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MSc Embedded Systems
University of Twente

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Project code P2203

Contents

Summary

Standard 1. Intended learning outcomes

The panel finds that the MSc Embedded Systems has formulated appropriate goals and learning outcomes on an academic master's level. These are clearly aligned with the expectations of the academic and professional field through the Consolidated Requirements in the domain-specific framework of reference. Further alignment is achieved through the External Advisory Board, which the panel considers to be a valuable platform for interaction with the professional field. Within the domain of Embedded Systems, the UT programme increasingly focuses on Embedded AI, security and the Internet-of-Things. The panel appreciates this focus and the careful process through which this new focus has been implemented. This focus is also reflected in the ILOs. The panel recommends ensuring that the related ILO stays up to date, as it relates to a swiftly developing field. Regarding the collaboration between UT, TU/e and TU Delft, the panel recommends exploring opportunities to create further benefits for students and staff.

Standard 2. Teaching-learning environment

The panel concludes that the curriculum of the MSc Embedded Systems reflects the ILOs of the programme. It is well-structured and flexible, allowing students to build on the compulsory core with several elective options, an internship and a final project of choice. The courses are interactive and often challenge-based. The choice for an English language programme fits the international character of the field. Academic and professional skills are trained implicitly, in particular in the internship and final project. The panel recommends a more structural embedding of skills in the curriculum to ensure that all students practice skills in a comparable way. This could be achieved by attaching skills to specific educational components in the compulsory core, and creating a skills learning trajectory throughout the curriculum. Specific attention should be paid to reflection on ethical and social consequences of technologies. Furthermore, the panel advises to make the split between a thesis preparation and execution phase mandatory for all students.

Student support and guidance are organized in an appropriate way, with attention paid to the well-being of individual students and any knowledge gaps related to the heterogeneous intake. Students report that they miss a community feeling. The panel advises the MSc programme to consider creating a physical space where students can meet. The curriculum is feasible, although the programme should investigate whether there are any structural hurdles regarding differences in workload between courses. The teaching staff is well-qualified and of sufficient quantity to teach in the programme, and sufficient attention is paid to the challenges of high workload of staff members.

Standard 3. Student assessment

The MSc's assessment system is appropriate, with varied assessment methods and sufficient checks and balances to safeguard the quality of assessment. The Board of Examiners is proactive and in control of assessment quality assurance. The panel recommends setting up a more structural assessment of skills, coupled with the recommended skills learning trajectory. The thesis assessment is well-designed, with solid assessment procedures, an insightful form and associated rubrics. The use of fully independent second examiners and the attention paid to the training of first examiners are good practices. To further improve thesis assessment, the programme should pursue more uniformity in the quantity of feedback provided to students on the assessment form and strive for a single grading system for all students with a separate assessment of the thesis proposal.

Standard 4. Achieved learning outcomes

The quality of the theses as well as the job prospectives and satisfaction of the alumni show that students of the MSc Embedded Systems achieve the intended learning outcomes.

Score table

The panel assesses the programme as follows:

MSc Embedded Systems	
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

Prof. dr. Andy Pimentel
Chair

Peter Hildering MSc
Secretary

Date: 5 September 2023

Introduction

Procedure

Assessment

On 9 May 2023, the master's programme Embedded Systems of the University of Twente was assessed by an independent peer review panel as part of the cluster assessment Embedded Systems. The assessment cluster consisted of 3 programmes, offered by the institutions Delft University of Technology, Eindhoven University of Technology and University of Twente. The assessment followed the procedure and standards of the NVAO Assessment Framework for the Higher Education Accreditation System of the Netherlands (September 2018).

Quality assurance agency Academion coordinated the assessment upon request of the cluster Embedded Systems. Peter Hildering MSc acted as coordinator and secretary in the cluster assessment. He has been certified and registered by the NVAO.

Preparation

Academion composed the peer review panel in cooperation with the institutions and taking into account the expertise and independence of the members. On 7 February 2023, the NVAO approved the composition of the panel. The coordinator instructed the panel chair on his role in the site visit according to the Panel chair profile (NVAO 2016) on 16 January 2023.

The programme composed a site visit schedule in consultation with the coordinator (see appendix 3). The programme selected representative partners for the various interviews. It also determined that the development dialogue would be part of the site visit. A separate development report was made based on this dialogue.

The programme provided the coordinator with a list of graduates over the period 2019-2022. In consultation with the coordinator, the panel chair selected 15 theses per programme. He took the diversity of final grades and examiners into account, as well as a diversity in topics. Prior to the site visit, the programme provided the panel with the theses and the accompanying assessment forms. They also provided the panel with the self evaluation report and additional materials (see appendix 4).

The panel members studied the information and sent their findings to the secretary. The secretary collected the panel's questions and remarks in a document and shared this with the panel members. In a preliminary meeting, the panel discussed the initial findings on the self-evaluation report and the theses, as well as the division of tasks during the site visit. The panel was also informed on the assessment framework, the working method and the planning of the site visits and reports.

Site visit

During the site visit, the panel interviewed various programme representatives (see appendix 3). The panel also offered students and staff members an opportunity for confidential discussion during a consultation hour. No consultation was requested. 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 preliminary findings.

Report

The secretary wrote a draft report based on the panel's findings and submitted it to a colleague at Academion for peer assessment. Subsequently, the secretary sent the report to the panel for feedback. After processing this feedback, the secretary sent the draft report to the programme in order to have it checked for factual irregularities. The secretary discussed the ensuing comments with the panel chair and changes were implemented accordingly. The panel then finalised the report, and the coordinator sent it to the programme.

Panel

The panel assessing the masters programme Embedded Systems at the University of Twente consisted of the following members:

- Prof. dr. Andy Pimentel, professor of Embedded Computer Systems, University of Amsterdam (chair);
- Prof. dr. sc. Jari Nurmi, professor of Computer Engineering, Tampere University;
- Prof. dr. Wim Van Petegem, professor of Engineering Technology and Educational Policy, KU Leuven;
- Canan Kasaci-Öztürk MSc, team leader and product owner at ASML;
- Nienke Wessel BSc, master's student in Computing Science: Data Science and in Linguistics, Radboud Universiteit (student member).

Information on the programme

Name of the institution:	University of Twente
Status of the institution:	Publicly funded institution
Result institutional quality assurance assessment:	Positive

Programme name:	Embedded Systems
CROHO number:	60331
Level:	Master
Orientation:	Academic
Number of credits:	120 EC
Specialisations or tracks:	-
Location:	Enschede
Mode(s) of study:	Full time
Language of instruction:	English
Submission date NVAO:	1 November 2023

Description of the assessment

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

Profile and aims
The MSc Embedded Systems is organized by the Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS) of the University of Twente. It is organized in close cooperation with the Electrical Engineering (EE) and Computer Science (CS) programmes at EEMCS, organized by the same departments. It shares a Board of Examiners with EE and CS, and a Programme Committee with EE. The MSc aims to educate students in academic and professional competencies for embedded systems design. Embedded systems are application-specific computing systems found in a wide variety of modern-day products, ranging from household items and smartphones to airplanes and factories. Based on a relevant BSc background in fields such as computer science or electrical engineering, students learn to understand, analyze and design the hardware as well as the software of such embedded systems. Graduates can be expected to work in high-tech industry or in research. The MSc Embedded Systems is a small-scale programme, with an average intake of 30-40 students per year.

The MSc Embedded Systems started out in 2006 as a collaborative master between the three TUs (Technical Universities) in the Netherlands. Although the programmes started to develop towards more independence in recent years, there is still close collaboration. The programmes have jointly composed Consolidated Requirements: requirements related to knowledge and skills that form the basis of all three curricula. These are derived from the domain-specific framework of reference (DSFR) that was constructed by the three MScs in a joint effort. In constructing this DSFR, the programmes analyzed a number of relevant international frameworks related to cyber-physical systems. They also conducted an international benchmark of comparable MSc programmes. The resulting core competencies were connected to the MSc requirements as described in the Meijers criteria, the interpretation of the Dublin descriptors often used by engineering programmes. Each of the three programmes translated the DSFR's Consolidated Requirements into a set of Intended Learning Outcomes (ILOs).

The panel studied the programme's profile and aims, the DSFR and the intended learning outcomes of the programme. It concludes that the programme has an appropriate set of ILOs that clearly reflect the academic master's level and the requirements of the field through the Meijers criteria and the DSFR. The DSFR describes a comprehensive overview of the field of Embedded Systems, using relevant international frameworks and benchmarks. Within this common core, the individual programmes are free to highlight certain aspects. The UT decided to emphasize systems design through the addition of core courses in Embedded AI, Security Services for the Internet of Things and Systems Engineering. This change was implemented after an analysis of comparable MSc programmes, an inventory of the development in research expertise at the UT and discussion with the students, the programme committee and the External Advisory Board. An extra ILO on top of the Consolidated Requirements (ILO 6) that specifically mentions knowledge of the domains artificial intelligence, security and Internet-of-Things (IoT) has been added as a result. The panel approves of this 'couleur locale', and appreciates the careful process through which the update of the

programme's focus has been implemented. Specifically for ILO 6, it notes that this reflects current 'hot topics' in Embedded Systems. It recommends periodically revisiting this ILO to ensure that it stays up-to-date regarding developments in the field.

External Advisory Board
The MSc programme has an External Advisory Board of professional field representatives that is shared between this programme and the other two Embedded Systems-programmes at TU/e and TUD. This board meets once per year to provide solicited and unsolicited advice relevant to the development of the programme. It is regularly consulted regarding curriculum developments, and provides input for the DSFR. The panel appreciates that the three TU programmes have strong connections to the professional field through the External Advisory Board. The panel had the opportunity to speak to the External Advisory Board (during the site visit to Eindhoven in the same cluster), and found that its members are very much involved in the programmes and actively contribute to discussions on programme development. The panel considers this board an asset of the programmes and encourages them to keep investing in it.

4TU.Federation collaboration
As discussed above, the MSc Embedded Systems was originally designed as a collaborative 4TU.Federation master involving three of its universities At the time of the previous accreditation in 2017, the three Dutch Embedded Systems MSc programmes shared a common set-up, with five compulsory core courses offered by all three TU universities covering the Consolidated Requirements of the DSFR, and opportunities for students to specialize in courses at all three universities. The previous panel recommended exploring further opportunities for strengthening the collaborative nature of the programmes. However, due to local developments in the programmes, which included curriculum renewals and the merger between the MSc Embedded Systems and the MSc Computer Engineering in Delft, this intention took another turn. From 2021 onwards, the three programmes decided to create more room for differentiation, leaving the decision on how to compose their curriculum and develop their profile to the individual programmes. Students are still given the opportunity to follow courses at the other three universities, and there is frequent informal interaction between the programme managements to share experiences.

During the site visits at all three universities, the panel discussed the current status of the collaboration with programme management, teaching staff and students. The panel understands and approves of the reasons behind the recent divergence of the programmes. Further integration as suggested by the previous panel is no longer self-evident. Due to the flexibility of the curricula and the many opportunities for a tailor-made curriculum offered within the own university, student interest in taking courses at other universities has decreased, especially due to the travel involved. The panel noted that the collaboration is still very fruitful on a management level, and that there are individual initiatives between teachers that align on the organization of similar courses. As such, it is positive on the current situation.

In case the programmes want to pursue new initiatives for student exchange between the programmes, the panel noted down some ideas mentioned in discussions at the three site visits. Since several courses taught in the various programmes are still quite similar, multi-university teacher teams could co-develop courses and share content. Students could also work on team challenges, either in mixed teams or in student competitions between the universities. This might also strengthen the community feeling and the sense of identity as an Embedded Systems student (see standard 2). Furthermore, using the experiences from the COVID-19 pandemic, it might be feasible to offer (parts of) shared courses online. The panel recommends exploring the abovementioned opportunities and, if there is sufficient enthusiasm between all three partners, work on implementing this to the benefit of students and staff.

Considerations

The panel finds that the MSc Embedded Systems has formulated appropriate goals and learning outcomes on an academic master's level. These are clearly aligned with the expectations of the academic and professional field through the Consolidated Requirements in the domain-specific framework of reference. Further alignment is achieved through the External Advisory Board, which the panel considers to be a valuable platform for interaction with the professional field. Within the domain of Embedded Systems, the UT programme increasingly focuses on Embedded AI, security and the Internet-of-Things. The panel appreciates this focus and the careful process through which this new focus has been implemented. This focus is also reflected in the ILOs. The panel recommends ensuring that the related ILO stays up to date, as it relates to a swiftly developing field. Regarding the collaboration between UT, TU/e and TU Delft, the panel recommends exploring opportunities to create further benefits for students and staff.

Conclusion

The panel concludes that the programme meets standard 1.

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

Curriculum

The curriculum of the MSc Embedded Systems consists of compulsory core courses (30 EC), elective courses (40-45 EC, including the option for a 20 EC internship), homologation courses (5-10 EC) and the final project (40 EC).

- The *compulsory core* consists of six courses closely related to the Consolidated Requirements in the DSFR, three of which are organized by the MSc Embedded Systems, and three of which are organized by the MSc EE or CS. The compulsory core was recently (2022-2023) redesigned to reflect the choice to further focus the programme on systems design. New courses related to Systems Engineering, AI and the Internet-of-Things were added in favour of courses on Systems Validation and Quantitative Evaluation of Embedded Systems, which are now electives. This redesign (as well as an earlier redesign in 2018-2019) was implemented partly in answer to the recommendations of the previous accreditation panel, that recommended a realignment of the courses with the ILOs and the DSFR, and more research-oriented content.
- Each student follows at least one *homologation course*: students holding a BSc in Computer Science follow a homologation course in Electrical Engineering, and vice versa. Students with additional smaller deficiencies can follow an extra homologation course. Students with larger deficiencies, such as graduates from a university of applied sciences, follow a fixed pre-master programme of 30 ECs.
- Students choose either 40 or 45 EC in *electives* (depending on the number of homologation courses followed). These can be chosen from a pool of courses offered by the MSc EE, CS and Embedded Systems. In order to assist students in selecting their electives, the programme has defined five themes with associated courses for students to choose from (Computer Architectures, Embedded AI, Internet-of-Things, Dependable Computing and Cyber-Physical Systems). Students can also opt for an individual set of electives, which have to be approved by the programme mentor (see below). As part of the electives, students can choose a 20 EC internship. The goal of the *internship* is to

experience working life and to apply knowledge while working at a company or a research institute. Students who already have work experience or have done a major internship earlier in their education (in the case of hbo students), are not allowed to do the internship and follow 20 EC of extra electives instead. Students can look for their own internship position (which can also be abroad) and propose an assignment together with their external supervisor. The proposal is then assessed for suitability by the university supervisor. The internship is concluded with a report detailing the activities and learning process of the student.

- *Final projects* are research projects that can be done within any Computer Science of Electrical Engineering department within the Faculty EEMCS, after approval of the programme. There are a number of closely associated research groups where most students do their projects. The project is executed in close supervision within the research group. In some cases, an external final project in a company is allowed when this company is already collaborating with the research group. In such cases, the academic supervisor remains responsible for the project. The final project is completed with a report and a presentation.

The panel studied the curriculum of the programme, as well as the content of a number of courses. It concludes that the curriculum is well-organized and structured, and that it reflects the MSc's ILOs. The redesign of the core curriculum reflects the focus of the programme on systems design, with the new courses focusing on relevant aspects related to this approach of embedded systems. The content of the courses is closely related to the current trends in the academic fields, and students have the opportunity to further connect to state-of-the-art research topics in the courses associated with the themes, and in the final project. The curriculum offers multiple options for students to adapt it to their own preferences, with the five themes providing the necessary structure to compose a coherent curriculum. The panel found in the interviews that the internship is very much appreciated by students, and that it is an important curriculum element for them to develop professional skills and prepare for a future career.

Regarding the final project, the panel found that students have the option to split their project into two phases: a preparatory phase completed with a research proposal, and an execution phase where they conduct the research project. These two phases can also be graded separately. The panel thinks that this is a very good approach that helps students formulate suitable research questions and realistic projects. It recommends making this preparatory phase mandatory, as it would benefit all students.

Didactic approach

The programme applies a broad range of teaching methods with emphasis on challenge-based learning in interaction between teacher and students. Examples are interactive lectures, lab work, assignments and projects based on open research and design questions. The programme also aims to connect students with industry and industrial challenges related to Embedded Systems. Next to the internship, this is organized through frequent guest lectures by industry representatives. The curriculum and the name of the MSc Embedded Systems are in English, since a large part of graduates of the programme will be active in an international industrial or academic context.

The panel appreciates the didactic approach and teaching methods used in the courses. Students were positive on the interactive courses, and the use of open assignments. The choice for English as language of instruction fits the predominantly international character of the academic and professional fields.

The panel noted from the documents as well as the discussions with programme representatives that skills are covered implicitly throughout the courses. For instance, students learn communication skills through group work and the internship, and research skills in the thesis trajectory. They study ethical and societal

aspects of embedded systems when they encounter these in their internship or thesis. The panel values this master-apprentice approach where students learn skills 'on the job', but also thinks that skills education could be more explicitly integrated in the courses. This would ensure that all students encounter skills in a comparable way throughout their studies. The panel noted with appreciation that the programme is increasingly working in this direction. The recently introduced course Systems Engineering explicitly aims to teach students various academic and professional skills, such as group work and presenting. The panel recommends expanding on this, and couple all relevant academic and professional skills to educational elements in the compulsory core, for instance in the form of learning trajectories. This ensures that the courses build up to the internship and thesis, where students practice these skills in an actual professional or research setting. This includes giving students the opportunity in the core courses to practice their reflective skills related to ethical and societal consequences of technology, as the panel considers this an increasingly important skill for future engineers.

Guidance and feasibility
The MSc Embedded Systems is a small-scale programme that invests in close personal guidance. Each student is assigned a programme mentor at the start of their studies: a staff member who helps the students compose a coherent schedule and supervises students during the start-up phases of the internship and the final project until the moment the project supervisor takes over. The programme mentor helps students plan their projects, and maintain realistic objectives and a feasible time schedule. The UT mobility office helps students who opt for an internship outside the UT in organizing this. Furthermore, the study advisor monitors the study progress twice a year, and contacts the student if issues with progress of well-being are suspected. Students can also make an appointment with the study advisor on their own initiative.

The panel concludes that student support and guidance are well-organized in the programme, and appreciated by students. The small-scale nature of the programme allows for close monitoring and guidance of students. The panel noted that it also results in short feedback cycles: in redesigning the compulsory core of the MSc, both formal and informal student feedback was explicitly taken into account. Even though students appreciate the short communication lines with teaching staff members as well as the interactive courses, they reported to miss an overall community feeling within the programme. Students take most of their courses with students from other MSc programmes, and are spread out over multiple elective and individual course components. Furthermore, they are not connected to a single study association, but can join both the computer science and electrical engineering study associations. In order to promote a shared identity and community as embedded systems students, the students expressed the wish for a physical location on campus where they can meet and work together. The panel supports this, and asks the programme whether this can be realized.

To help students complete the curriculum within the designated time, the programme invests in homologation of the heterogeneous intake at the start of the curriculum. Students follow one or more courses to remedy any gaps in pre-knowledge, and take a premaster in the case of larger deficiencies. The panel appreciates the efforts to level knowledge gaps in the heterogeneous intake. Students reported to the panel that they feel generally well-prepared for the courses after taking the homologation courses. The panel considers the diversity of backgrounds of students to be an asset of the programme, and thinks that his could be further exploited by deliberately mixing students in group projects in the core courses, so that students with different nationalities and disciplinary backgrounds can learn from each other's experiences. An additional benefit would be that this can promote community feeling (see above), as students get to know more fellow students. The panel recommends exploring opportunities for realizing this.

The MSc's success rates are relatively low. Students often take 3-4 years to complete the curriculum. When discussing this with the programme management and students, the panel found that the programme stepped up its efforts to monitor the causes for this as recommended by the previous panel. The main reason the programme found is however outside its span of control. Many students have part-time jobs, either to provide for themselves or because they receive attractive job offers from companies due to their IT skills, and as a result study at a slower pace. Based on the discussions, the panel concludes that in general, the curriculum is feasible in two years, but it can differ based on individual choices. Some students mention that there can be an imbalance in workload between courses. Due to the large elective space, students therefore sometimes take fewer courses or adapt their choice of electives to compensate for this. The panel recommends investigating whether this is a structural issue, and if any hurdles or bottlenecks are found, to strive for a better balance in workload throughout the curriculum.

Teaching staff

The teaching staff of the programme is associated with the Faculty EEMCS, and for the large majority consists of active researchers in fields related to Embedded Systems. There are nearly 100 teaching staff members associated with the courses, electives and final projects, although a smaller group of 15-20 teachers active in the core courses is more directly associated with the MSc Embedded Systems. 51% of all teaching staff members is in possession of the University Teaching Qualification (UTQ) or in the process of obtaining this. Of the remaining staff members, the majority has a diploma similar to UTQ from another institution, dispensation due to 20+ years of teaching experience or no UTQ obligation due to a small part-time contract. Furthermore, all lecturers are required to be proficient in English on C1 level minimum.

The panel is positive on the quality and quantity of the teaching staff. Sufficient attention is paid to professionalization through the UTQ (or similar qualifications), and to proficiency to teach in an English-language programme. The panel learnt that the UTQ also pays specific attention to individual supervision of students, which the panel appreciates. The teaching staff have relevant research expertise in the field covered by the programme, and actively use this expertise to shape the courses and the thesis projects. The panel noted from the interview that the teaching staff members sometimes experience a generally high workload, as is often the case in academia. The faculty has set up a pilot project where teaching staff members work together with support staff members to organize courses, which the panel considers to be a positive development to reduce the workload related to teaching. The panel understood that the long-term aim of the MSc is to grow in student numbers, which makes it all the more relevant that the resources for organizing this remain sufficient.

The panel and programme management discussed the unfavourable gender balance in the staff (20% female) and student population (10% female). The panel understands that stereotyping of engineering and computer science already starts at a young age, and that this issue goes beyond the sphere of influence of the programme. It encourages staff members to engage in promoting engineering in high schools and invite students to visit the university. Regarding staff diversity, the panel sees that the faculty and university in general pursue various initiatives to promote gender balance, which the panel supports and encourages.

Considerations

The panel concludes that the curriculum of the MSc Embedded Systems reflects the ILOs of the programme. It is well-structured and flexible, allowing students to build on the compulsory core with several elective options, an internship and a final project of choice. The courses are interactive and often challenge-based. The choice for an English language programme fits the international character of the field. Academic and professional skills are trained implicitly, in particular in the internship and final project. The panel recommends a more structural embedding of skills in the curriculum to ensure that all students practice

skills in a comparable way. This could be achieved by attaching skills to specific educational components in the compulsory core, and creating a skills learning trajectory throughout the curriculum. Specific attention should be paid to reflection on ethical and social consequences of technologies. Furthermore, the panel advises to make the split between a thesis preparation and execution phase mandatory for all students. Student support and guidance are organized in an appropriate way, with attention paid to the well-being of individual students and any knowledge gaps related to the heterogeneous intake. Students report that they miss a community feeling. The panel advises the MSc programme to consider creating a physical space where students can meet. The curriculum is feasible, although the programme should investigate whether there are any structural hurdles regarding differences in workload between courses. The teaching staff is well-qualified and of sufficient quantity to teach in the programme, and sufficient attention is paid to the challenges of high workload of staff members.

Conclusion

The panel concludes that that the programme meets standard 2.

Standard 3. Student assessment

The programme has an adequate system of student assessment in place.

Findings

System of assessment

Assessment in the MSc Embedded Systems is based on the assessment policy of the Faculty EEMCS, which describes the rules and regulations for assessment in each programme. This includes policies such as peer review on all exams and assignments, evaluation and adaptation of the assessment of each course based on student feedback, and a sufficient balance between individual and group assessment within courses to prevent free-riding. The programme maintains a mapping of the ILOs to the core courses, ensuring that all ILOs are assessed in mandatory course components. Each course has a dedicated assessment plan, that is communicated to students at the start of the course. This plan lists the assessment methods and planning, and, if applicable, the rubrics for assessing projects and assignments. The internship is examined by the university supervisor based on an internship report and the performance of the student during the internship. To this end, the examiner receives advice from the company supervisor in the form of an advisory report.

The programme shares a Board of Examiners with other programmes in the Faculty EEMCS. Programme-specific responsibilities such as handling requests and safeguarding the quality of course and thesis assessment are mandated to subcommittees. Embedded Systems is part of the subcommittee for Electrical Engineering & Embedded Systems. Quality assurance mechanisms include checks on exams and examination methods of the core courses, and checking for each thesis committee whether the team of examiners is varied and includes sufficient experience and external input from outside the research group.

The panel studied the system of assessment and interviewed the Board of Examiners. It concludes that the assessment system regarding courses and the internship is solid, and has sufficient checks and balances to safeguard the reliability, validity and transparency of assessment. The assessment methods are varied, and include exams, project reports and presentations. As recommended in standard 2, the panel thinks that skills education should be more structurally integrated in the curriculum. This includes a more structural assessment of skills beyond the internship and final project in a learning trajectory. The panel advises to

explicitly couple assessment of these skills to this learning trajectory. For the internship and/or the final project, this could include a separate assessment criterium related to reflection on ethical and societal consequences of technology.

The Board of Examiners is in control, and proactively monitors the quality of assessment in the programme. During the interview, the panel and Board discussed the implication of generative AI for assessment in the courses. Several strategies and policies are currently being discussed on a faculty and university level. The panel adds to this that the Board could reach out to the Boards of Examiners of the other two Embedded Systems programmes to discuss what the domain-specific consequences of these policies could be.

Thesis assessment
The final project is assessed by an assessment committee of at least two members, consisting of at least a committee chair (first examiner) from within the group where the thesis is executed, and an external examiner (second examiner) from outside the group. Other examiners can be added based on the expertise required. The thesis is assessed during a committee meeting after the final presentation by the student. The grading takes place in discussion between the examiners, with other committee members acting as advisors. After the examiners reach consensus, the first examiner notes down the findings in the assessment form, using a rubric describing the assessment criteria (Scientific Quality, Organisation/Planning/Collaboration and Communication) and communicates the results to the student.

The panel concludes that the thesis assessment procedure is solid and efficient. Using second examiners that are unrelated to the project adds to the reliability and validity of thesis assessment. The panel also learnt with appreciation that first examiners are trained for their responsibility: supervisors only qualify as first examiner if they have sufficient experience as advisory committee member in thesis assessment committees.

As part of the assessment, the panel studied 15 final projects of the programme and the accompanying assessment forms. The forms are used in an insightful way, using clear rubrics to substantiate the grades, which were appropriate in all cases. The panel appreciates the introduction of rubrics, which answers the recommendations of the previous panel on a better substantiation of the grades. The amount of feedback given on the form differs between examiners: sometimes the panel would have appreciated more explanation of a specific aspect on the form. The panel recommends striving towards more uniformity in this. Furthermore, the panel noted that there are two grading systems in use in the programme: some students choose to have their thesis proposal separately graded in an earlier phase of the project, whereas others opt for a single assessment at the end of the process. Related to the comment on this in standard 2, the panel recommends choosing one of the grading systems for all students, where the panel prefers a separate thesis preparatory phase for all students.

Considerations
The MSc's assessment system is appropriate, with varied assessment methods and sufficient checks and balances to safeguard the quality of assessment. The Board of Examiners is proactive and in control of assessment quality assurance. The panel recommends setting up a more structural assessment of skills, coupled with the recommended skills learning trajectory. The thesis assessment is well-designed, with solid assessment procedures, an insightful form and associated rubrics. The use of fully independent second examiners and the attention paid to the training of first examiners are good practices. To further improve thesis assessment, the programme should pursue more uniformity in the quantity of feedback provided to students on the assessment form and strive for a single grading system for all students with a separate assessment of the thesis proposal.

Conclusion

The panel concludes that the programme meets standard 3.

Standard 4. Achieved learning outcomes

The programme demonstrates that the intended learning outcomes are achieved.

Findings

In order to determine the exit level of students, the panel studied 15 recent master's theses of the programme, taking care that a variety of grades and topics were covered. It concludes that all students convincingly achieve the MSc's intended learning outcomes. The theses cover a wide variety of topics and methods, and in all cases demonstrate an appropriate design of an embedded system. The panel noted that in some cases, the discussion part of the thesis could be more elaborate: it thinks that this could improve if more attention is paid to the formulation and scope of the research questions for all students (see standards 2 and 3). The panel learnt that 11 MSc students co-authored publications related to thesis projects in the past four years. The panel considers this to be further proof of the high level of the programme's graduates.

Based on a recent alumni survey, the majority of graduates end up working in industry within the Netherlands (73%) or abroad (10%). 6% of the graduates pursue a PhD. The remaining 11% are active in a variety of positions in research, education or the government. Alumni report to be satisfied with their education, and would without exception choose the programme again. The External Advisory Board confirmed that graduates of the programme are in high demand and generally valued. The panel concludes that this demonstrates the graduates' achievement of the intended learning outcomes, and the field's appreciation of these graduates.

Considerations

The quality of the theses as well as the job prospectives and satisfaction of the alumni show that students of the MSc Embedded Systems achieve the intended learning outcomes.

Conclusion

The panel concludes that the programme meets standard 4.

General conclusion

The panel's assessment of the MSc Embedded systems is positive.

Development points

1. Embed skills education and assessment more structurally in the curriculum beyond the internship and final project by attaching skills to specific educational components and associated assessments in the compulsory core, creating a skills learning trajectory throughout the curriculum. Specific attention should be paid to reflection on ethical and social consequences of technologies.

2. Invest in community forming between students, for instance by creating a physical space where Embedded Systems students can meet and work together on campus.

3. Investigate possible hurdles in the feasibility of the programme related to imbalance in workload between courses.

4. Harmonize the thesis trajectory for all students, splitting the final project into a preparatory phase resulting in a research proposal and an execution phase resulting in a thesis for all students.

5. Pursue more uniformity in the quantity of feedback provided to students on the thesis assessment form.

Appendix 1. Intended learning outcomes

The graduate

1. has an all-embracing view on embedded systems, their design and their application in systems (e.g. in small robots, cyber-physical and networked systems) including their evolution over time, demonstrated by an integration approach in system design.

2. is able to describe, study and specify the functional aspects of embedded systems taking into account the performance of the system during its lifetime.

3. is able to describe, study and specify the non-functional aspects of embedded systems, e.g., resource boundedness and dependability. The graduate is also aware of costs and environmental issues making optimal use of the available resources.

4. has a thorough knowledge of state-of-the-art methods and techniques for embedded systems design such as requirements engineering, hardware-software integration, performance modelling and analysis, validation, and testing. Knows how to use these methods and techniques in a structural way using appropriate abstractions.

5. is able to design embedded systems. The designs satisfy functional and non-functional requirements (see ILOs 2 and 3) and state-of-the-art methods and techniques are used (see ILO 4).

6. has basic knowledge of, and (design) skills in the following areas that are relevant to the domain of embedded systems: artificial intelligence, security, Internet-of-Things (IoT). (Besides the basic knowledge in hardware design, software design and system design which are covered by ILOs 1-5.)

7. has the ability and attitude to include other disciplines or involve practitioners of these disciplines in his/her work, where necessary. As an engineer he/she is therefore able to work in a multidisciplinary setting.

8. is able to conduct research and design independently and has a scientific approach to complex problems.

9. possesses intellectual skills that enable him/her to reflect critically, reason, and form opinions.

10. has the ability to communicate the results of his/her learning, thinking, and decision making processes at an international level.

11. is aware of the temporal and social context of science and technology (comprehension and analysis) and can integrate this context in his/her scientific work.

Appendix 2. Programme curriculum

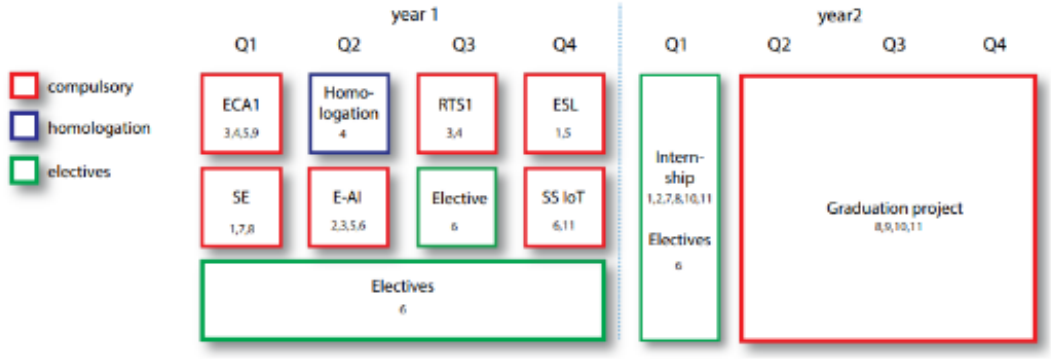

Figure 2.1 Overview of the curriculum with relations to the ILOs (See Table 2.3)

Compulsory Courses (starts in the academic year 2023/2024)

Table C.1
Compulsory courses

192120240	Embedded Computer Architectures 1
191211080	Systems Engineering
202200159	Embedded AI
192130200	Real Time Systems 1
201000168	Embedded Systems Laboratory
201700083	Security Services for IoT

The course codes refer to the course information system OSIRIS [26].

The themes and their associated courses are indicated in Table C.2-C.6.

Table C.2
Theme: Computer Architectures

191211590	System-on-Chip for Embedded Systems
192130250	Embedded Computer Architectures 2
192130112	or Distributed Systems
192130022	Design of Digital Systems
201000231	Computer Arithmetic (201000231, TUD)
191210950	or Implementation of Digital Signal Processing
202200135	Dependable Computing Systems
192130210	or Real Time Systems 2

Table C.3
Theme: Embedded AI

201600070	Machine Learning 1
201600071	Machine Learning 2
192130022	Design of Digital Systems
191210950	Implementation of Digital Signal Processing
202200112	AI for Autonomous Robots

Table C.4
Theme: Internet of Things

202100101	Wireless Communication Systems
192130112	Distributed Systems
192620010	Mobile and Wireless Networking
202100244	Pervasive Computing
201700073	Ad-Hoc Networks

Table C.5
Theme: Dependable Computing

192140122	System Validation
201200006	Quantitative Evaluation of Embedded Systems
192130022	Design of Digital Systems
202001472	Software Testing and Risk Assessment
202200135	Dependable Computing System
192130210	or Real Time Systems 2

Table C.6
Theme: Cyber-Physical Systems

191210910	Image Processing & Computer Vision
202200105	Robot Perception, Cognition and Navigation
192130250	or Embedded Computer Architectures 2
202200109	Advanced Software Development for Robotics
202200110	Tele-presence in Robotics
202200112	AI for Autonomous Robots

Appendix 3. Programme of the site visit

Mon 8 May

16.00-19.00	Panel preparation (incl. consultation hour)

Tue 9 May

08.30-09.00	Preparation
09.00-09.45	**Management UT**
09.45-10.00	Break
10.00-10.45	**Students and alumni UT**
10.45-11.00	Break
11.00-11.45	**Teaching staff UT**
11.45-12.00	Break
12.00-12:45	**General session: Embedded Systems Domain**
12.45-13.30	Lunch
13.30-14.00	**Board of Examiners UT**
14.00-14.30	Internal panel session
14.30-15.00	**Concluding session management UT**
15.00-16.15	Internal panel session
16.15-16.45	**Feedback and conclusion**
16.45-17.15	**Development dialogue**

Wed 10 May

12.00-12:45	**General session: Industrial Advisory Board** (during TU Eindhoven site visit)

Appendix 4. Materials

Prior to the site visit, the panel studied 15 theses. Information on the theses is available from Academion upon request. The panel also studied other materials, which included:

- Self-evaluation report
- Report previous assessment committee
- Intended Learning Outcomes
- Detailed mapping of programme to ILOs
- Intake and success rates of students
- Information External Advisory Board
- Domain-Specific Frame of Reference (DSFR)
- Embedded Systems Curriculum 2023-2024
- Education and Examination Regulations
- Course catalogue
- Time schedule of the courses
- EEMCS internship canvas page
- Tools for online teaching
- Quality Assurance Framework for Student Assessment UT
- EEMCS faculty assessment policy
- Questionnaire to check for potential issues due to Corona
- Internship Supervisor Evaluation Form
- Final project evaluation form
- Alumni Survey (NAE)
- Monitor student progress master Embedded Systems
- Analysis of Exams of core courses
- Reports of examination committee and programme committee
- Staff of the programme