NVAO

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INITIAL ACCREDITATION

ACADEMIC MASTER
QUANTUM COMPUTER SCIENCE
University of Amsterdam

FULL REPORT
15 March 2024

Content

1 Peer review

The Accreditation Organisation of the Netherlands and Flanders (NVAO) determines the quality of a new programme on the basis of a peer review. This initial accreditation procedure is required when an institution wishes to award a recognised degree after the successful completion of a study programme.

The procedure for new programmes differs slightly from the approach to existing programmes that have already been accredited. Initial accreditation is in fact an ex-ante assessment of a programme. Once accredited the new programme becomes subject to the regular review process.

The quality of a new programme is assessed by means of peer review. A panel of independent peers, including a student, reviews the plans during a site visit to the institution. A discussion amongst peer experts forms the basis for the panel's final judgement and the advisory report. The agenda for the panel visit and the documents reviewed are available from the NVAO office upon request.

The outcome of this peer review is based on the standards described and published in the limited NVAO Assessment framework for the higher education accreditation system of the Netherlands (Stcrt. 2019, nr. 3198). Each standard is judged on a three-point scale: meets, does not meet or partially meets the standard. The panel will reach a conclusion about the quality of the programme, also on a three-point scale: positive, conditionally positive or negative.

NVAO takes an accreditation decision on the basis of the full report. Following a positive NVAO decision with or without conditions the institution can proceed to offer the new programme.

This report contains the findings, analysis and judgements of the panel resulting from the peer review. It also details the commendations as well as recommendations for follow-up actions. A summary report with the main outcomes of the peer review is also available.

Both the full and summary reports of each peer review are published on NVAO's website www.nvao.net. More information on NVAO and peer reviews of new programmes can also be found there.

2 New programme

2.1 General data

Institution	University of Amsterdam
Programme	Quantum Computer Science
Variant	Fulltime
Degree	Master of Science
Location	Amsterdam
Study load	120 ECTS credits[1]

2.2 Profile

The master's programme Quantum Computer Science (QuCS) intends to educate computer scientists who understand quantum computing at a deep level. It focuses on the development of software and algorithms. The programme has a strong theoretical and research focus, combining elements from the disciplines mathematics, physics and computer science. QuCS offers students substantial flexibility to create a learning trajectory according to personal preferences and interests. All students finish the programme with a substantial thesis project (30 or 54 ECTS credits), which may be combined with an internship. Graduates may pursue a career in academia or find a research-related job in industry.

The programme will be embedded in the Graduate School of Informatics, part of the Faculty of Science, which has ample experience with the design and delivery of related master's programmes. QuCS has been developed in strong cooperation with the Dutch research centre for quantum software and technology QuSoft.

2.3 Panel

Peer experts

- Prof. dr. ir. W. (Wim) van Petegem (chair), Associate Professor at the Faculty of Engineering Technology, KU Leuven;
- Dr. ir. S.J.A. (Sissi) de Beer, Associate Professor in Sustainable Polymer Chemistry and Programme Director of the bachelor's programme Applied Physics and the master's programme Applied Physics at the University of Twente;
- Prof. dr. K.L.M. (Koen) Bertels, Professor of Quantum Computer Engineering at the University of Ghent and founder of QBee;
- N. (Nienke) Wessel BSc (student member), master's student Computing Science (Specialisation: Data Science) at Radboud University.

Assisting staff

- Anne Martens MA, secretary;
- drs. Dirk van Loon, NVAO policy advisor and process coordinator.

Site visit

Amsterdam, 29 January 2024.

Absence of a panel member during the site visit

Due to unforeseen circumstances, one of the panel members could not participate fully in the entire procedure and this member could not attend the site visit. As soon as this became clear,

[1] European Credit Transfer and Accumulation System

the process coordinator discussed this with the programme and the other panel members. All agreed to proceed with the site visit without the fourth panel member.

The absent panel member assessed the programme's information file, attended the preparatory panel meeting and shared their considerations with the other panel members. Their considerations were taken into account by the panel during the site visit.

The panel member read the draft version of the advisory report and provided feedback on the report. They agreed with the positive advice about the quality of the programme.

3 Outcome

The NVAO-approved panel reaches a positive conclusion regarding the quality of the master's programme Quantum Computer Science (QuCS) offered by University of Amsterdam (UvA). The institution intends to offer the programme of 120 ECTS credits as a fulltime programme in Amsterdam. The programme complies with the three standards of the limited NVAO assessment framework.

The ambitious programme intends to educate computer scientists who understand quantum computing at a deep level, responding to the needs in industry and research institutes that work with quantum computers. It focuses on the development of software and algorithms and has a clear theoretical and research focus. QuCS has been developed by UvA's Faculty of Science in close cooperation with the Dutch research centre for quantum software and technology QuSoft. The programme aligns with relevant international academic and disciplinary frameworks.

The programme's courses cover relevant knowledge as well as academic, programming and soft skills. QuCS has a strong research orientation, which is reflected in the content of the courses, the profiles of the academic staff members and the strong cooperation with QuSoft. It is a plus that the curriculum includes a course that addresses ethics and awareness of the impact of the discipline on society. Overall, the programme offers a considerable degree of flexibility and enables students to create a personal learning trajectory based on their interests. The programme offers adequate guidance in this process. The programme deploys a suitable variety of assessment modes that support students' learning processes.

Students finish the programme with a substantial and well-thought-out thesis project, which will be carried out at QuSoft or a (research) organisation in the quantum field. The thesis project requires them to show that they can conduct research in a relatively independent way. The project may be combined with an internship at a company or at a research centre. It is a good idea that UvA participates in the Quantum Talent Learning Centre to coordinate internships.

The academic staff members are highly qualified. They are active researchers at UvA's Faculty of Science and/or QuSoft and many are leading experts in their field. Their involvement in current research ensures that new developments are incorporated in the programme. The lecturers cooperate in a truly interdisciplinary team to design and deliver the programme. The programme benefits from the staff's experience in other master's programmes offered by UvA's Faculty of Science, both in terms of curriculum development and assessment.

The panel concludes that QuCS is an attractive and relevant new programme. It enables students to deepen their understanding of quantum computing and prepares them for a research-related career in academia or industry. The panel agrees with the programme's argumentation regarding its choice for an English-taught curriculum and a study duration of 120 ECTS credits.

Standard	**Judgement**
1. Intended learning outcomes	meets the standard
2. Teaching-learning environment	meets the standard
3. Student assessment	meets the standard
Conclusion	*positive*

4 Commendations

The programme is commended for the following features of good practice.

1. Development – The programme has been developed in close cooperation with researchers, lecturers and students. The use of the EU Competence Framework for Quantum Technologies is a strength.

2. Lecturers – The programme has been designed and will be delivered by dedicated and highly qualified academic staff members, who are active researchers.

3. Admission – The admission requirements are clearly defined and fit for the challenging programme.

4. Thesis – The thesis project is well-thought-out and requires students to show that they can conduct research in a relatively independent way

5. Experience – The programme builds on the experience in related UvA master's programmes that have a similar setup.

5 Recommendations

For further improvement to the programme, the panel recommends a number of follow-up actions.

1. Learning outcomes – Sharpen the learning outcomes related to research skills.

2. Advisory Board – Involve more representatives from the quantum industry in the further development of the programme to cover its broad spectrum, prevent bias in a rapidly evolving domain and to ensure that the programme educates students who are valuable to both academia and industry.

3. Learning lines – Improve the visibility of the learning lines related to skills development.

4. Community feeling – Make concrete plans before the start of the programme to foster a sufficient community feeling amongst QuCS students and staff.

6 Assessment

6.1 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.

Judgement
Meets the standard.

Findings, analysis and considerations
The master's programme Quantum Computer Science (QuCS) intends to educate computer scientists who understand quantum computing at a deep level. The programme has been developed by the Faculty of Science at the University of Amsterdam (UvA). The institution participates in the Dutch research centre for quantum software and technology QuSoft and is one of the founders of Quantum.Amsterdam, a hub within the Quantum Delta NL ecosystem that focuses on quantum software, sensing and simulation. The development of QuCS aligns with the quantum education action line of Quantum Delta NL. Graduates may pursue a career in academia or find a job in industry, which is currently research-oriented but expected to shift towards applications in the next four to five years.

During the site visit, the programme director adequately explained the position of the programme in the broader field of quantum education – both within the Netherlands and abroad. QuCS focuses on the development of software and algorithms. It has a theoretical and research focus, combining elements from the disciplines mathematics, physics and computer science. Thus, it sets itself apart from related programmes offered by Dutch universities that address the development of quantum computing hardware. The difference in focus also explains the unique name of the programme – in line with agreements that have been made within Quantum Delta NL. Also, compared to programmes at other European universities, QuCS has a specific and relevant programme.

The programme's fourteen intended learning outcomes have been formulated based on the Dublin descriptors for the master's level. According to the panel, the programme is ambitious in its aim to deliver graduates who have a thorough understanding of the fundamentals of quantum computing and a good command of algorithms and information processing protocols, as well as specialised knowledge of two subfields that are related to the QuSoft research areas. Considering the strong research focus, the panel recommends sharpening the learning outcomes related to research skills.

The panel appreciates the use of the EU Competence Framework for Quantum Technologies (QTEdu, 2023) in the development of the programme. During the site visit, the panel learnt that QuCS matches the profile 'Quantum Computing Software Engineer', addressing specifically the framework's pillars related to a theoretical background in quantum physics, quantum computing and simulation, and practical skills. For these pillars, the programme aims for the level innovation (C2) and higher, preparing students for a career in quantum research. Additionally, the programme includes aspects of the pillar quantum communication.

The programme has been developed in close cooperation with QuSoft, a partnership of UvA and CWI.[2] Based on the information file, the panel was under the impression that the

[2] National Research Institute for Mathematics and Computer Science ('Centrum voor Wiskunde en Informatica')

involvement of the professional field had been limited to this partnership. However, during the site visit the panel established that – through QuSoft and staff members – a wider network of stakeholders has been consulted, both formally and informally. The programme management also explained that students of related programmes have been involved in the development of the programme. In addition, the Faculty of Science has an Advisory Board to which one member will be added to represent the quantum field. The panel recommends involving more representatives from the quantum industry in the further development of the programme to cover its broad spectrum, prevent bias in a rapidly evolving domain and to ensure that the programme educates students who are valuable to both academia and industry. This could also strengthen the connection to other industries that (plan to) work with quantum computers. The panel spoke with representatives of the professional field who underlined the great need for QuCS graduates. Taking into account the (research) options in industry, the panel notes that the programme's expectation that half of the QuCS graduates will continue in academia may not be realised.

The panel concludes that QuCS's intended learning outcomes represent the academic master's level and align with relevant international frameworks. The programme is ambitious and has a clear research focus. The programme is well connected to current developments, especially through UvA's participation in Quantum Delta NL and QuSoft. Based on these findings and considerations, the panel concludes that the programme meets standard 1. In addition, the panel makes two recommendations.

6.2 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.

Judgement
Meets the standard.

Findings, analysis and considerations
QuCS has a proposed study duration of 120 ECTS credits and lasts two years. The curriculum consists of core courses, restricted-choice courses and a master thesis. In total, 81 ECTS credits are compulsory. The panel established that the core of the curriculum covers all intended learning outcomes. Students fill the remainder of their programme with electives from other master's programmes, a research project, additional restricted-choice courses, an internship or an extended master's thesis. Four of the core and restricted-choice courses have previously been offered in related master's programmes.

The programme has a strong research orientation, which is reflected in the content of the courses, the profiles of the academic staff members and the strong cooperation with QuSoft. However, in the programme's documentation, the panel missed a clear learning line related to the development of research skills. During the site visit, lecturers explained that the development of these skills is woven into the curriculum, and they gave multiple examples of how they do this in their courses. The panel recommends making this more visible and visualising the learning line related to research skills. This will clarify to students how they gradually develop their research competences throughout the curriculum.

The programme also enables students to develop other relevant skills, including programming and soft skills such as communication and cooperation. Programming in QisKit is addressed in a restricted-choice course. The panel appreciates that the mandatory course Quantum in Society addresses ethics and awareness of the impact of the discipline on society. The panel advises to pay sufficient attention to the possible applications of quantum computing. Soft skills and

general academic skills are addressed in multiple core courses. Additionally, the Faculty of Science offers 1.5-credit courses on different professional skills, for instance critical thinking and writing. These are offered as electives, so students can choose courses that are most relevant to them. The panel understands this approach and encourages good promotion of these courses. Creating a learning line related to professional skills development may improve their visibility in the curriculum.

Students finish the programme with a substantial thesis project of 30 or 54 ECTS credits. They may combine a 30-credit thesis with a quantum-related internship in industry. Students with the ambition to pursue a PhD may combine the thesis project with a research internship. The information file explains that students can start their thesis project from the start of the second year, combined with courses. It is also possible to concentrate a 30-credit thesis project in the final semester. All thesis projects will be carried out at QuSoft or a (research) organisation in the quantum field. The responsibility of the scientific quality always remains with a UvA staff member and students are supervised by a first reader who is a senior researcher. A dedicated thesis coordinator keeps track of the progress of all students. According to the panel, the programme has described the thesis process in a clear way. The panel is positive about the two presentations that students give to an audience of peers and QuSoft staff, focusing on (1) the research proposal and (2) progress, possible problems and preliminary results.

Students who wish to pursue a career in industry may opt for an internship in the second year. This curriculum component is still under development. To coordinate internships, the programme will participate in the Quantum Talent Learning Centre, an initiative of Quantum Delta NL that is hosted by the Amsterdam University of Applied Sciences (HvA). The panel applauds this initiative and believes that UvA can benefit from HvA's experience with internships. Representatives of the professional field told the panel that they see ample opportunities for internships in their organisations. All QuCS internships will be supervised by a UvA academic supervisor. An internship coordinator will keep track of all QuCS internships. The panel advises to develop clear guidelines for internships – including a clarification on the content criteria and the distinction between the internship and thesis project – and supports the idea to appoint separate coordinators for the internship and thesis.

The panel appreciates the flexibility in the curriculum, which enables students to shape the programme according to their own preferences and interests. Representatives of the professional field also value the combination of a broad curriculum with room for some specialisation. However, the flexibility also requires sufficient students support. In the first semester, students may consult a study advisor to choose relevant courses. It is important that students are informed that their choices in the first year may impact their options in the second year. The second semester includes a mandatory Orientation course to prepare for the second year. This course is geared towards the thesis topic and, if relevant, the internship. The choice for a topic may affect the selection of second-year electives. It is positive that the course includes a thesis fair to inform students about possible thesis topics. At the end of the first year, students create a digital Study Plan with their selection of courses and submit this plan to the Examinations Board for approval. Lecturers explained that they have experience with this set-up in related UvA programmes, which gives the panel confidence that QuCS will be able to arrange a wide variety of personal learning trajectories.

The programme's underlying principles 'learning by doing' and 'active learning' are visible in multiple aspects of QuCS's education. Lectures are combined with seminars, where students work on assignments to apply theoretical knowledge to specific problems. The assignments provide students with continuous feedback on their learning process. Students often work in groups and thus learn to cooperate in an interdisciplinary setting. The information file explains

that the programme will experiment with the concept of a flipped classroom to further stimulate active learning.

The Teaching and Examination Regulations include the programme's clearly defined entry requirements. QuCS intends to attract students with a bachelor's degree in (or equal to) computer science, mathematics, or physics. Applicants must demonstrate 'mathematical maturity' to be able to follow the mathematical courses. All students start the programme with a 1-credit Catch-up Course. During the site visit, the lecturers explained that the goal of this course is to create a common language and mindset. In addition, it enables students to identify any weak points. The Catch-Up Course offers students supplementary materials to prepare for the mandatory courses Introduction to Quantum Hardware, Quantum Computing, and Quantum Information Theory. Students select relevant materials depending on their individual background and knowledge gaps. The panel advises to evaluate whether the entry requirements combined with the Catch-up Course leads to an adequate selection and preparation of students.

It is positive that the programme will organise social events during the Catch-up Course, to foster community building at the start of the programme. The programme management hopes that an intense first week with shared struggles will also contribute to a community feeling. In the future, second-year students will also guide first-year students through a buddy system. Additionally, the programme management indicated that students may join the study association for students of the Computer Science, Artificial Intelligence and Information Sciences disciplines. The panel understood that this has not yet been discussed with the association. The panel therefore advises the programme management concretising plans to further facilitate the creation of a learning community.

The panel appreciates the programme's highly qualified and dedicated academic staff members. They are active researchers at UvA's Faculty of Science and/or QuSoft. The panel acknowledges that many lecturers are leading experts in their field. All lectures are taught by senior researchers, who have obtained the University Teaching Qualification or are in the process of obtaining it. Lecturers can call upon their experience in other UvA master's programmes, which will benefit QuCS. They gave the panel multiple examples of how they work together as an interdisciplinary team in the design and delivery of the programme. PhD students and post-docs conduct the practical seminars. The panel values the didactical training prior to the start of their teaching activities, as well as the Faculty's initiatives to increase the diversity among staff members.

The Faculty of Science has adequate facilities for the programme. UvA plans to open a new building ('LabQ') for quantum education, research and related companies in 2027. In the meantime, QuCS will find a home in the existing buildings. In this context, the panel recommends making concrete plans before the start of the programme to foster a sufficient community feeling amongst QuCS students and staff. Canvas is used as the digital learning environment. The Education Service Centre at the Faculty of Science supports the programme with programme coordinators, study advisors, assessment experts and policy officers for educational innovation and quality assurance. It is a good idea that a separate Programme Committee will be installed for QuCS.

The programme is fully taught in English and bears an English name. The panel agrees with the programme that this is a reasonable choice because of the international workforce in the quantum industry. The programme argues that graduates should be able to express themselves easily in English and master the technical jargon. The panel acknowledges that an international classroom with students from the Netherlands and abroad will prepare students for their future

international work environment, including cooperating with people from different cultural backgrounds. Finally, the programme remarks that quantum-versed talent is scarce. It is necessary to recruit academic staff internationally, while graduates who remain in the Netherlands may strengthen Dutch quantum-related activities. Applicants should adhere to UvA's policy regarding English language proficiency. Academic staff members are used to English as a working language because of their everyday international environment.

The panel concludes that the programme has developed a curriculum that covers all intended learning outcomes. QuCS offers a considerable degree of flexibility and enables students to create a personal learning trajectory based on their interests. The programme offers adequate support in this process. The academic staff members are highly qualified and cooperate as an interdisciplinary team. Their involvement in current research ensures that new developments are incorporated in the programme. The institution has adequately argued why the programme is taught in English and why it bears an English name. Based on these findings and considerations, the panel concludes that the programme meets standard 2. In addition, the panel formulates two recommendations.

6.3 Standard 3: Student assessment

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

Judgement
Meets the standard.

Findings, analysis and considerations
The programme has developed an adequate assessment plan, based on the UvA assessment policy and the guidelines of the Faculty of Science. The assessment procedures safeguard valid, reliable and independent assessments. The panel is of the opinion that QuCS uses an appropriate variety of assessment forms, including formative and summative assessments. Throughout the curriculum, students work on assignments that promote active engagement with the course materials. The courses' Canvas pages include information about the type of assessment and assessment criteria, and inform students prior to the actual assessment. Course coordinators are responsible for assessment in their courses and ensure that, overall, all learning outcomes are assessed. Staff members are further supported by assessment experts at the Faculty of Science.

The panel studied a matrix with an overview of intended learning outcomes and assessments, and noted that the thesis does not address all intended learning outcomes. When asked about it, the programme director explained that the exact contents of the thesis will differ from student to student. Therefore, the matrix only contains the learning outcomes that will be part of every thesis. Individual theses are likely to cover more learning outcomes. Although the panel understands this position, it suggests to investigate whether it is possible to include all intended learning outcomes in all thesis projects.

A separate and well-thought-out assessment procedure is in place for the thesis project. Each thesis is assessed by a supervisor as well as a second reader who was not involved in the project. The assessment consists of three components: the quality of the research report (60%), workplace skills (25%) and two intermediate presentations (15%). The research report is assessed by both examiners independently. Workplace skills refer to academic and professional behaviour and are graded by the supervisor only. The presentations are graded by the thesis coordinator. Together, the supervisor and second reader determine a student's final grade. They use assessment criteria that have been derived from existing master's programmes. The

panel is confident that these will support the examiners to determine grades, but advises to reconsider some formulations so the meaning will be clearer to students.

The information file mentions that the programme will organise calibration sessions for thesis grading once a certain number of students has graduated. This made the panel wonder how the master's level will be established for the first cohorts of students. During the site visit, the lecturers explained that examiners will come together to discuss the grading in advance – also for the first cohort. Moreover, the examiners have experience with grading theses in other UvA master's programmes. This gives the panel sufficient confidence that the examiners will be able to assess the master's level properly.

The programme provided draft documents for the internship and noted that students do no not receive a mark but a pass or fail for this curriculum component. Although the panel understands this premise because of a possible wide range of internship positions and deliverables, the panel advises developing more detailed assessment criteria. This will support the internship assessors and inform students about the requirements of the internship. The panel believes that the programme will manage to provide clarity on this matter before the first students start an internship.

QuCS will get its own subcommittee in the Examinations Board (EB) for Informatics and Natural Sciences. The panel believes this is a suitable setup and the experience of the board with other master's programmes will be valuable. The programme has set relevant criteria for EB members and new members are offered a training to prepare them for their role. The Teaching and Examination Regulations provide a clear overview of the programme, assessment and students' rights.

The panel concludes that the programme has an adequate system of assessment in place. The panel appreciates that QuCS can benefit from the experience in the wider UvA community. The programme deploys a variety of assessment modes that supports students' learning processes. Together, they cover all intended learning outcomes. Based on these findings and considerations, the panel concludes that the programme meets standard 3.

6.4 Duration of the programme

In the information file, the programme provides several reasons for the study load of 120 ECTS credits. Firstly, the QuCS intends to attract students from a range of academic backgrounds and a two-year programme is necessary to overcome possible knowledge gaps. Secondly, quantum computer science is a broad and complex field of study, and students need to acquire specialised knowledge in several subfields to be able to work effectively as quantum computer scientists. Thirdly, the programme expects that a considerable number of students will continue with a PhD, requiring substantial research experience during the master's programme. The programme concludes that it is not possible to combine various specialised courses and a thesis project in a one-year programme, and adds that related programmes at UvA and other Dutch universities have a study duration of 120 ECTS credits for similar reasons.

The panel agrees with this argumentation. The programme addresses a complex topic that covers elements of multiple disciplines. QuCS intends to deliver students who have expertise in at least two subfields of quantum computer science and who can conduct research in a relatively independent way. This enables graduates to work as researchers in academia or in industry. The panel agrees that this aim requires a thorough understanding of the topic and sufficient time to carry out a substantial thesis project. The panel therefore agrees with the proposed study duration of 120 ECTS credits for the QuCS programme, based on the requirements of the professional field.

6.5 Degree

The panel advises awarding the following degree to the new programme: Master of Science.

Abbreviations

EB	Examinations Board
ECTS	European Credit Transfer and Accumulation System
HvA	Amsterdam University of Applied Sciences
NVAO	Accreditation Organisation of the Netherlands and Flanders ('Nederlands-Vlaamse Accreditatieorganisatie')
QTEdu	European Competence Framework for Quantum Technologies
QuCS	master's programme Quantum Computer Science
UvA	University of Amsterdam

The full report was written at the request of NVAO
and is the outcome of the peer review
of the new master's programme
Quantum Computer Science
offered by University of Amsterdam

Application no: AV-2170

NVAO

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