MASTER'S PROGRAMME

COMPUTER SCIENCE

FACULTY OF ELECTRICAL ENGINEERING,
MATHEMATICS AND COMPUTER SCIENCE

DELFT UNIVERSITY OF TECHNOLOGY

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This report was finalized on 8 January 2020.

REPORT ON THE MASTER'S PROGRAMME COMPUTER SCIENCE OF DELFT UNIVERSITY OF TECHNOLOGY

This report takes the NVAO's Assessment Framework for the Higher Education Accreditation System of the Netherlands for limited programme assessments as a starting point (September 2018).

ADMINISTRATIVE DATA REGARDING THE PROGRAMME

Master's programme Computer Science

Name of the programme:	Computer Science
CROHO number:	60300
Level of the programme:	master's
Orientation of the programme:	academic
Number of credits:	120 EC
Specializations or tracks:	Data Science and Technology (DST) Software Technology (ST)
Location(s):	Delft
Mode(s) of study:	full time
Language of instruction:	English
Submission deadline NVAO:	01/05/2020

The visit of the assessment panel Computer Science to the Faculty of Electrical Engineering, mathematics and computer science of Delft University of Technology took place on 26 and 27 June 2019.

ADMINISTRATIVE DATA REGARDING THE INSTITUTION

Name of the institution:	Delft University of Technology
Status of the institution:	publicly funded institution
Result institutional quality assurance assessment:	positive

COMPOSITION OF THE ASSESSMENT PANEL

The NVAO has approved the composition of the panel on 15 april 2019. The panel that assessed the bachelor's programme Computer Science and Engineering and the master's programme Computer Science consisted of:

- Em. prof. dr. T. (Theo) D'Hondt, emeritus professor in Software Languages and Software Engineering at the Faculty of Sciences and Bioengineering Sciences of Vrije Universiteit Brussel (Belgium) [chair];
- Prof. dr. ir. W.E.A. (Wim) Van Petegem, professor and policy coordinator Learning Technologies at the Faculty of Industrial Engineering Technology of KU Leuven (Belgium);
- Prof. dr. S. (Sjouke) Mauw, professor in Security and Trust of Software Systems at the Department of Computer Science of the University of Luxembourg (Luxembourg);
- A. (Antonia) Wildvank, owner and manager of the company Wildvank Management en Advies;
- B. (Baran) Erdogan, third year bachelor's student Computer Science at the University of Amsterdam [student member].

The panel was supported by M. (Mark) Delmartino MA, who acted as secretary.

WORKING METHOD OF THE ASSESSMENT PANEL

The site visit to the master's programme Computer Science at the Faculty of Electrical Engineering, Mathematics and Computer Science of Delft University of Technology was part of the cluster assessment Computer Science. Between June and December 2019 the panel assessed 29 programmes at 10 universities. The following universities participated in this cluster assessment: Leiden University, Delft University of Technology, University of Utrecht, Eindhoven University of Technology, Open University, University of Amsterdam, Vrije Universiteit Amsterdam, Radboud University, University of Groningen and University of Twente.

On behalf of the participating universities, quality assurance agency QANU was responsible for logistical support, panel guidance and the production of the reports. P.A. (Peter) Hildering MSc. was project coordinator for QANU. P.A. (Peter) Hildering MSc. and M. (Mark) Delmartino MA acted as secretary in the cluster assessment.

During the site visit at Delft University of Technology the panel was supported by Mark Delmartino, who is a certified NVAO secretary.

Panel members
The members of the cluster assessment panel were selected based on their expertise, availability and independence. The panel consisted of the following members:

- Em. prof. dr. T. (Theo) D'Hondt, emeritus professor in Software Languages and Software Engineering at the Faculty of Sciences and Bioengineering Sciences of Vrije Universiteit Brussel (Belgium) [chair];
- Prof. dr. ir. W.E.A. (Wim) Van Petegem, professor and policy coordinator Learning Technologies at the Faculty of Industrial Engineering Technology of KU Leuven (Belgium);
- Prof. dr. S. (Sjouke) Mauw, professor in Security and Trust of Software Systems at the Department of Computer Science of the University of Luxembourg (Luxembourg);
- Prof. dr. J.J. (John-Jules) Meyer, full professor Computer Science and Artificial Intelligence at Utrecht University;
- Drs. L. (Lennart) Herlaar, owner/director at Redbits.nl, a company specialized in software development and IT consultancy, and assistant professor Computer Science at the Faculty of Science of Utrecht University;
- A. (Antonia) Wildvank, owner/CEO at Wildvank Management en Advies, specialized in IT-management and -consultancy;
- Prof. dr. J. (Jan) Aerts, full professor Visual Data Analysis at the University of Hasselt and associate professor Visual Data Analysis at the faculty of Engineering Science at KU Leuven (Belgium);
- Drs. H.C. (Jeroen) Borst, senior consultant Smart Cities at TNO;
- Prof. dr. P. (Petros) Koumoutsakos, full professor Computational Science at ETH Zürich (Switzerland);
- Prof. dr. ir. J.M.W. (Joost) Visser Chief Product Officer at Software Improvement Group Nederland en professor Large-scale Software Systems at Radboud University;
- Drs. E.A.P. (Ewine) Smits, Manager in Advanced Analytics & Big Data at KPMG Nederland;
- Prof. dr. D.P. (Danilo) Mandic, full professor Signal Processing at the department of Electrical and Electronic Engineering of Imperial College London (United Kingdom);
- Dr. ir. J.C. (Job) Oostveen, Research Manager at the Department Monitoring and Control Services at TNO;
- Prof. dr. B.A.M. (Ben) Schouten, full professor Playful Interactions at Eindhoven University of Technology.
- Dr. ir. N. (Nico) Plat, owner/CEO at Thanos IT-consultancy and architecture;
- N. (Nienke) Wessel BSc, master's student Computing Science, master's student Mathematics and bachelor's student Linguistics at Radboud University Nijmegen [student member];
- E. (Evi) Sijben BSc, master's student Computing Science in the specialization track Data Science at Radboud University Nijmegen [student member];

- B. (Baran) Erdogan, third year bachelor's student Computer Science at University of Amsterdam [student member];
- M. (Martijn) Brehm, third year bachelor's student Computer Science at University of Amsterdam [student member].

Preparation
On March 21st, 2019, the panel chair was briefed by QANU on his role, the assessment framework, the working method, and the planning of site visits and reports. A preparatory panel meeting was organized on May 9th, 2019. During this meeting, the panel members received instruction on the use of the assessment framework. The panel also discussed its working method and the planning of the site visits and reports.

The project coordinator and secretary composed a schedule for the site visit in consultation with the Faculty. Prior to the site visit, the Faculty selected representative partners for the various interviews. See Appendix 4 for the final schedule.

Before the site visit to Delft University of Technology, QANU received the self-evaluation reports of the programmes and sent these to the panel. A thesis selection was made by the panel's chair and secretary. The selection existed of 15 theses and their assessment forms for the programmes, based on a provided list of graduates in the academic years 2016-2017 and 2017-2018. A variety of topics and tracks and a diversity of examiners were included in the selection. The secretary and panel chair ensured that the distribution of grades in the selection matched the distribution of grades of all available theses. After studying the self-evaluation report, theses and assessment forms, the panel members formulated their preliminary findings. The secretary collected all initial findings and questions and distributed these amongst all panel members.

At the start of the site visit, the panel discussed these initial findings, identified the key issues to be discussed during the sessions, and agreed on a division of tasks during the site visit.

Site visit
The site visit to Delft University of Technology took place on 26 and 27 June, 2019. Before and during the site visit, the panel studied the additional documents provided by the programmes. An overview of these materials can be found in Appendix 5. The panel conducted interviews with representatives of the programmes: students and staff members, the programme's management, alumni and representatives of the Board of Examiners. It also offered students and staff members an opportunity for confidential discussion during a consultation hour. One student made use of this opportunity.

The panel used the final part of the site visit to discuss its findings in an internal meeting. Afterwards, the panel chair publicly presented the panel's preliminary findings and general observations.

The visit was concluded with a development conversation, in which the panel and the programmes discussed various development routes for the programmes. The result of this conversation is summarized in a separate report.

Consistency and calibration
In order to ensure the consistency of assessment within the cluster, following measures were taken: the panel composition ensured regular attendance of three core panel members, including the chair, and the project coordinator was present at the panel discussion leading to the preliminary findings of each programme at all site visits.

Report
After the site visit, the secretary wrote a draft report based on the panel's findings and submitted it to the project coordinator for peer assessment. Subsequently, the secretary sent the report to the panel. After processing the panel members' feedback, the project coordinator sent the draft report to the Faculty in order to have it checked for factual irregularities. The project coordinator discussed

the ensuing comments with the panel's chair and changes were implemented accordingly. The report was then finalized and sent to the Faculty and University Board.

Definition of judgements standards
In accordance with the NVAO's Assessment framework for limited programme assessments, the panel used the following definitions for the assessment of the standards:

Generic quality
The quality that, from an international perspective, may reasonably be expected from a higher education Associate Degree, Bachelor's or Master's programme.

Meets the standard
The programme meets the generic quality standard.

Partially meets the standard
The programme meets the generic quality standard to a significant extent, but improvements are required in order to fully meet the standard.

Does not meet the standard
The programme does not meet the generic quality standard.

The panel used the following definitions for the assessment of the programme as a whole:

Positive
The programme meets all the standards.

Conditionally positive
The programme meets standard 1 and partially meets a maximum of two standards, with the imposition of conditions being recommended by the panel.

Negative
In the following situations:
- The programme fails to meet one or more standards;
- The programme partially meets standard 1;
- The programme partially meets one or two standards, without the imposition of conditions being recommended by the panel;
- The programme partially meets three or more standards.

SUMMARY JUDGEMENT

This evaluation concerns the master's programme Computer Science (CS), a two-year full-time 120 EC programme offered by the Faculty of Electrical Engineering, Mathematics and Computer Science at the Delft University of Technology.

The CS programme aims to provide students with knowledge, skills and a clear understanding of the area of computer science, in order for graduates to independently perform professional and scientific activities. To reach this goal, the programme offers students a variety of courses clustered around two broad tracks–Data Science and Technology and Software Technology - and three special programmes: Bio-Informatics, Information Architecture and Cybersecurity. An important item of discussion during the site visit was the number of master students, a figure that is likely to increase further given the enormous growth of the bachelor's programme Computer Science and Engineering.

The programme's ambitions are embedded properly in the intended learning outcomes, which are founded in the faculty's research portfolio, the European-wide Dublin Descriptors and the international ACM curriculum. The panel considers that the formulation of the intended learning outcomes appropriately reflects the discipline, level and orientation of the programme. Nonetheless, it encourages the programme to perform another round of ILO re-formulation in line with the 3TU Criteria. Because it is not explicitly mentioned in the end qualifications, the panel recommends the programme to ensure that CS students (learn to) work together in multidisciplinary teams during their master's study. The panel appreciates the recent revival of the External Advisory Board and encourages its representatives to provide the programme with timely input on the expectations of the professional field with regard to the competencies of computer science graduates.

The teaching-learning environment of the CS programme is up to standard. The programme offers students a thorough education in one or more research specialisms of the computer science departments. Each individual study/exam programme is structured along a set of clear rules that cover all intended learning outcomes. The didactical principles are appropriate and implemented rigorously. Talented students attending the honours programme appreciate this additional opportunity. Long-standing faculty is highly qualified in terms of both disciplinary know-how and didactics. Student services organized both centrally and at programme level facilitate the study period of CS master students. Notwithstanding the panel's overall appreciation, there are three elements which are being addressed but require further attention: the systematic involvement of industry in the CS curriculum, measures for newly appointed staff to obtain the university teaching qualification and the English language certification, and the success rate of the master programme. The latter point is of particular priority because the situation has not improved since the recommendation of the previous assessment committee. The panel considers the latest plans to be a viable way to reduce the lead time of the programme and therefore urges the programme to implement the envisaged measures, monitor their impact and where necessary adjust their implementation.

Student assessment is well organized in the CS programme. The policy and principles underlying the course assessments are fine. The constructive alignment theory is applied in the day-to-day reality of teaching and assessment. The panel considers that CS course assessments are valid, reliable and transparent. Following its review of thesis assessments, the panel noticed that the thesis assessment form is of good quality, but that its potential is not always used to the full. It invites the programme to organize calibration sessions for thesis assessors and to monitor that assessors motivate their (sub-)grades in the assessment form through qualitative feedback. The Board of Examiners has accumulated good expertise and produced relevant documents since the previous assessment. In view of the programme developments, notably the growing student numbers, the panel invites the Board of Examiners to take a more proactive attitude in assuring the quality of assessment.

Students who graduate from the CS programme are adequately prepared for, and successfully enter, both the labor market and a PhD trajectory. Having established that all master theses meet the

expectations of a final academic project at master level, it is fair to state that the intended learning outcomes of the CS programme are achieved at the end of the curriculum.

In sum, the panel concludes that the quality of the master's programme CS is up to standard on all accounts, hence its overall positive conclusion.

The panel assesses the standards from the *Assessment framework for limited programme assessments* in the following way:

Master's programme Computer Science

Standard 1: Intended learning outcomes	meets the standard
Standard 2: Teaching-learning environment	meets the standard
Standard 3: Student assessment	meets the standard
Standard 4: Achieved learning outcomes	meets the standard
General conclusion	positive

The chair, em. Prof. dr. T. (Theo) D'Hondt, and the secretary, M. (Mark) Delmartino MA, of the panel hereby declare that all panel members have studied this report and that they agree with the judgements laid down in the report. They confirm that the assessment has been conducted in accordance with the demands relating to independence.

Date: 8 January 2020

DESCRIPTION OF THE STANDARDS FROM THE ASSESSMENT FRAMEWORK FOR LIMITED FRAMEWORK ASSESSMENTS

Standard 1: Intended learning outcomes
The intended learning outcomes tie in with the level and orientation of the programme; they are geared to the expectations of the professional field, the discipline, and international requirements.

Findings
The master's programme in Computer Science (CS) is provided by the Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS) of Delft University of Technology. The faculty offers five other master's programmes and three bachelor's programmes. The bachelor's programme Computer Science and Engineering, which was also part of the assessment visit, supplies the largest number of CS students. The faculty is organized in six departments; almost all CS courses are provided by two departments devoted to computer science studies: Intelligent Systems and Software Technology.

The CS programme is a two-year academic master's programme that aims to provide students with knowledge, skills and a clear understanding of the area of computer science, in order for graduates to independently perform professional and scientific activities. To reach this goal, the programme offers students a variety of courses clustered around two broad tracks–Data Science and Technology and Software Technology–and three special programmes: Bio-Informatics, Information Architecture and Cybersecurity. The courses, tracks and programmes reflect the research priorities of the computer science departments: computer graphics and visualization , cybersecurity, interactive intelligence, multimedia computing, pattern recognition and bio-informatics, algorithmics, distributed systems, embedded and networked systems, programming languages, software engineering, and web information systems.

Until recently the CS programme has also offered the EIT Digital programme ICT Innovation as a track within the programme. The involvement of TU Delft in this programme will be discontinued as of the academic year 2019-2020 and therefore this track/option is not part of the current accreditation assessment.

There is a common understanding among Dutch universities offering computer science programmes that the so-called ACM Computer Science Curricula 2013 serve as domain-specific framework of reference for both bachelor's and master's programmes. As the ACM framework was formulated for undergraduate programmes, it only forms a basis for master's programmes. This is also the case for CS, whose intended learning outcomes (ILOs) cover the eleven characteristics of computer scientists as formulated by the Association for Computing Machinery but are deepened and extended to a graduate level. These characteristics, as well as a link to the reference document, are provided in Appendix 1 to this report.

The goal of the master's programme is reflected in its ILOs, which are listed in appendix 2 to this report. The panel noticed that these ILOs have been formulated in a generic way and are not linked to specific content. It is an explicit choice of the programme to describe the knowledge, skills and attitudes that are expected from a CS graduate in abstract terms because the field of computer science is constantly changing. Looking into the ILOs, the panel found that they cover the five Dublin Descriptors and fit the programme's structure with two tracks.

The previous assessment committee noted in 2013 that the set of ILOs was not optimal and supported the programme's intention to make the level and orientation more visible and their formulation more specific for the domain of computer science. The current panel learned that the ILOs have undergone two rounds of modification: right after the previous visit, the formulation was amended in line with the remarks of the assessment committee; later on, the ILOs were adapted to fit the new structure of the programme with two instead of four tracks.

The CS programme is considering a re-formulation of the ILOs according to the 3TU Criteria for bachelor's and master's programmes in engineering in the Netherlands. A similar exercise has already taken place in the bachelor's programme. The panel supports this intention because it noticed in the bachelor's programme that such adjustment makes the formulation of the ILOs more concrete. In addition to paying proper attention to disciplinary knowledge, research and design, cooperation and communication skills, the panel finds it particularly important that the envisaged ILOs also explicitly refer to–and expect the CS graduate to take into account–the ethical, temporal and social context.

The panel acknowledges the quality of the current ILOs as they reflect the discipline of computer science, the master level and the academic orientation. The panel notices, however, that the multidisciplinary dimension is not addressed in the ILOs and therefore advises the programme to ensure that working together in a professional manner in a multidisciplinary environment gets proper attention in the curriculum.

The panel learned that there have always been contacts with potential employers, but that these contacts have not been used systematically as input for the study programme. After several years of inactivity, the External Advisory Board (EAB) met again early 2019. The EAB consists of alumni and representatives of companies and organization s that hire graduates. From the discussions with programme management and EAB representatives, the panel understood that there is a strong intention to continue these meetings in a structural way in the future. An important and recurring theme in these meetings will be the knowledge, skills and attitude which EAB representatives seek in computer science graduates from TU Delft. The panel appreciates the efforts to revive the EAB, and encourages the programme to continue this.

Considerations
The panel considers that the goal of the master's programme CS is properly embedded in the intended learning outcomes, which are grounded in the faculty's research portfolio, the European-wide Dublin Descriptors and the international ACM curriculum.

The panel recognizes the efforts undertaken by the programme to address the remarks from the previous assessment committee with regard to the ILOs and considers that the formulation of the current ILOs is appropriate. Nonetheless, the panel encourages the master's programme to perform another round of ILOs re-formulation in line with the 3TU Criteria as the experience with the bachelor's programme has shown that it constitutes added value. Moreover, the panel recommends the programme to ensure that CS students (learn to) work together in multidisciplinary teams during their master's study.

The panel appreciates the recent revival of the External Advisory Board and encourages its representatives to provide the programme with timely input on the expectations of the professional field with regard to the competencies of computer science graduates.

Conclusion
Master's programme Computer Science: the panel assesses Standard 1 as 'meets the standard.'.

Standard 2: Teaching-learning environment
The curriculum, the teaching-learning environment and the quality of the teaching staff enable the incoming students to achieve the intended learning outcomes.

Findings

Student numbers
An important item for discussion during the site visit was the increased number of students in both the bachelor's and the master's programme. The intake of the CS programme has risen from 88 students in 2013-2014 to 159 students in 2018-2019. This intake is likely to increase even more

rapidly over the next few years when the current bachelor students–whose intake has quadrupled to almost 900 in the same period–graduate and seek to enrol in the CS master's programme. The panel understood from the discussions that the current and envisaged growth will affect the teaching and learning environment of the master's programme. While individual measures will be discussed throughout this section of the report, the panel generally thinks that the management has devised adequate plans and is implementing appropriate measures to address the situation now and in the near future. This appreciation of the panel is also based on its discussion with the faculty management which supports–also financially–the plans of the CS programme team.

Curriculum
The master programme CS consists of 120 EC, which are spread over two years of four quarters each. Since the previous assessment visit, the curriculum has changed offering two broad tracks and three special programmes instead of four tracks. Students in the Software Technology track focus on designing and engineering software artefacts, while students in the Data Science and Technology track focus on answering research questions using sophisticated data analysis techniques. In addition, students can choose one of three "special programmes": The Bioinformatics programme focuses on data analysis and modelling with CS students performing research on bioinformatics for health and disease and on bioinformatics for (industrial) microbiology. The Cyber Security programme is offered together with the University of Twente: students do research on fundamental and applied cryptography. Together with the Faculty of Technology, Policy and Management, the CS programme offers a special programme on Information Architecture, which concentrates on the alignment between organizational needs and the engineering opportunities and solutions offered by new ICT solutions. The panel gathered from the extensive information in the self-evaluation report and the discussions on site that the tracks, programmes and courses strongly reflect the specific research interests of the EEMCS faculty and its computer science departments.

The panel noticed that the CS programme does not feature a standard curriculum, but has set a number of rules which students must adhere to when composing their individual exam programme (IEP). These rules are stated in the Teaching and Examination Regulations and ensure that each student meets the programme's intended learning outcomes. Every IEP consists of common core courses (20-25 ECS) to be selected among a range of track-specific courses, specialization courses (at least 15 EC) that are closely linked to research groups and can be extended with special programme courses, a research course (5-10 EC), and a thesis project (45 EC). If an IEP does not add up to 120 EC, students choose free electives (up to 25 EC). On top of the thesis project, at least 40 EC should be obtained from courses in the field of computer science. The panel acknowledges the viewpoint of all stakeholders that this set-up entails both strengths and drawbacks.

The major strengths are that students have the freedom to specialize according to their interests and talents and that the programme offers students a wide variety of courses and research opportunities that belong to the core specialism of the lecturers. The main drawback is that students have a difficult time in choosing an individual path of courses that leads towards their goal. In order to mitigate this, the programme provides several means of support, ranging from master coordinators to mentoring meetings and an online application MyStudyPlanning. Every IEP has to be submitted to, and validated by, the Board of Examiners, which constitutes an insurance that the approved IEP complies with all requirements. According to the panel, the programme has built in sufficient support mechanisms to ensure that each individual student ends up with a relevant exam programme that is tailored to his or her interests. Furthermore, the panel understood from talking to students that the academic and research skills are addressed throughout the curriculum, and in particular in one compulsory seminar. According to the panel, these skills could be accounted for more visibly and explicitly.

Overall, the panel thinks highly of the wealth of opportunities that this CS programme offers and of their alignment with the research interests of the teaching staff. Students indicated that they would like more involvement of industry in the curriculum. The panel agrees to this viewpoint and invites the programme management to reflect on the inclusion of an internship period as an optional activity for all master's students within the regular curriculum framework of 120 EC.

Students who want more challenges can participate in the university-wide Honours programme, which adds 20 EC to the regular curriculum and consists of the centrally offered course Critical Reflection on Technology and a faculty-specific programme, which in the case of CS is a research project in one of the research groups of TU Delft. Another option for students to show excellence is to participate in highly competitive internships with IBM or Google among others. The panel understood from current and former honours students that they highly appreciate these additional opportunities.

Educational concept
The curriculum is implemented according to the constructive alignment principle: students use their own activities to develop new knowledge, while building on their prior knowledge. This entails that lecturers are expected to clearly formulate prerequisites, set study goals that are based on the programme ILOs, choose appropriate forms of assessment, and align their teaching methods with the type of assessment. The panel gathered from the discussions with students and staff that in the day-to-day teaching and assessment practice, the principles of constructive alignment are upheld by the lecturers. The panel appreciates both the concept and way it is implemented in the programme.

The CS programme provides students not only with theoretical knowledge of computer science, but also emphasizes the importance of applying this knowledge. Hence, almost every course has a lab in which students apply the newly acquired knowledge thereby gaining valuable skills and new insights. Students indicated that they appreciate this opportunity. The panel welcomes the programme's attention to knowledge application.

Furthermore, the panel learned that the master-apprenticeship approach is a specific feature of the CS programme. In specialization courses that work with small student numbers, lecturers provide (small groups of) students with frequent formative feedback. Moreover, students consult and discuss scientific literature with staff in the research courses. During the master thesis, students are supervised by scientific staff members and are part-time members of the research group to which their thesis advisor belongs. In this way they participate in scientific and social meetings of the group. Students indicated that they appreciate this approach and that some lecturers are particularly good at this, which in turn increases their popularity when students have to decide on a thesis topic and research group. The discussion with lecturers convinced the panel that this is an important feature of the programme that should be maintained as much as possible, also in the near future when the number of master students is likely to grow substantially.

Contrary to the bachelor's programme, the CS programme has been taught entirely in English since its introduction in 2002. This decision was taken in line with the Bologna Process and the policy of TU Delft. Students appreciate the international dimension in the classroom and the growing balance between Dutch and non-Dutch students as this facilitates inter-cultural integration and forces all students to speak English. The panel subscribes to the rationale of the programme and university that teaching in English fits with the aim to prepare CS students for a career in- and outside academia where they are expected to work in an international community. Further to comments from students, alumni and employers, the panel does advise the programme to ensure that international students can benefit from Dutch language courses to facilitate their integration on the Dutch labor market afterwards: while the working language at several companies may be English, the company culture often requires at least some knowledge of the Dutch language.

Feasibility
The CS programme does not consist of a standard curriculum but expects students to build their own study programme. The panel noticed that this unrestricted nature of the CS programme results in individual programmes that share a common number of study credits but may differ in the study load per student. Moreover, the scheduling of courses differs per student and is not necessarily evenly spread over the different quarters. Master students indicated both in the Student Chapter and during the visit that some courses are more demanding than others and that student feedback on this matter is not always taken into account. Furthermore, data in the self-evaluation report show

that only a low percentage of students finish the programme within the nominal period of two years (on average 16%), that less than half of the students finish within three years, and that even after four years, only 64% of students receive a diploma. On average 10% to 20% of students drop out from the CS programme and do not graduate at all. Such figures, according to the panel, cannot only be linked to the external condition that several students combine the master's study with a part-time job in the field of computer science.

Based on these data, the panel shared its worries on the feasibility of the CS programme with the lecturers and management. The panel feels strongly about this issue because the current study yield figures are not much better than at the time of the previous assessment visit when the committee advised the programme to amend the graduation process in order to improve the completion rates. The current panel acknowledges that the CS programme has undertaken steps in supporting the composition of the IEP, in counselling students with a study delay and in structuring the master's thesis trajectory, but it seems that these measures are taken too recently to generate a significant impact.

As the panel was of the opinion that the measures presented in the self-evaluation report and the initial discussions were not sufficient to address the issue, the programme management shared two documents with the panel indicating the measures (an enhanced IEP alignment tool, a master market platform for thesis subjects and a fixed two-step thesis process/progress cycle) it envisages to reduce the lead time of the CS master programme. According to the panel, these plans appear to be a serious attempt to gain control over the issue: the plans do not only clarify the specific nature of the envisaged measures, but also provide an analysis of the underlying problems. Furthermore, the plans seem to have been discussed with several formal bodies in the faculty. While the current panel deplores the delayed implementation of the plans to address the recommendation of the previous assessment panel, it does consider the plans a viable way to address the issue. Hence, the panel encourages the programme to implement the plans giving them high priority and to monitor–and where necessary adjust - their implementation and impact on a yearly basis.

Staff
The self-evaluation report indicates that in January 2019, 58 staff members were involved in the CS programme. Over the last two years, 15 new members have been hired. Slightly over one quarter of the staff is female. The panel welcomes these recent appointments and encourages the programme to further enlarge the team when student numbers continue to grow.

The panel learned that due to the high number of recent appointments, several teaching staff are either following the university teaching qualification (UTQ) or are on the waiting list to start UTQ. Similarly, many newly recruited staff have not yet completed the assessment/certification regarding the English language requirement (CEFR level C1). The panel understands that the qualification and certification rates also depend on the available number of trainers and on the priorities of each individual lecturer. It encourages the programme to monitor carefully the progress of all new staff in complying with didactical and language requirements.

Students indicated to the panel that they are generally satisfied with the quality of the lecturers, an appreciation that encompasses disciplinary know-how, educational skills and language proficiency. Discussing the developments in the bachelor's programme, the panel thought highly of the recently installed teaching teams. In view of the growing student numbers in the master's programme, the CS programme may want to look into setting up similar teaching teams to assist scientific staff in the execution of the master courses. According to the panel, these teaching team members would constitute a valuable addition to the long-standing and highly qualified faculty.

Facilities
The activities related to the CS programme are currently split over two buildings on the TU Delft campus: lectures mainly take place in the former faculty building, while lecturers and research facilities are hosted in the new EEMCS building. Students indicated to the panel that they find this a

very unfortunate situation because it reduces the opportunity to consult lecturers. Master students working on their thesis can work in reserved areas in the new building, in close proximity to their supervisor and research group. The panel was informed by the faculty management that a new building is under construction and will eventually include lecture halls, faculty and research facilities in one location.

Apart from university-wide services, such as the electronic learning environment Brightspace or a state-of-the-art library, the EEMCS faculty has at its disposal a number of trained academic counsellors who can support students on a variety of issues such as studying with a disability, study delay, study planning sessions, etcetera. The panel understood from the discussions on site that students appreciate the services offered by the faculty.

The study association "Christiaan Huygens" plays an important role in gathering feedback from students and in sharing this feedback with the appropriate faculty structures and - in the case of the informative Student Chapter - with the panel. Similarly the Faculty Student Council and the Education Committee offer formal channels for students to voice their concerns. While students invariably indicated that individual faculty and lecturers are open to their feedback, the panel has the impression from the discussions on site that official communication between students and faculty is less than optimal: while both informal and formal mechanisms are in place, and students are heard, the decisions of the management are not always communicated properly to, or noticed by, students. The panel welcomes in this regard the intention of the programme management to monitor that all modifications to a course are communicated by the respective faculty/lecturer at the start of the new course run. Moreover, decisions based on student feedback will also be shared systematically at Faculty Council meetings.

Considerations
The panel considers that the teaching-learning environment of the CS programme is up to standard. The programme does not feature a standard curriculum, but offers students a thorough education in one or more research specialisms of the computer science departments. Each individual study/exam programme is structured along a set of clear rules that together cover all intended learning outcomes. The educational principle of constructive alignment and the master-apprentice model are appropriate. Talented students attending the honours programme appreciate this additional opportunity. Long-standing faculty is highly qualified in terms of both disciplinary know-how and didactics. Student services organized both centrally and at programme level facilitate the study period of CS master students.

The panel noticed that the growing student numbers are starting to impact on the teaching-learning environment of the programme and are likely to further affect the choice of thesis topics, the master-apprentice model, staff recruitment and facilities in the near future when a peak of bachelor students seeks to enrol in the CS programme. The panel considers that the management is taking adequate measures to mitigate these effects. In this regard, it invites the management to consider implementing the concept of team teaching, which seems to work well in the bachelor's programme.

While the quality of the teaching-learning environment is definitely appropriate, there are two elements which are addressed but require attentive monitoring: the involvement of industry in the CS curriculum beyond the master's thesis, and the measures for (newly appointed) staff to obtain the university teaching qualification and the English language certification.

Furthermore the panel issues a strong recommendation to the CS programme management with regard to the excessively long lead times–and thus very poor success rates–of the master's programme. The panel considers this a priority for the programme because the current figures are not much better than at the time of the previous assessment visit when the committee advised the programme to improve the completion rates. The panel considers the latest plans provided by the programme management to be a viable way to address the issue. It urges the programme to

implement the measures, monitor the impact and where necessary adjust their implementation on a yearly basis.

Conclusion
Master's programme Computer Science: the panel assesses Standard 2 as 'meets the standard'.

Standard 3: Student assessment
The programme has an adequate system of student assessment in place.

Findings

Assessment system
The panel obtained extensive information in the self-evaluation report and the annexes on the principles that underpin student assessment in the CS programme. It gathered from the written materials that the master's programme adheres to the EEMCS Faculty Assessment Policy and implements the procedures described in the Programme Specific Assessment Policy of the computer science programmes. Organising the curriculum components according to the constructive alignment principle, the learning goals of individual courses are derived from the intended learning outcomes at programme level, and the specific assessment form of a course is chosen based on its alignment with the teaching method of that course. Furthermore, each course assessment is checked on quality principles with regard to validity, reliability, transparency and efficiency.

Most common core and specialization courses are taught using a combination of (interactive) lectures, lab sessions and project work. Assessment methods, both formative and summative, are aligned with the content and the teaching methods of the courses. Many teaching methods require small group sizes and are based on the Master Apprentice approach. Active supervision and regular individual feedback play an important role in assessing project work and lab sessions. Lectures are mostly assessed under examination conditions through essay questions or written assignments. Faculty who are responsible for individual courses have obtained the university teaching qualification, which includes dedicated training on assessment. Staff is applying these assessment skills to peer-review each other's examinations using a specific assess-the-assessment template.

The panel learned from the discussions on site that the growing student numbers are affecting the way assessment is organized, and are jeopardising the Master Apprentice model, which thrives on small course sizes and individual supervision. Following indications from several interviewees, the panel has the impression that the problem is not yet present–but imminent–and that the programme is actively exploring ways to maintain this close contact between lecturers and students.

Course and thesis assessments
The panel noticed that the assessment principles underlying the programme are sound and have been implemented rigorously in the individual courses. On site the panel looked into course materials and their respective assessment forms and found these to be appropriate: the questions were valid and reliable. Moreover, students indicated to the panel that course descriptions and lecturers give a clear indication of what is important subject matter to learn and how students will be graded.

As part of its thesis review, the panel studied a sample of 15 theses completed in the academic years 2016-2017 and 2017-2018. The panel noticed that the programme uses one assessment form. The template was developed and approved in 2016 following the recommendation of the previous assessment committee. The form is extensive with rubrics per component (quality of work, performance, report, and presentation/defence), criterion and sub-grade. Assessors can add free text remarks per component. Students and alumni informed the panel that they are receiving/had received extensive and useful feedback throughout the master's thesis, and the alumni the panel spoke to mentioned that they agreed with their final score on the thesis. While the form as such allows for insightful and calibrated assessments, the panel noticed a lot of variation in the way the

form had been completed. Some assessors made full use of the opportunities of the form; others only ticked boxes without even diversifying the score per criterion. In several cases assessors did not add text to motivate the score per component. Overall, the panel found that in only one third of the forms, assessors provided insightful comments that substantiated the final grade. And although there was no doubt about the pass/fail quality of the entire thesis sample, the panel would have scored six theses (slightly) differently. During the visit, the panel already urged the programme to ensure that all assessors make optimum use of the assessment form: this means that assessors should be encouraged to not only score the thesis by ticking the most relevant boxes in the extensive set of rubrics, but also motivate their scores through qualitative feedback in the free text boxes. Furthermore, the panel recommended the programme to organize calibration sessions for all thesis assessors in order to normalize the grades. According to the panel, the assessment form–if used properly - does allow thesis committees to end up with a similar score for theses that are of a similar quality.

Exam committee
The quality of assessment in the CS programme is assured by the Board of Examiners, and in particular by the Board's subcommittee on computer sciences. This subcommittee has six members–lecturers with permanent appointments in the computer science departments–and is responsible for the bachelor's programme Computer Science and Engineering, as well as for the master's programmes Computer Science and Embedded Systems. The Board of Examiners is supported by an official secretary and by the faculty's educational and assessment specialists.

The previous assessment committee reported in 2013 that the Board of Examiners functioned well but still had to give substance to its new legal responsibilities. The panel now learned that over the last few years, the Board of Examiners published new policy documents and quality assurance measures. Furthermore, the Board of Examiners has paid extensive attention to fraud prevention. Currently, lecturers explain in their courses more explicitly what is correct and incorrect behaviour. Following the growth in student numbers, the workload of the Board of Examiners has increased as it has to approve each individual exam programme.

The panel appreciates the efforts of the Board of Examiners and found the documents pertaining to the assessment system to be of good quality. Moreover, the Board as a whole and the individual members of the subcommittee have the appropriate expertise for their tasks. The panel did notice, though, that there is room for a more proactive attitude of the Board of Examiners, for instance with regard to monitoring the fraud policy it has developed and to the systematic and proper use of the master's thesis assessment form. In this regard, the panel was surprised that the Board of Examiners had not spotted the lack of qualitative feedback motivating the final grade. It therefore suggests the Board of Examiners to monitor the quality of the thesis assessment more closely in the future.

Considerations
The panel considers that student assessment is well organized in the CS programme. The policy and principles underlying the course assessments are up to standard. The constructive alignment principle is applied in the day-to-day reality of teaching and assessment. Based on the discussions on site and the limited sample of individual assessments it reviewed, the panel considers that CS course assessments are valid, reliable and transparent.

While it thinks highly of the thesis assessment form that has been in use since 2016, the panel noticed that there is room for improvement with regard to the way (sub-)grades are accounted for in the assessment form through rubrics and feedback. The panel invites the programme management to organize calibration sessions for all thesis assessors and to monitor that assessors make full use of the opportunities offered by this assessment form, notably by motivating their sub-grades/final mark through qualitative feedback.

According to the panel, the Board of Examiners has accumulated meaningful expertise and produced relevant documents on the quality assurance of assessment. In view of programme developments in

terms of student numbers, it invites the Board of Examiners to take a more proactive attitude in assuring the quality of assessment.

Conclusion
Master's programme Computer Science: the panel assesses Standard 3 as 'meets the standard.'.

Standard 4: Achieved learning outcomes
The programme demonstrates that the intended learning outcomes are achieved.

Findings

Thesis quality
In order to establish whether students achieve the intended learning outcomes, the panel has reviewed a representative sample of 15 master theses that were accepted in the academic years 2016-2017 and 2017-2018. The master thesis amounts to 45 EC and can be performed at the faculty or in industry. Students are supervised by one or more scientific members of the staff–and possibly an industry representative–who provide continuous formative feedback. The learning goals of the thesis are linked in particular to four intended learning outcomes and are reflected/graded as the four main components in the thesis assessment form: quality of work (design), performance (execution), report (academic writing), and presentation (defence). Given the size of the thesis, student progress is reviewed twice: during a mid-term meeting and six weeks before the graduation date.

The panel found that each of the fifteen theses was of the quality that can be expected from a final project of academic orientation at master level. Moreover, the panel thought that several theses were of good quality. The topics covered were relevant for the domain of computer science and reflected the variation in research themes of the two departments. Theses that received a lower score tended to be weaker in terms of their scientific approach: setting the research problem, formulating research questions and motivating the research methodology. Moreover, the panel was surprised to notice the wide variety in thesis formats.

Based on the sample it reviewed, the panel found that students who successfully pass the master's thesis have indeed achieved all intended learning outcomes. The panel suggests the management to reflect on the variety in thesis formats and harmonize the formal requirements.

Alumni
In addition to verifying the quality of the final deliverables, the labor market performance of graduates is another way to establish whether students achieve the intended learning outcomes upon completion of the programme. The panel gathered from the written materials and the discussions on site that in general CS graduates have a positive opinion about their competencies as computer scientist.

Asked if CS graduates were lacking certain competencies when entering the labor market, both alumni and industry representatives mentioned the exposure to (working together in) multidisciplinary teams and the familiarity with implementing a complex and long-running project. Following these inputs, the panel recommends the programme to involve the professional field more in the curriculum, notably in the skills courses.

Notwithstanding this limited exposure to industry, both internal and national surveys indicate that alumni easily find employment, even before graduation. This finding was confirmed during the visit by alumni and industry representatives. Very often students start their professional career as software engineer; several students do so by starting their own company. About 15% of the CS graduates pursue a doctorate afterwards. This figure does not come as a surprise to the panel given

the many good quality theses in the sample it reviewed and the number of publications they resulted in.

Considerations
Based on its thesis review and the discussions on site, the panel considers that students who graduate from the CS programme are adequately prepared for–and successfully enter - both the labor market and a PhD trajectory.

Having established that all master theses meet at least the minimum requirements of what can be expected of a final academic project at master level - and are often of much higher quality - it is fair to state that the intended learning outcomes of the CS programme are eventually achieved at the end of the master curriculum.

Conclusion
Master's programme Computer Science: the panel assesses Standard 4 as 'meets the standard''.

GENERAL CONCLUSION

In the previous sections, the panel has come to the conclusion that the CS programme fulfils the quality requirements with regard to each of the four standards set by the NVAO's Assessment Framework for the higher Education Accreditation System of The Netherlands for limited programme assessments: intended learning outcomes, teaching-learning environment, student assessment, and achieved learning outcomes. Hence, the panel's overall assessment of the *master's programme Computer Science* is 'positive'.

APPENDICES

APPENDIX 1: DOMAIN-SPECIFIC FRAMEWORK OF REFERENCE

The master's programme Computer Science uses the ACM Computer Science Curricula 2013 as domain-specific framework of reference. This curriculum framework is used by many programmes across the world and the Dutch computer science programmes have agreed to use it for bachelor's as well as master's programmes. However, as the ACM framework is formulated for undergraduate programmes, its characteristics are deepened and extended to post-graduate academic level for the master's programme. The full version of the extensive document is available through the following link: https://www.acm.org/binaries/content/assets/education/cs2013_web_final.pdf

The Association for Computing Machinery (ACM) is an internationally recognized institute that produces resources with the intention of helping computer science and similar fields advance scientifically as well as professionally. Besides giving detailed lists of subject matter to be covered in an undergraduate programme, it describes a computer science graduate in 11 characteristics.

At a broad level, the expected characteristics of computer science graduates include the following:

1. Technical understanding of computer science
2. Familiarity with common themes and principles
3. Appreciation of the interplay between theory and practice
4. System-level perspective
5. Problem solving skills
6. Project experience
7. Commitment to life-long learning
8. Commitment to professional responsibility
9. Communication and organizational skills
10. Awareness of the broad applicability of computing
11. Appreciation of domain-specific knowledge

For a more detailed coverage, please refer to chapter 3, page 23 on the above link.

APPENDIX 2: INTENDED LEARNING OUTCOMES

Master's programme Computer Science

Graduates of the master's programme in Computer Science

1. have general knowledge of computer science and the relevant issues of mathematics and computer engineering.
2. have in-depth knowledge in either Software Technology or in Data Science and Technology and have demonstrated the ability to apply it through a Master's thesis project.
3. are able to identify, analyse, model and solve problems and to implement and test solutions within their chosen domains for a broad range of application areas.
4. know how to work individually and in teams.
5. are able to analyse and conceptualize at a formal and abstract level.
6. understand the fundamental issues of this field and contribute to research and the further development of the field.
7. position their contributions within the wider scope of the overall development of science and technology, as well as within industry and society.
8. are able to communicate (orally and in writing) about results and methodology to their colleagues in the professional field, as well as to lay audiences.

APPENDIX 3: OVERVIEW OF THE CURRICULUM

The Master's programme Computer Science consists of two tracks: Data Science and Technology (DST) and Software Technology (ST). The programme has also been home to students from the EIT Digital programme 13 ICT Innovation. The university's involvement in this EIT programme will be discontinued as of 2019-2020.

Students in the ST track focus more on designing and engineering software artefacts, while students in the DST track focus more on answering research questions using sophisticated data analysis techniques. Additionally, students can choose one of three "special programmes": Bioinformatics, Cyber Security, Information Architecture.

Each master student composes an individual exam programme (IEP) according to the rules of the chosen track and/or special programme. Every IEP in computer science consists of the following components:

- Common core courses: these provide students with a broad basis of advanced computer science knowledge. Common core courses are chosen from two lists, one for each track. Students choose 20 to 25 ECTS worth of common core courses.
- Specialization courses: courses in which the student receives advanced knowledge and skills in a certain field or fields. Students choose at least 15 ECTS worth of specialization courses.
- A research course: a literature survey worth 10 ECTS or a seminar-type course worth 5 or 6 ECTS in which students study scientific papers and produce a paper themselves.
- A thesis project worth 45 ECTS carried out at one of the research groups of the computer science departments.
- If the IEP does not amount to 120 ECTS, students may choose a maximum of 25 ECTS on free electives. If the student does not have all required prior knowledge, 15 ECTS of these may be obtained from courses at bachelor's level.
- At least 40 ECTS credits of the IEP, excluding the thesis project, must be obtained from courses in the field of computer science.

APPENDIX 4: PROGRAMME OF THE SITE VISIT

Venue: Social Data Lab, building 28, TU Delft campus

Wednesday 26 June 2019

10.00	Arrival panel and welcome
10.15	Internal panel meeting (and lunch)
12.30	Session with management
13.00	Session with programme team
14.15	Session with bachelor students
15.00	Session with lecturers of the bachelor's programme
15.45	Open consultation
16.30	Session with Board of Examiners and assessment expert
17.15	Session with alumni, employers and external advisory board
18.00	Internal panel meeting
18.30	End of day 1

Thursday 27 June 2019

09.00	Internal panel meeting
09.45	Session with master students
10.45	Session with lecturers of the master's programme
11.30	Internal panel meeting
12.00	Final session with management
12.45	Internal panel meeting (with lunch)
15.00	Development dialogue
16.15	Plenary presentation of on preliminary findings
16.30	End of site visit

APPENDIX 5: THESES AND DOCUMENTS STUDIED BY THE PANEL

Self-evaluation report MSc Computer Science 2019

Prior to the site visit, the panel studied 15 theses of the master's programme Computer Science. Information on the selected theses is available from QANU upon request.

Following materials were made available by the EEMCS Faculty before or during the site visit, either as hard copy or in digital format through the QANU document site or the faculty's electronic learning environment:

- ACM Computer Science Curricula 2013
- Annual Report of the BoE EEMCS 2015, 2016 and 2017
- Assessment Rubrics Research Project
- B Thesis Project Proposal Guide
- Bachelor's Thesis Guide
- Confidential list of theses
- Context Project Brightspace site
- Criteria for Academic Bachelor's and Master's Curricula
- CSE and CS Midterm audit report 2018
- CSE Annual Report 2015, 2016 and 2017
- CSE curriculum committee 2018 report
- CSE Curriculum Handbook 2018
- CSE End-of-Y1 inquiry 2017-2018
- CSE Planning Advice
- CSE Planning Chart
- Curriculum chart 2013
- Curriculum chart 2018
- Digital Study Guide (in PDF)
- Digital Study Guide Bachelor's Thesis
- EEMCS Faculty Assessment policy
- EEMCS Towards 2020
- End of BSc questionnaire report
- Evaluation Research Project 2017-2018
- Evatool quarter reports (feasibility) 2017
- Fraud prevention at EEMCS BSc's
- Intended Learning outcomes
- Internal Programme Audit Report 2018
- Leerlijnen Technische Informatica 2013
- List of staff members active in the bachelor's and the master's programme
- List of members of the Computer Science External Advisory Board
- Maatregelen Taskforce
- Midterm self-assessment report CS TUD 2015-2017
- Minutes of the CS External Advisory Board
- NSE Results CSE 2018
- Peak handling of Bachelor students
- Plans and measures to reduce the lead time of the Master Computer Science
- Programme specific assessment policy CSE, CS and ES
- Research Project Manual and Rubrics
- Rules and Regulations of the Board of Examiners EEMCS 2018/2019
- TA Procedures
- TA Training Presentation
- Teaching and Examination Regulations BSc CSE 2018-2019
- Team Teaching policy document
- Team Teaching presentation