

Report on
Comparison of Curricula in Computer Science
IDEA League

IC London - Imperial College, University of London

TU Delft – Technische Universiteit Delft

ETH Zürich - Eidgenössische Technische Hochschule Zürich

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2. *Executive summary*

The Computer Science working group of the IDEA league has compared the curricula in the four universities. In spite of the variety of programmes there are common features and principles such as the emphasis on fundamentals, the internship and the core subjects in computer science. Technology in CS is rapidly changing, research and curricula in CS have to adapt to this pace. The IDEA league universities are aware that teaching fundamentals is more important than training in trendy features of current software systems.

All partners also share common problems like the steadily growing number of students, the difficulty of hiring new faculty and the shortage of resources (space, funding, and equipment) because of the expansion of the departments.

IC offers Bachelor's and Master's degrees. Delft is about to start a new curriculum with sequential Bachelor and Master's degrees, while ETH and RWTH Aachen offer a Diploma curriculum and are presently introducing Master's/Bachelor's degrees, respectively examining the situation. Aachen and Delft already offer a Master's degree for foreign students with a BSc. The regulations and experience of IC (for example, admission of selected students only) will be very valuable for the other members of the IDEA group.

The working group agreed that one semester or one year is a reasonable duration for horizontal mobility (temporary study at a partner university) after the second or third year of the curriculum. Because of the different examination systems (ETH and Delft are using a credit system, Aachen has oral final Diploma exams and IC has the examination period in May), it is important that the courses and the examinations to be taken are discussed and scheduled in agreement with the home university before the student visits the guest university.

Vertical mobility (permanent move to another university) to acquire a Master's degree (or Diploma) at another university is currently only possible by examining the student "sur dossier" at ETH and Aachen. IC requires the student to have a Bachelor's degree before admission, which prevents ETH and Aachen diploma-students from being admitted at this stage.

There is agreement among the partners that a primary goal of their curricula is to ensure a professional standard by which a transfer from research to industrial practice is possible. This must be based on studies of 4-5 years, leading to the Master's or Diploma degree.

The working group observed that a comparison of the curricula is incomplete if the different boundary conditions under which the curricula are implemented are not taken into account. In contrast to a wide agreement of the contents of the curricula, the situation is quite diverse regarding conditions of student admission, numbers of admitted students (in relation to available staff), strictness of study organization, emphasis on neighbor disciplines of CS, and financial matters (student fees and funding). The working group recommends that this important issue is addressed seriously and comprehensively on a more general level (than for a single subject like CS) within the IDEA league.

The working group observes a move of Electrical Engineering (EE) curricula towards CS. Some EE-departments in Germany and Switzerland have changed their name to Information Technology and EE. In IC and Delft both departments are in a common faculty. The trend of interdisciplinary cooperation in research and curricula is profitable for both sides.

We also observe that degrees of BSc level at technical universities and Universities of Applied Sciences (UAS) could be confused but are in fact not equivalent as qualification for the Master (or Diploma) curriculum of technical universities. Provided the Technical Universities do not lower their standard in the mathematical and scientific foundations, they will, however, retain their market for top quality students.

The Annex contains a detailed description of the required and core courses in the four CS-curricula of the IDEA partners.

This report is an assessment of the current situation in CS in the IDEA league. We hope it will be valuable for further efforts for harmonizing the curricula to devise practical guidelines for horizontal mobility and to explore options for staff exchange.

3. Introduction: aim of this study

In June 1999 the European Ministers of Education signed the Bologna declaration. One of its goals is to harmonise of the university education systems by re-structuring tertiary education into two main cycles: undergraduate and graduate. Another goal of the Bologna declaration is to promote the mobility of students. To achieve these goals it will help to have a general framework for horizontal and vertical mobility, if possible based on the ECTS credit system.

In autumn 1999, the four technical universities *Imperial College (IC)*, *Delft University of Technology (TU Delft)*, *ETH Zürich (ETHZ)* and *Aachen (RWTH)* agreed to form the IDEA League. The aim of the IDEA League is the collaboration on strategic policy issues.

In March 2001 a working group was formed by the CS partners of the IDEA-league to compare existing curricula and to agree on recognition of study achievements. A further assignment of the working group was to develop proposals for mobility (student exchange) and discuss Bachelor's and Master's level. Imperial College already has Bachelor and Master level programmes, TU Delft is implementing a Bachelor-Master structure, and ETH Zürich and RWTH Aachen are in the process of re-considering their current curricula, which at present terminate with the Diploma after a programme of 4.5 years. In addition, the working group took the liberty to discuss some relevant issues which directly influence the situation of the CS curricula, such as the increasing number of students in the field, the admission strategies, and the embedding of the Computer Science curricula within the university. The relation with the polytechnics is also discussed.

The working group met four times, once at each of the universities.

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4. CS at IDEA-league

Imperial College

IC consists of four faculties: Engineering, Physical Sciences, Biological Sciences and Medicine, each with several departments. CS is included in the Engineering Faculty. Computer Science at IC has its roots about 1945, a recognised centre by 1966, and an academic department since 1970. Currently, the Department of Computing at IC has 44 Permanent Academic Staff, 10 Teaching Assistants concerned with Student Laboratory Projects and Coursework, about 10 Computer Laboratory support staff, who also service research use of the Laboratory and networked facilities, and a number of staff in administrative and clerical positions. There are also Research project staff, at various levels determined by external research funding.

IC is the only partner that already has a Bachelor-Master structure in place. IC offers the following curricula:

- MEng: the Master of Engineering degree is of four years duration with a choice of five specialisations: Artificial Intelligence, Computational Management, European Programme, Mathematical Foundations and Software Engineering.. The MEng degree includes a six month industrial placement.
- BEng: the Bachelor degree is of three academic years duration and shares the first two years with the MEng.
- MSc (advanced): A one full year course for graduates with at least a Bachelor's degree in CS.
- MSc (conversion): A one full year course for students with a Bachelor degree from other (technical) fields.
- MSc (Computing for Industry): A new part-time modular course for students sponsored by their employer.

IC accepts each year about 150 new undergraduate students (for the MEng and BEng degrees). This number is determined by agreement with the Higher Education Funding Council. The acceptance rate is about 6%. So even the 'tail' is well qualified. Students are well tutored and the drop-out rate is low. Although the BEng is an Honours degree in its own right, it is also used as an early way out for students that are not qualified to remain on the MEng after the second year. The full time MSc courses together admit more than 100 students each year.

TU Delft

CS in Delft emerged from Mathematics and became a formal curriculum in 1981. In 1998 the department for Computer Science and Mathematics merged with the department for Electrotechnical Engineering, to form the new faculty Information Technology and Systems (ITS). CS has seven chairs (two vacant) and about 40 fulltime equivalent (fte) of permanent staff, about 20 project-paid PhD/PD research positions and about 10 technical supporting staff.

CS - TU Delft has a five-year curriculum that grants the Ir-degree (Ingenieur). The number of students enrolling each year is about 200. The university has to accept all students with a suitable entrance level qualification.

From September 2001 a revised curriculum is in place with Bachelor-Master structure. Students that finish the bachelor (three years) will automatically be accepted for the Master (two years). Students from other curricula and from outside the TU Delft will have to apply to be accepted.

The old curriculum has a fixed programme for the first three years and offers three specialisations in the fourth and fifth year: core informatics (software technology and computer systems), information systems (design and management of information systems), and technical applications (knowledge engineering and computer graphics). In the new curriculum the student can specialise from the first year on in one of the three directions (one-third of the programme):

- Software Technology (ST): software engineering, computer technology, operating systems, control theory, embedded systems
- Information Systems/Architecture (IS): development and management of information systems and its embedding in financial and logistic organisations
- Media and Knowledge Engineering (MK): human-computer interaction, computer graphics, image processing and knowledge engineering

The first year (the 'propadeuse') is meant as a selection/qualification year. Only 50% pass the first year. Even then the drop-out rate in later years is still considerable. The average study-length is over six years. For some years now, CS Delft has been running an international MSc programme. The acceptance rate is about 10% with a total of 12-24 students accepted each year.

ETH Zürich

CS at ETH Zürich has its roots in 1950, when the ZUSE Z4 machine was installed at ETH. Computer Science was founded in 1968 by H. Rutishauser as an institute in the Department of mathematics. Diploma studies were introduced in 1981. A CS department with 4 institutes was formed in 1989. There are currently 23 professors, 100 assistants, 40 project-paid positions and 23 permanent supporting staff. ETHZ has currently about 1000 CS students with about 300 freshmen. Every student who has passed an equivalent of a Swiss Matura is accepted as student at ETH and also into the CS curriculum if chosen.

The first two years of the CS curriculum is fixed. After the first year and after the second year there is a qualification exam ("Vordiplom") covering the material presented over the whole year. Since students are not selected before their entry to ETHZ, the first exam is seen as an entry exam. On the average the drop-out rate at the 1st Vordiplom is about 50% and at the 2nd it is about 20%. About 70% of the students that pass both Vordiploms finish the Diplom study in 4.5 years (9 semesters).

In the second part of the study program, the students are free to choose from any of about 60 courses in addition to four core courses (out of five) which must be taken.

RWTH Aachen

The CS group at RWTH Aachen was founded 1971 in the Faculty of Mathematics and Natural Sciences, now called Faculty of Mathematics, Computer Science and Natural Sciences.

Computer Science at RWTH Aachen consists of 15 professors, each of them heading a research group, and around 45 state-paid assistants. These assistants are mostly on temporary positions, doing PhD work, and helping in teaching (problems classes, practical work, project work). In addition there are around 70 assistants on temporary positions paid by the German Science Foundation, the European Union, and industrial partners, involved in research project work, also mostly at PhD level. These research positions are officially not admitted for assistance in teaching, but in practice it is necessary to use them partly also for this purpose.

CS in Aachen has now over 2500 students altogether, with presently about 800 beginners each year. Many students are working part-time, and when doing this extensively they are prolonging their studies considerably. This is possible due to a lack of time restriction in the curriculum. The nominal duration of studies is 4.5 years, in practice it is about 6 years.

The main curriculum is that of the Diploma in Computer Science. The first two years, which consist of basic courses without much choice, are ended by the “Vordiplom” examination. There is a high drop-out rate, which is not easily determined because of the lack of time restrictions. Roughly between one half and two thirds of the original beginners will pass their Vordiplom. Of those who have achieved this, the vast majority (around 90%) eventually also pass the diploma examination.

The first two years of the curriculum provide solid and comprehensive foundations (with a considerable amount of mathematics and an introduction to core disciplines of CS). The advanced studies after the Vordiplom are organized according to very liberal rules. Six courses have to be taken in the domains of theoretical and practical computer science (3 courses in each domain). Apart from this, three further examination threads have to be passed: a freely chosen “special area” (with 3 courses), a minor subject, and the diploma thesis. The latter three can be bundled in some application area of CS, like electrical engineering, mechanical engineering, economics, or medicine, and thus a truly interdisciplinary study program can be realized. Another option is to specialize in CS itself, usually by combining the special subject and the diploma thesis into a unit.

There are additional CS curricula, most of them introduced recently:

- MSc in Software Systems Engineering (offered to foreign students with a suitable BSc, i.e. sufficiently advanced and close enough to CS)
- Gymnasium Teacher Curriculum in CS (overlapping considerably with the diploma curriculum)
- M.A. “Technical Writing” (in cooperation with the philosophical faculty, aiming at a competence in efficient and competent communication between CS and “customers”, in neighbouring disciplines and application domains).

Several further curricular are in preparation, among them:

- An Engineering diploma in “Technical Computer Science” (sometimes called Computer Engineering), offered by the Faculty of Electrical Engineering and Information Technology, supported by the CS department,
- An M.A. in “Business Information Systems”, offered by the Faculty of Economics, supported by the CS department.

The recently introduced MSc in Software Systems Engineering required the courses to be offered in English. As a consequence, an increasing portion of the Department’s courses are provided in English, although only advanced ones so far. These English medium courses are given for MSc students as well as for diploma students; the experience is very positive.

5. Comparison of the curricula

Introduction

The curricula for Computer Science at the four technical universities educate students in the fundamental aspects of computing and in its use in technical applications. The education qualifies the graduates for a professional position in the Information and Communication Technology (ICT) industry or to begin a research career (in either case subject to further professional or research training). This means that the graduate is well-versed in current technology and its applications, including active knowledge of software systems and languages, and well educated to perform as an expert in the field.

Overview of curricula

As a general rule it can be said that the basics of computer science are taught in the first two years, when the students have little or no flexibility, whereas students can choose from a wide range of options in the third and fourth year¹.

Table 1 (page 8) gives an overview of the four curricula. Comparison of the study programmes shows that the third/fourth year leaves considerable possibilities for specialisation and that the programmes converge. Table 2 (page 9) summarises the available options and compulsory courses at the four universities. In the Annex, an overview is given of the contents of the major courses.

An indicator for the level of knowledge are examinations. The WG decided to exchange samples of written examinations among its members.

¹ IC London and CS TU-Delft deviate slightly from this scheme in that some choice is given in the first years and basic courses are spread over the first three years.

Weighting of subjects in the first two years

To compare the importance that is given to subjects in the first two years, we measure the importance in percent of the total number of hours in the first two years.

<i>Subjects in Computer Science</i>	<i>IC London</i>	<i>TU Delft</i>	<i>ETH Zürich</i>	<i>RWTH Aachen</i>
Programming *	17	17.5	13.7	10.5
Data Structures and Algorithms *	10	3.5	5.5	7.0
Discrete Mathematics and Logic	10	7.0	4.5	11.6
Theoretical Computer Science	10	7.0	4.5	9.3
Computer Architecture & HW-Prog. *	17	7.0	5.5	10.5
Communication (Networking, Distr. Systems) *	3	7.0	5.5	4.6
Special CS Topics (Databases, AI, Graphics, HCI) *	13	22.4**)	4.5	3.0
Scientific Computing *	3		9.1	4.6
Other Subjects				
Mathematics	7	16.6	20.0	16.3
El. Engineering			10.0	4.6
Physics			10.9	
General Education or Minor Subject	10	12.0	6.4	18.6

* Practical Laboratory Programming work involved

***) Some of these points could be spent on Software Technology and Information Systems topics as well.

Programming includes imperative, declarative, OO-concepts and elements of Software Engineering.

Theoretical Computer Science includes Computability, Complexity and Formal Languages

Mathematics includes Analysis, Algebra, Statistics and Probability

Scientific Computing includes Numerical Computing and the use of Computer Algebra

General Education: Humanities and Business Sciences

Noteworthy is that 30-40% of the courses in the first two years are related to formal and mathematical topics (Analysis, Linear Algebra, Discrete Mathematics, Logic, Theoretical Computer Science) which shows the formal and conceptual training CS students receive. These courses are the basis of the competences in "discrete modelling", a central task of professional computer scientists. The mathematical training of the CS students is therefore much more focused on discrete and logical structures than on continuous mathematics.

It took some decades in the development of modern Computer Science before the appropriate elements of abstract and linear algebra, logic, set theory, and statistical methods were distilled in order to underpin the rationality of programming and algorithmics (incl. data structures, object oriented methods, complexity, data bases, operating systems, compilers, graphics and human computer interfaces, and emerging technologies from artificial intelligence).

In this development, CS is moving far beyond the scope of its roots which have been in nearby fields, most notably in Electrical Engineering and Mathematics. Nevertheless, there has been a tendency to retain in the CS curricula some material of intellectually attested quality which has been in practice neither fundamental nor useful for the typical software engineer. Examples include traditional Mathematical Analysis, Electronic Circuit Analysis, Mechanics, and Physics. These subjects, however, are now gradually being diminished. Delft has recently departed from mechanics and physics, and the CS curricula at Imperial College have replaced Mathematical Analysis by a course on Mathematical Methods and Graphics. The CS education therefore differs considerably from Electrical Engineering and Physics.

Table 1. Overview of curricula

	1 st year	2 nd year	3 rd year	4 th year	thesis
IC London	Hardware & arch. Programming, incl. OO, FuncT-, LogicP Mathematics, include. Logic & Discrete Operating Systems Humanities/other	Computability Operating Systems, Databases, Software Design including HCI, Networking & Communications, Statistics, Compilers, Architecture, Artificial Intelligence Humanities/other	Software Eng. Management Advanced topics (+6 courses) Group project Industrial Placement for MEng (6 months) Humanities/other	Advanced CS topics (8 courses) Humanities/other	Bachelors project (3 months of Year 3) Masters project (3 months of Year 4 over Oct-June period)
TU Delft	Analysis Linear alg. Discrete str. and alg. OO-programming Computer systems General education Specialisation Project	Statistics Logics Programming lang. Software engineering Databases and AI Specialisation Project	Mathematics Theoret. comp. sci. General education Selective courses	Graduate courses within ST/IS/MK: Obligatory (16 pts) Selective (24 pts) Minor or internship (12 pts)	Bachelor thesis (3 months of year 3) Master thesis (9 months of year 5)
ETHZ	Programming, Data Structures, Physics, Mathematics, Statistics, Logics	System Programming, Introductions to: Theoretical Computer Science, Scientific Comp., Databases, Elec. Engineering	Theoretical Computer Science, Scientific Computing, Databases, Electrical Engineering, Digital Technology, Specialisation Industrial Placement (internship) at least 10 weeks Free choice of minor	Diploma thesis (exactly 4 months of year 5)	
RWTH	Programming, Data Structures, Linear Algebra, Discr. Structures Analysis Num.Math. Minor Subject	System Progr. Computability, Automata Theory SW project HW laboratory Logic, Probability Minor Subject	Theoretical Computer Science, Practical Computer Science, Special Subject, Application Subject (3 courses of each + 2 seminars + practicum) Minor Subject	Diploma thesis (6 months of year 5)	

Table 2. Options in third and fourth year

	Compulsory core courses	Available Options for deepening and/or specialisation within computer science	Other Subjects	Application of Computer Science
IC London	S/w Eng Methods Management & Finance Group project	Year 3: + 6 of Adv databases, Advance in AI, Distributed Systems, Info & Decision Supp, Operations Research, Advanced architecture, Computational Logic, Performance analysis. Adv, Knowledge Mgt, Custom computing, Robotics, Simulation Year 4: 8 of Concurrent Computation, Network security Safety critical systems, Adv OR, Comp. vision, Datamining, Modal & Temp Logic, Natural Lang Proc., Automated reasoning, Multi-agent systems, Complexity, Parallel algorithms, Quantum computing, etc.	Options on Humanities, Foreign Language, Economics	Group project Indiv. Project presentation Project Outsourcing Report for MEng stud. + MEng; Industrial Placement (6mths) Seminar on placement
TU Delft	For year 3, see table 1. Year 4: 30 pts in one of the masterspecialisations ST, IS or MK.	ST (1, 2 and 3 rd year): Digital Technology, Operations Systems, Realtime embedded systems, Computer architecture, Compilers, Process synchr, Computer security, Coop. agent-based systems, High performance computing, etc. IS (1, 2 and 3 rd year): Design of IS, Internet, Management of inform. systems, Business process model., System engineering, Workflow systems, Database design, etc. MK (1, 2 and 3 rd year): Human-Computer Interaction, Knowledge engineering, Multimodal interaction, Image processing, 3D computer graphics, Expert systems, Neural networks, etc.	Fourth year: selective courses on social sciences and business sciences	Bachelor project can be done within industry. The fourth year has room for a minor or an external stage/internship.
ETHZ	Hardware and Computer Arch., System Software, Databases, Theoretical CS, Scientific Comp. (4 out of the 5 required).	6 out of 75 required <i>Main areas:</i> Databases and Information Systems, Graphics, Distributed Systems, Communication and Networking, Security, Compilers, Software Engineering, Algorithms, Computational Science	Minor (1/10 of study programme) Often: Robotic, Business courses or Social courses	Two projects (1 in CS, 1 in the minor) seminar talk Internship (at least 10 weeks)
RWTH	3 courses from Theoretical CS 3 courses from Practical CS (1 course = 4 h/week + problems class)	3 courses from one of the following special areas: algorithms and complexity, logic and deduction, automata and theory of discrete systems, programming languages, program verification, compiler construction, software engineering, communication and distributed systems, performance evaluation, operating systems, inform. systems and data bases, knowledge based systems and robotics, speech processing and pattern recognition, computer graphics and multimedia, high performance computing, visualization of numerical simulation	Minor Subject: Elect.Engin., Math., Physics, Economics, or other	1 Practicum 2 Seminars (each incl.15 pp. paper)

6. *Formal procedures*

Exams and credit systems

The frequency of the exams and the regulations concerning the examinations are different:

IC: Examinations take place each year in May. If a student fails marginally he can redo at most two examinations in September for qualification (but not for obtaining a better mark). Laboratory work and exercises count separately (with no second chance). These are used for the continuous assessment. Failure to fully participate in the continuous assessment process can be grounds for a student to be required to withdraw from the course. High entry requirements mean that only about 10% drop out of the course, and most of these complete a degree at another UK university, with some credit for their IC work.

TU Delft: A credit system is valid from the first semester on (not ECTS: 42 credits p.a.). Students can repeat examinations an unlimited number of times. Points are only given for passed exams. There is no upper limit on the total study time but students are limited by financial support. Each course has a written exam (unless there are fewer than 5 students in the course). The exam is held twice per year, there is no “global” or final exam. The transcript shows only the highest or latest grades.

ETH Zürich: Written examinations (Vordiplom) take place in Fall after the first and second year. All subjects taught are examined. The first examination, after a year of studies (1. Vordiplom) is de facto an entrance exam. Drop out rate is about 50% after the first year and about 30% in the second year. The average of the grades of one exam must be sufficient for passing. A failed Vordiplom can be repeated as a whole once, usually in Spring. All subjects taught in the first two years are mandatory and examined.

For the third and fourth year (Fachstudium), a credit system (American style) is used. Every course taken in a semester is examined before the next semester starts. Credit points (adapted to the ECTS) are only given if the grade is sufficient. The diploma can be obtained if the student has acquired 120 credit points. Courses that were failed because of an insufficient grade in the examination are reported on the transcript. In order to limit the total time of study, the student has to acquire the 120 credit points (i.e. the last two years) in 4 years.

RWTH Aachen: The Vordiplom consists of six parts, assessed only by written examinations (the only way to handle the present large number of students): three parts of the Vordiplom belong to CS, two to mathematics, and one to a rather freely chosen minor subject (EE, economics, a natural science, mathematics, ...). More specifically, the parts are the following: programming and data structures, computer organization and system programming, theoretical computer science (computability, complexity, automata, languages), linear algebra and discrete structures, analysis and probability/ statistics, minor subject.

The diploma exam consists of five parts: four oral exams, each consisting of an individual interview of about 40 minutes, covering the material of 2-3 courses, and the diploma thesis, which should address a scientific, methodological aspect and in most cases involves practical work in some CS system development or CS application project.

The four oral exams deal with the following subjects: theoretical computer science (3 courses covered), practical computer science (3 courses covered), an area of specialization (3 courses covered in a selected field in CS or in the intersection of CS with a neighbour discipline), plus a minor subject (2 courses in the same minor subject as in the Vordiplom).

Because of the significance of the minor subject, the diploma examination does not only require in-depth studies but also involves a broadness of spectrum which is not present in usual MSc degrees. The Aachen diploma insists on these interdisciplinary connections.

Internship, projects, theses

IC London: The MEng degree includes a six month agreed industrial internship, including report. Both MEng and BEng also include group and individual projects. Because the MEng gives full exemption from Professional Institute examinations of the IEE and BCS, a successful industrial internship, group project, and individual project is mandatory.

TU Delft: Currently the third year has a project of 10 weeks which in most cases is done in industry. The project encompasses full analysis, design and implementation tasks for an information system. The new Bachelor’s degree (12 weeks) will be modelled accordingly. The Master’s thesis project extends over 32 weeks, which is considerable longer than the thesis projects at the other partners. With this extended period the technical universities in the Netherlands want to stress the importance of a large engineering project with a reasonable amount of implementation and testing. Most of these projects are done in industry.

ETH Zürich: Each student is required to pass an internship of at least 10 weeks in industry. S/he has to write a report on the internship. A student has to do two larger programming projects (Semesterarbeiten) of at least 180 hours of work, write a report and give a talk in a seminar. One of the Semesterarbeit is in core computer science and one in the minor. The Diploma thesis is another practical work of 4 months.

RWTH Aachen: Before doing the Vordiplom, a software project is required, usually a semester project which is done in small teams of two or three students. Often these teams are part of a larger project in which a class (30 students) join for construction of a larger system. In the advanced studies, most students enter project work within the CS research groups, or in project groups of engineering departments, or in system development of the local CS industry. Although an internship is not formally required, the overwhelming majority of the students acquires practical experience of six months and more after the Vordiplom examination. In many cases this is connected with system development in connection with the diploma thesis.

7. Position of CS at the technical universities

Computer Science has emerged rapidly and has shown a dramatic increase in the number of students over the last ten years. Except for IC, the other partners have to accept every student that qualifies at school examination level. However, the growth in number of students has not been balanced by a similar growth in staff and building space. Even if staff positions are available it is often hard to find qualified staff. The overload on teaching then further hampers the development of research.

CS departments also have to compete for their share of scarce resources with other departments within the university that are long established and traditionally better resourced. At the same time, the CS curricula have to respond to the fast changing conditions in industry and the rapid developments in the discipline itself.

Regarding the position of CS degrees, we address here two issues: the relation to Electrical Engineering and to the polytechnics.

Relation with Electrical Engineering

In general we can observe a move in EE towards CS. Hardware becomes programmable (FPGA, Field Programmable Gates Arrays) and thus CS knowledge and tools become necessary. Communications systems, mobile and embedded computing are further typical examples of areas where both CS and EE overlap. Many EE departments have reacted by changing their orientation to include computer engineering and information technology, sometimes even reflected in a name change. These conversions should not obscure the fundamental differences in the curricula as already mentioned earlier: EE necessarily retains physics and is thus more concerned with *continuous* than with *discrete* mathematics. CS being primarily concerned with software systems needs to emphasize discrete mathematics and logic, and moves away from traditional engineering foundations like mechanics and general physics. As explained below, there are profitable combinations, but attempting to combine in depth education in each of these areas makes the program too heavy or will result in a problematic compromise (i.e. too many topics in too few hours).

For ten years **IC London** has had a joint course with EE, attended by the best students. This course has now become a stream within EE, with CS contributing only to the third and fourth year. CS and EE are both embedded in the Engineering Faculty. CS is not concerned with losing some students to EE, strong students with good job opportunities still remain in CS.

TU Delft has recently merged CS, EE and TW (technical mathematics) into one faculty, the Faculty for Information Technology and Systems. The aim was to reduce administrative overheads and to improve synergies and collaboration among groups in EE and CS. This may have prevented some of the controversies that are manifest in other institutions. A similar development is being done at ETH Lausanne. The central board of the TU Delft has the further intention to reduce the number of Bachelor degrees to 5 or 6 (compared to the 17 degrees now). This could mean that CS students would have to take more general engineering courses (mechanics and physics) than they do now.

At **ETH Zürich** CS students at ETH Zürich can specialize in EE by taking courses from the EE curriculum and also by writing a term paper and doing their diploma thesis under supervision of an affiliated EE professor. About one third of the EE professors are affiliated to CS and thus allowed to supervise diploma theses of CS students. There are proposals to establish a common Master's curriculum in Communication and Information Systems. Merging CS and EE, or some of the research groups, is also being discussed.

At **RWTH Aachen**, several professors of the EE faculty are integrated into the CS curriculum. They do not teach courses of the first two years but contribute to the areas of specialization from which a CS student has to choose. Also the minor subject can be chosen to be EE. On the level of research, e.g. in diploma thesis supervision, there is a tradition of cooperation. Recently, there are more explicit moves of EE towards computer science: The name of the EE faculty has been changed to "Faculty of Electrical Engineering and Information Technology", and a new curriculum called "technical computer science" (Computer Engineering) has been introduced. This curriculum, however, has only a small portion of mathematical education devoted to discrete structures, languages, and the science of programming.

Conclusions:

The WG observed that EE is in general better equipped with resources and positions than CS, especially in TUD, ETH, RWTH where CS has a very high number of students. The trend of interdisciplinary cooperation in research and curricula most likely will be profitable for both sides, but one should not underestimate the basic differences in the approach between EE and CS.

Relation to Polytechnics (Universities of Applied Sciences)

UK: Since 1992 the polytechnics are funded by the government in the same way as the universities, also for research. However, all universities and university departments in the UK are ranked by various public research and teaching assessments and vary considerably in the spectra of courses offered. The rankings are fairly stable, with IC among the top ranked universities. Furthermore the Professional Societies of Electrical Engineering and of Computer Science grant a “professional” status to certain degrees, distinguishing Professional grades from Technical grades. Students accepted at prestigious places must bear significant pressure. For a student to leave without a degree is not good for the Department or the student, but if a student gets a degree at another university with less pressure it is ok. Companies go after the students of the best universities. A few of the new universities do better than some traditional ones.

The Netherlands: The differences between the technical universities and the polytechnics are widely acknowledged, and there is up to this moment no confusion. This may change as the same title ‘Bachelor’ is applied to degrees.

Switzerland: The polytechnics are in the stage to become *Universities of Applied Sciences* (UAS). Their duration of studies is 3 years and the degree obtained is a Bachelor. Some polytechnics introduce more fundamental courses (mathematics, physics) to upgrade their programme and to compete with the Universities. There is a concern that a University Bachelor in CS might be less attractive for the industry than a Bachelor in CS from a UAS.

Germany: “Universities of Applied Sciences” (“Fachhochschulen”) were founded more than 20 years ago and meanwhile have acquired a well-recognized status in the German system of tertiary education. The UAS have four-year curricula (also ending with a “Diploma”), focussing on the training to apply state-of-the-art engineering techniques in the construction of (CS-) systems. There is a move in German politics to lift the UAS level to that of proper universities (maybe even including the right to grant doctoral degrees). The introduction of a sequential BSc/MSc scheme is recommended to the universities as a decisive step for this unification. The technical universities fear that, in comparison with the UAS diploma which runs for 4 years, the introduction of a three year BSc degree would mean creating a weaker degree whose acceptance on the labor market is unclear. Moreover, the CS departments of UAS are allowed to impose admission rates (to comply to their class oriented teaching), and to choose the best applicants if these rates are exceeded. Neither of these options has been conceded to the universities.

Under these conditions, universities are presently offered a strict either-or-decision to adopt the (supported) sequential BSc/MSc scheme or to stick to the (temporary tolerated) diploma curriculum. In order to preserve its standards and to fulfill its primary task as a place of transfer from research to industrial practice, CS of RWTH Aachen decided to continue with the diploma curriculum (however offering a two-year's Master program for foreign students with a Bachelor's degree).

Conclusions:

Relations with polytechnics (Universities of Applied Sciences) is an issue in the continental universities. There is less concern in UK because all the universities (including the former polytechnics) come under the same funding system and are ranked by a variety of criteria. In the Netherlands and in Switzerland there is at present no confusion because bachelor's degrees have been confined to the UAS. The situation would change if students begin leaving the universities with a Bachelor's degree instead of the traditional Diploma or Master. Especially in Germany (where there is a 4 year Diploma curriculum in the UAS), the Universities fear that a three year BSc degree would mean creating a weaker degree whose acceptance on the labor market is unclear.

8. Bachelor/Master Degrees

The Bologna declaration proposes a uniform scheme for university education consisting of two sequential phases of education: undergraduate and graduate cycle. The introduction of bachelor-master degrees along these lines marks a significant departure from the traditionally undivided curricula, like the Engineering Diploma.

The current situation within IDEA

Imperial College awards bachelors as well as master degrees, but the main MEng-degree is an undivided four-year course, and the BEng only shares the first two years with the MEng. The bachelor is therefore not an intermediate degree; it is an earlier way out to the labour market or to another discipline.

Imperial College also offers an Advanced MSc programme for students with a good Bachelor degree in Computer Science, typically from another institution. This Masters track is comparable to the final (4th) year of the standard MEng. As a third option, IC runs a *conversion* MSc, for students with a good bachelor's degree in other technical subject, plus a certain amount of computing experience. These students have a special programme that is comparable to a compressed selection from second and third year of the bachelor's programme, followed by an extended individual project where some demonstration of computer science skill is expected.

Both Aachen and Delft currently have an international MSc which accepts students with good and evaluated Bachelor degrees.

Delft will implement a sequential bachelor-master structure for the regular curriculum, but prefers to see the bachelor as a 'virtual' degree.

Aachen and Zürich offer the 4.5 year Diplom and do not presently grant Bachelor degrees.

The undivided engineering degree

The practice of a longer period of study for recognition as a professional engineering graduate (the German-style Diplom) is a tradition which has only recently been practised in the UK, where the MEng degree has now become recognised, but it is only offered at a few leading research oriented universities. At the same time there is political pressure in some countries where the Diplom is traditional to reduce the duration of study for the majority of students; hence we see the pressure for a vertical separation between the core competences but limited in depth breadth of study of the Bachelors level, and the more professional higher level of engineering expertise which requires four to five years of study.

To impose a BSc/MSc division on the current undivided MEng or Diploma curriculum may in fact be inefficient in cases where a change of university or subject is not intended. At IC it is not current practice for its own best students to require a bachelor's degree. Instead, an internal quality check is imposed on those students who aspire to a full MEng. This is comparable to the Vordiplom level at Aachen and Zürich and the propadeuse in Delft. To require the Bachelor qualification introduces some inefficiencies for master students who in any case will be doing project/thesis work at the Master's level as well. The BSc/MSc division could be imposed in each case, at some cost to local traditions. However, there seem to be few benefits of requiring this division in all cases, as opposed to allowing it, which is the *de facto* case at IC.

BSc as an early out

In Aachen, Delft and Zürich, since there is no selection for admission, it is likely that, after introduction of a Bachelor degree, a significant proportion of students will leave university after the bachelor. This raises the issue whether a bachelor (from a technical university with unselected admission) is relevant to the European labor market as an appropriate level of qualification, and how it compares with the existing bachelor degrees of the polytechnics. Aachen and Zürich are concerned that their bachelors will not meet the expectations of their industrial customers.

There is also concern that with a bachelor degree standards are lowered in the basic courses, because one would have to treat too practical topics from the first year on. Good students would then not get what they deserve. One possibility is that the UK solution for BSc course in Computer Science may need to be adopted, where on the one hand the less immediately relevant physics, electronics and non-discrete mathematics is much reduced and where on the other hand a Y-model is used instead of a sequential Bachelor-Master curriculum. In the Y-model it is decided after two years which of the students go for a Bachelor and which follow the undivided MEng curriculum.

Conversion MSc

The general idea of the bachelor-master division is to have an exit point with certified qualification that gives access to any number of “specialised” masters. This can also involve inter-disciplinary crossings. This will lead to an influx (to the master) of students from other disciplines than computer science. In that case there could exist a serious deficiency, which then introduces the need of special *homologation* or conversion courses. As mentioned above, IC has a special Conversion MSc. TU Delft considers adaptation courses in the fourth year.

Definition of level/qualification

The Bachelor’s Level

At a typical UK University the Bachelor degree provides the competences of at least three years tertiary education attaining in depth state of the art knowledge in one recognised field of study. In the UK this is the normal graduation level for students intending to enter any professional field, although most professions, including Engineering and Computer Science then require further work-related professional training.

The authors of this report can recognise a core level of competences for a bachelor level in computer science as comprised of problem solving, state of the art knowledge, and software engineering skills. Thus we expect in depth theoretical and applied skills in programming (including object oriented programming, data structures, databases, graphics, networks, concurrent programming systems and human computer interaction), along with the underpinning knowledge in logic, algebra, and statistics, reasonable appreciation of the state of the art in computer architecture and operating systems, and practical awareness of the state of the art in scientific software-engineering methods.

It is also usual to require evidence of the ability to perform work in an independent way, accessing sources of knowledge, often demonstrated by a bachelor’s level individual project. There is also usually some opportunity to obtain more specific technical competences and/or cultural breadth or appreciation of management skills.

There is a consensus in this report that to attain bachelors level skills in the field in three years of study it becomes essential to prune out some traditional areas of study from nearby fields.

In short terms one can summarize the profiles of **bachelor** as follows:

- Core competences in the subject, i.e. understanding of simple hardware systems, mastering the method of systematic programming, mastering the fundamental concepts of algorithm and data structures, knowledge of the most important classical and modern algorithms and data structures, ability to evaluate qualitatively and quantitatively algorithms and data-structures with respect to a specific application, knowledge of the important program paradigms (e.g. imperative, functional, logic), mastering of the concepts of the programming in the large (e.g. interfaces, modularizing, classes, frameworks, multi-processes, distributed systems), insight in data bases in consideration of implementation- and application aspects
- Acquaintance with the state of the art, ability to access and understand the relevant knowledge sources
- Ability to perform some work in the field in an independent way

The Master’s Level

The Masters level student is expected to reach a still higher technical and abstract level of skill and maturity. A profound overview vertical through all abstraction layers of a computer system (e.g. the layers of specification, of problem- and machine-oriented programming, of computer architecture, of compilation) is expected. This is a level where complex new systems can be conceived, modelled, and designed using a range of emerging specialist computing technologies, often involving applications with artificial intelligence, security implications and distributed network applications. Such engineering competences also often require a level of interdisciplinary awareness of related fields that is second only to specialist of those fields. Thus at the master’s level we expect considerable awareness of advanced subfields, a capacity for mathematical modelling and appreciation of the physical, electronic and cultural environment of application. There is often interface with technologies emerging from research and development. A master’s level graduate should have the capacity to plan and contribute to such projects, reflect on the state of the art and communicate with professionals from other fields. This level of sophistication requires practical experience of industry, working with others, and independently. So a Master’s programme will include training periods intended to provide each.

At IC, each student is required – prior to the master’s year - to undertake an industrial placement in a technically structured environment, to make a contribution, and to report on it. Specialist options typical of the Master’s student are listed in the curricula of section 2, but some professional or business training courses are also provided. A Master’s level individual project is more advanced and original than at the Bachelor’s level.

One can summarize the profiles of **master** as follows:

- Understand and model large systems, their architecture, construction and maintenance; profound overview vertical through all abstraction layers of a computer system (e.g. layer of specification, of problem- and machine-oriented programming, of computer architecture, of compilation).
- Ability to plan and execute a larger scale project (thesis work) which captures the state of the art or is at the frontiers of current research; ability to present a computer project concept written and orally.
- Specialist knowledge on near research level in at least one area of computer science
- Ability to reflect on the state of the art
- Ability to communicate with professionals of other disciplines, and the ability to use computer science as tool in other disciplines.

9. Mobility

We distinguish two concepts of mobility: Horizontal mobility refers to student moves for some semesters (usually, a year) to a partner university, after which a return takes place and the degree is finished in the home university. In contrast we speak of vertical mobility if the student moves permanently to a partner university where he obtains a degree.

Horizontal mobility

The benefits and goals connected with external periods of study are the following, listed here in the order from the more general to the more specific gains:

- The student is trained in a foreign language and gets experience with different academic environments and different cultures.
- The professional competence on the international level is improved considerably.
- A stay at a host university where certain areas are well represented will lead to better expertise in these areas, giving a gain to the overall quality of the studies performed.

To obtain an attractive program of options for horizontal mobility, an essential prerequisite are regulations of the respective home university which allow studies in the foreign university to be recognized for the final exam at the home institution.

The partners agreed that the best time for moving temporarily to a foreign university is in the 3rd or 4th year of study, and that the time spent at the host university should be one or two semesters.

This form of horizontal mobility is easy in the sense that everything is finally integrated into only one curriculum (the one of the home university); it requires, however, the definition of interfaces between the respective two partner universities.

IC: Exchange of students is often limited due to low language confidence and local parochialism. Also some institutional obstacles exist, e.g. the financial need to balance the number of incoming students with the number of outgoing students. The UK system is now much more commercially based than it used to be, with student tuition fees and University teaching funded by contracts with the National Higher Education funding body. This makes it expensive for students and difficult to arrange horizontal mobility because it needs to be financially neutral. For the MEng (European Studies) Programme the students do their 4th year at the technical university of Grenoble, Paris, or Karlsruhe, only exchanging 4th year assessments.

TU Delft: There are no formal restrictions. Many students (50%) spend some time at other universities either for their 3rd year project, their master thesis work, or for Erasmus and other european course exchange programs.

ETHZ: With its ETCS compatible credit system horizontal mobility is relatively simple for ETHZ students. It is, however, restricted to a maximum of one year (60 credit points), and not applicable in the first two years of the curriculum.

RWTH Aachen: A practical and well-established way to support international exchange is to send students abroad for one year, where they can pass the equivalent of one or two parts of the Aachen diploma. These exams (including marks) are transferred to the Aachen diploma certificate. Also preparatory work for the diploma thesis could be done abroad; however, the diploma thesis itself has to be supervised and evaluated by a professor from the Aachen CS department. The details are settled for each case individually, but according to these general rules.

Conclusions:

The working group agreed that one semester or one year is a reasonable duration for horizontal mobility (temporary study at a partner university) after the second or third year of the curriculum. Because of the different

examination systems (ETH and Delft are using a credit system, Aachen has oral final Diploma exams and IC has the examination period in May), it is important that the courses and the examinations to be taken are discussed and scheduled in agreement with the home university before the student visits the guest university.

Vertical mobility

The goal of vertical mobility is to continue the studies (for a master) at another institute to achieve competence in a different or more specialised field. Typically this requires completion of a first degree (Bachelor) in order to gain admission to the postgraduate programme (MSc).

The working group agrees that within the IDEA League a necessary condition for the final stages of a masters program is high level Bachelor's grades. Thus it recommends that the Bachelor's level be formalised at each institution, and in such a way that mobility be encouraged.

IC: The 4-year MEng courses do not have an intermediate bachelor's degree. To continue on the MEng master program after the second year, a high grade is required, otherwise a student is transferred to an appropriate point on the (3-year) BEng programme. A Student may also choose to do BEng, rather than an MEng degree for educational or financial reasons. The BEng is shorter (3 years), and it provides an educational foundation in Computing Science for less specialised technical work in Industry, or for further postgraduate training.

Good Computer Science students from outside IC are accepted for an Advanced MSc. This takes a full year, including an individual project. Many courses are the same as the MEng fourth year options. There is also a conversion MSc of one year for students with other Science and Engineering degrees (see section 6). To assess the quality and background of a student from elsewhere, IC relies on its registry, the student's transcript, individual BSc project, and on letters of recommendation. MSc programmes are considered postgraduate; the candidate needs a bachelor to be admitted.

ETH Zürich: Every application to enter the current Diploma study is discussed individually "sur dossier". There is usually an entrance examination which can consist of some subjects examined in the Vordiploms. This also holds for students with a bachelor degree from polytechnics.

TU Delft: There is a quality check before being admitted to a master program. A bachelor of the home institution is always required to enter the master program.

RWTH Aachen: Foreign students may enter the Diploma curriculum after an individual check of their previous studies. For the M.Sc. curriculum, foreign bachelor degrees are accepted after an evaluation by the Aachen office of international studies.

Conclusions:

Vertical mobility (permanent move to another university) to acquire a Master's degree (or Diploma) at another university is currently only possible by examining the student "sur dossier" at ETH and RWTH Aachen. IC requires the student to have a Bachelor's degree before admission, which prevents ETH and Aachen diploma-students from being admitted at this stage. The teaching language (if different from English) is (still) an obstacle for vertical mobility, ETH offers already courses in English and is considering Master's programmes completely in English. RWTH Aachen offers several advanced courses in English for the students of the Master's program and of the Diploma curriculum.

10. Summary, recommendations, comments

An analysis of the curricula and explanations above shows many differences in the four universities. These differences are clearly visible in the following aspects:

- conditions of admission,
- number of admitted students (in relation to available staff),
- strictness of study organization,
- emphasis on relation to neighbour disciplines,
- details of examination procedures
- financial basis of participation and University funding.

On the other hand, there is a remarkable congruence in the academic essentials, namely in the overall aim of the CS studies as offered by the four universities, the distinct profile and orientation of the existing curricula, which covers both their content and their duration.

In short terms, it is agreed among the partner universities that their CS education is explicitly and continuously based on scientific principles (concepts, laws, methods), and that the CS training must be actively connected to

the current state of research. Only this exposure of students to current problems and research progress, which in itself requires a solid scientific background, will ensure an efficient transfer from IT research to industrial practice (which in fact is the strategic task of technical universities).

Thus a common feature of the curricula is the central status given to a broad and intensive training in CS foundations over the first two years. This is reflected in a high proportion of mathematical or theoretically oriented courses. A distinction to all other curricula, especially those of electrical engineering departments, is the emphasis on a wide spectrum of discrete mathematics, which somehow includes also the subjects of theoretical computer science. As a consequence, there is a common understanding among the four partner universities that a period of 4-5 years is necessary as the preferred duration of study. This duration is fixed in the diploma curricula at ETHZ and RWTH Aachen, and it is the recommended one at IC and TU Delft, which however also allow an early exit with bachelor degrees. For further development of the CS curricula it has to be discussed whether this option can be incorporated also at ETHZ and RWTH Aachen, and how to define the interfaces which are needed to support studies of one year abroad. The latter task is to be distinguished from the option of an early leave with the bachelor's degree.

All partners share common problems in implementing the curricula: It is hard to establish the necessary positions for academic staff and corresponding funds, while at the same time the number of students is rising extremely fast.

The present report does not give detailed information/suggestions on

- the research profiles (and options for specializations of study) at the four partner universities,
- practical guidelines for horizontal mobility,
- options for staff exchange.

This could be addressed in later activities of the WG together with other issues like a more elaborated curriculum comparison (minimum topic list) and a list of master specialisations (which are not yet available).