these issues further, we reached the conclusion that previously reported stakeholder interviews are quite consistent [2,10,11]. Furthermore we feel that there is a significant element of uncertainty when translating from a number {1, 2, 3, 4, 5} to specific learning outcomes. Although the numbers may be defined to correspond to the proficiency levels in Blooms taxonomy, they are likely to be perceived as just a grading scale by those participating in the survey. In the end we restricted the analysis to include only the advisory boards as explained below.

Each of DTU's departments has an advisory board consisting of a handful of prominent industry leaders and high profile professors from foreign universities. They meet with the department directors two times per year. At meetings in the fall and winter of 2006 the advisory boards were introduced to the CDIO-concept and briefed on the purpose and form of the survey. The result of the survey is shown in figure 3. "MEK" is the Department of Mechanical Engineering, "BYG" is the Department of Civil Engineering, "IMM" is the Informatics and Mathematical Modelling department and "Ørsted" is the Electrical Engineering department. The relative scores in the different categories are in line with previous findings [2,10,11].

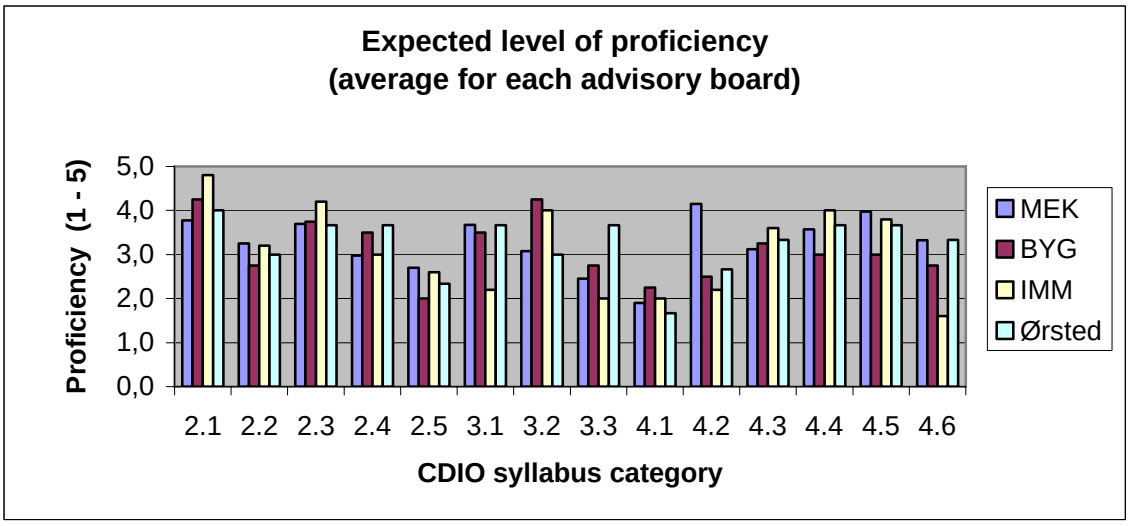

Figure 3: Benchmarking for CDIO syllabus categories 2-4.

5. The plan of action

The goal of the plan of action is to identify tasks which will contribute towards reforming the studies such that they meet the CDIO standards. In order to carry out these tasks a CDIO study program committee has been formed for each line of study. It is the responsibility of these committees that CDIO is fully implemented for students starting in the fall of 2008. The following six tasks have been identified [3]:

1. *Detailed course-level learning objectives must be developed and documented.*
2. *For each B.Eng. study program a "competence matrix" must be produced.*

   A first step towards the new CDIO-based studies is to chart the existing studies: which courses provide which competences and how is the progression across courses and semesters? This has the added benefit, that those (many) faculty members who have become involved in teaching B.Eng. courses after the merge in 2003, will get a much better understanding of these issues.

   As mentioned in section 3, detailed learning objectives are currently being produced for all of DTU's B.Eng., B.Sc., M.Sc. and Ph.D. courses as part of the process of introducing the new 7-step grading scale. These learning objectives will be included in the 2007/08 course catalogue and the CDIO effort can obviously benefit directly from this work. The next step is to assess learning objectives across the courses. Our aim is to follow the benchmark survey process outlined in [11], and to produce a competence matrix similar to the one in [11, Fig. 3]. Table 2 shows an example of a partially completed competence-matrix.

   Since learning objectives are expressed using active verbs reflecting the 5 levels of proficiency in Bloom's taxonomy we will use these levels {1, 2, 3, 4, 5} rather than the more coarse "I" (Introduce) and "T" (Teach) defined in [11]. The effort will cover semesters 1 through 4 (compulsory courses) and is scheduled to take place in May/June 2007 in a series of half-day workshops involving faculty members teaching courses on semesters 1 through 4. During the coming academic year 2007/08 we plan to repeat the above exercise for the new CDIO based B.Eng. studies which will start from the fall 2008.

Table 2. Competence matrix (uncompleted example).

Semester	**Course**		**CDIO syllabus categories**						
			2.1	**2.2**	**2.3**	**2.4**	**2.5**	**…**	**4.6**
1st	01905	Mathematics							
	31021	Electronics	1			2,U			
	02311	Digital Systems		1					
	02312	Basic programming			2, U				
2nd	02321	HW/SW programming	2						
	…	**…**							
3rd	**…**	**…**						3/U	
	…	**…**							
4th	**…**	**…**							
	…	**…**							

3. *Each of the first four semesters must include a multi-disciplinary project which relate to several courses on that semester.*
4. *Each study program must include at least two Design-Build projects, one on the first semester and one on the fourth semester or later.*
5. *For each of semesters 1 through 4 a team of lectures is formed (for every line of study).*

   In combination, these requirements form the basis for measures which will meet CDIO standards 3-7: Integrated Curriculum, Introduction to Engineering, Design-Build Experiences, CDIO Workspaces and Integrated Learning Experiences.

   As the design build projects go beyond the cross-disciplinary projects in terms of actually building systems, they qualify as cross disciplinary courses as well. Referring to figure 1, the following models may be used for the cross disciplinary projects:

   - An independent 5 ECTS project course
   - A part of a larger 10-15 ECTS multidisciplinary course
   - Embedded in a number of courses and evaluated as part of these courses. Requires careful cross-course coordination.

   The lecturer teams will be responsible for coordinating courses and projects on a given semester, and the plan of action states the detailed responsibilities of the teams. They must ensure that the semester projects progress in a satisfactory way. They must plan the teaching and learning activities in a way which ensures that students experience a steady workload throughout the semester. And they must ensure that the courses are coordinated and supporting each other when this is possible and relevant. Finally they must ensure that students are exposed to a varied mix of teaching and learning styles and environments.

6. *The rationale behind the CDIO concept is introduced in the pedagogical education of assistant professors.*

   LearningLab DTU runs a sequence of pedagogical courses which are compulsory for assistant professors, and as part of this activity the participants carry out a project related to their own teaching. In the process of advancing to a tenured position as associate professor this forms part of the assessment. In the future, this pedagogical education will include an introduction to CDIO.

6. Status and tasks for the coming year.

The action plan which was briefly reviewed in the previous section largely prescribes future activities. We feel we have come a long way, but we are also aware that we still have a long way to go. The schedule towards full introduction of CDIO is shown below in table 4.

When CDIO has been implemented, procedures must be set up to evaluate the quality and outcome of the change. This will be the joint responsibility of Learning Lab. DTU and the Office for Study Programmes and Student Affairs. This will include:

1. An evaluation of the teaching staffs view upon the implementation of CDIO including their view on the particular issues in the Syllabus.
2. An evaluation of the students view on the CDIO learning environment.
3. A comparison of the individual B.Eng. study programs.

Table 4: Time schedule for CDIO process.

Time interval		Activity / Milestone
2006	4Q	• CDIO task force formed
2007	1Q	• Plan of action completed and approved by DTU management
	2Q	• Course level learning outcomes and introduction of 7-step grading scale • CDIO study program committees formed • Benchmarking of existing studies
	3Q	• Development of future CDIO based study plans • Presented at seminar for all B.Eng. study program committees
	4Q	• Detailed planning of CDIO based studies
2008	1Q	• Course level learning objectives revisited and matched to CDIO syllabus
	2Q	• Benchmarking of new CDIO-based studies
	3Q	• Students start on new CDIO-based B.Eng. study programs
	4Q	

7. Conclusion

The paper has given an overview of the of DTU's effort towards introducing CDIO concepts and standards as the basis all its 8 B.Eng. study programs.

The B.Eng. studies have always emphasized applied engineering, and they have by tradition included integrated project work and design-build activities. We see the adoption of CDIO as a means to maintain and develop these characteristics in a changing organizational environment, and as a means to create a stronger awareness for learning objectives and how to achieve these.

The process was initiated by a decision made by DTU's management (rector, executive board and board of governors). The decision is even stated as one of the deliverables in DTU's contract with the Ministry of Science, Technology and Innovation for 2006-08. The process is not lacking support and resources. The challenges are in actually making the necessary reforms and in motivating faculty members who are also teaching B.Sc., M.Sc., and Ph.D. courses to participate in reforming the 3 ½ year B.Eng. study program.

Status is that we are roughly halfway into the process, having prepared a detailed plan of action and having benchmarked the learning objectives of the existing studies. The effort for the coming academic year will be to implement the tasks outlined in our plan of action. During the process we have benefited from the many resources which are available through the CDIO web-site.

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Biographical Information

Jens Sparsø is a Professor in computer science and engineering at the department for Informatics and Mathematical Modelling at the Technical University of Denmark and he is director of studies for the E. Eng. in IT study program. His current research activities are within application specific computing structures and processors, low power design techniques, design of asynchronous circuits and systems, and communication structures for systems-on-chip (i.e. Networks-on-Chip).

Peder Klit is Professor in machine elements at the Department of Mechanical Engineering at The Technical University of Denmark and he is the study program coordinator for the B.Eng. in Mechanical and Industrial Engineering. Research activities are mainly within tribology of machine elements.

Michael May is working as an e-learning consultant at LearningLab DTU at the Technical University of Denmark. His educational background is in psychology and Human Factors and his current research is focused on multimedia semantics, didactic aspects of learning objects, and on Human-Machine Interaction in safefy-critical work domains.

Gunnar Mohr is Dean of Studies and responsible for the B.Eng. Programmes. He has since 2001 been a member of The Executive Board at DTU. Previously Gunnar Mohr served as a professor in Mathematics at The department of Mathematics, DTU.

Martin E. Vigild is an Associate Professor at the Department of Chemical Engineering, DTU, where he serves on the Educational Committee. He teaches introductory and advanced courses in Materials Science, Colloid and Surface Chemistry, Chemical Product Design and Polymer Engineering. His research focuses on the characterization of structure-property relationships of polymeric and composite systems as well as chemical product design and development of novel materials based on molecular self-assembly. He is the director of the Industrial Research Consortium for Polymers at the Danish Polymer Centre, DTU.

Corresponding author

Professor Jens Sparsø
Informatics and Mathematical Modelling
Computer Science and Engineering section
Technical University of Denmark
Richard Petersens Plads, Building 322
DK-2800 Kgs. Lyngby
DENMARK
Phone (+45) 4525 3747
Email: jsp@imm.dtu.dk