NANOTECHNOLOGY

FACULTY OF SCIENCE AND TECHNOLOGY

UNIVERSITY OF TWENTE

Qanu
Catharijnesingel 56
3511 GE Utrecht
The Netherlands

Phone: +31 (0) 30 230 3100
E-mail: support@qanu.nl
Internet: www.qanu.nl

Project number: Q0808

CONTENTS

This report was finalised on 11 October 2021

REPORT ON THE MASTER'S PROGRAMME NANOTECHNOLOGY OF THE UNIVERSITY OF TWENTE

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

Name of the programme:	Nanotechnology
CROHO number:	60028
Level of the programme:	master's
Orientation of the programme:	academic
Number of credits:	120 EC
Location:	Enschede
Mode of study:	full-time
Language of instruction:	English
Submission deadline NVAO:	01-11-2021
Double degree programme:	
Partner institution involved:	*Technical University of Łódź (Poland)*
Type of degree awarded:	*double degree*

The visit of the assessment panel Applied Physics to the Faculty of Science and Technology of the University of Twente took place on 20-21 June 2021.

ADMINISTRATIVE DATA REGARDING THE INSTITUTION

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

COMPOSITION OF THE ASSESSMENT PANEL

The NVAO has approved the composition of the panel on 8 April 2021. The panel that assessed the master's programme Nanotechnology consisted of:

- Dr. C. (Cees) Terlouw, Senior Researcher and Consultant at Terlouw Consultancy & Advice (chair);
- Prof. P. (Petra) Rudolf, Professor Experimental Solid State Physics and Dean of Graduate Studies, University of Groningen;
- Prof. M.J. (Margriet) Van Bael, Professor Quantum Solid State Physics at KU Leuven;
- Dr. F.J.P. (Frank) Schuurmans, Vice President System Engineering at ASML Netherlands;
- Prof. P.J. (Patrick) French, Professor Biomedical Electronics at TU Delft;
- M.S. (Mare) Dijkstra BSc., master student Applied Physics at University of Groningen (student member).

The panel was supported by Peter Hildering MSc., who acted as secretary.

WORKING METHOD OF THE ASSESSMENT PANEL

The site visit to the master's programme Nanotechnology at the Faculty of Science and Technology of the University of Twente was part of the cluster assessment Applied Physics. In June 2021 the panel assessed eight programmes at three universities. The following universities participated in this cluster assessment: Delft University of Technology, Eindhoven University of Technology 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. As of 1 July 2021, Qanu was supported by evaluation bureau Academion. Peter Hildering was project coordinator on behalf of Qanu as well as Academion, and acted as secretary in the cluster assessment for all site visits.

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

- Dr. C. (Cees) Terlouw, Senior Researcher and Consultant at Terlouw Consultancy & Advice (chair);
- Prof. P. (Petra) Rudolf, Professor Experimental Solid State Physics and Dean of Graduate Studies, University of Groningen;
- Prof. M.J. (Margriet) Van Bael, Professor Quantum Solid State Physics at KU Leuven;
- Dr. F.J.P. (Frank) Schuurmans, Vice President System Engineering at ASML Netherlands;
- Prof. P.J. (Patrick) French, Professor Biomedical Electronics at TU Delft;
- M.S. (Mare) Dijkstra BSc., master student Applied Physics at University of Groningen (student member). X.M. (Xander) de Wit BSc., master student Applied Physics at Eindhoven University of Technology (student member).
- Em. prof. G. (Guido) van Oost, Professor Emeritus Nuclear Fusion at Ghent University (referent);

Preparation
On 29 March 2021, 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 organised on 27 May 2021. During this meeting, the panel members received instruction on the use of the assessment framework. The panel also discussed their working method and the planning of the site visits and reports.

The project coordinator 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 3 for the final schedule.

Before the site visit to the University of Twente, Qanu received the self-evaluation report of the programme and sent this to the panel. The panel chair and the project coordinator made a selection of theses to be read by the panel. The selection consisted of 15 theses and their assessment forms, based on a provided list of graduates between 2018-2020. A variety of topics and a diversity of examiners were included in the selection that also included three theses from the double degree programme. The project coordinator and panel chair assured 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 questions and remarks and distributed these amongst all panel members. At the start of the site visit, the panel discussed its initial findings on the self-evaluation report and the theses, as well as the division of tasks during the site visit.

Site visit
The visit to the University of Twente took place on 20-22 June 2021, and was combined with the site visit to the bachelor's and master's programme Applied Physics at the same Faculty. Before and during the site visit, the panel

studied the additional documents provided by the programme. An overview of these materials can be found in Appendix 4. The panel conducted interviews with representatives of the programme: students and staff members, the programme management, alumni and the Board of Examiners. It also offered students and staff members an opportunity for confidential discussion during a consultation hour. No request for private consultation was received. 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.

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 chair and changes were implemented accordingly. The report was then finalised 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

The profile and aims of the master's programme Nanotechnology are fitting for an academic programme within the field. The programme has a strong interdisciplinary and an international focus and a strong connection to the MESA+ institute. The double degree programme with the Technical University of Łódź is a strong addition. The recent refocus on both research and engineering is sensible with regard to demands of the field, and could appeal to a larger group of students. The panel recommends continuing to work on the balance between the academic and professional focus of the programme. It could consider setting up an external advisory board where both areas are represented. The goals of the programme have been well-translated into a coherent set of intended learning outcomes that are aligned with the requirements of the academic and professional field through the Meijer's criteria and a benchmark with comparable programmes. The panel recommends adding interdisciplinary skills to the ILOs, as this is a distinctive characteristic of the programme.

The master's programme Nanotechnology has translated the intended learning outcomes into a strong interdisciplinary curriculum in nanotechnology. The curriculum has sufficient attention to engineering skills as well as academic and professional skills. To make this more visible, the programme could consider creating a learning trajectory that describes the skills education throughout the curriculum. The panel also recommends offering students additional assistance in composing a coherent curriculum, and increasing options for students to work with larger companies. The double degree programme with the Technical University of Łódź is well-structured and offers a coherent curriculum covering the programme's ILOs.

The programme successfully uses small-scale interactive teaching methods. Students work closely together with their teachers, who are all active researchers and engineers, as well as with their fellow students with various disciplinary backgrounds. The panel considers this an important strength of the programme. The use of English throughout the programme is well motivated. The English language proficiency of students could be improved in some cases: the panel supports the planned measures to make the admission criteria stricter to prevent language barriers in courses and group projects. The programme is feasible for students from various backgrounds, with sufficient attention to deficiencies. The panel recommends continuing to pay attention to these aspects, and making sure that the workload of the courses stays manageable for all admitted students. Study delays due to the corona pandemic were minimized and issues were sufficiently addressed. The internship and final project are often a source of study delay; the panel recommends introducing stricter rules concerning duration at the start of a project. The expertise of the teaching staff reflects the interdisciplinary character of the programme, and consists of capable and qualified teachers. The panel supports efforts to further improve professionalization of teachers through UTQs. The Homebase area provides students with excellent study facilities, and the programme's lab facilities are state-of-the-art.

The programme has a valid, transparent and reliable system of assessment in place. The assessment methods are varied and fit the learning goals of the courses. During the corona pandemic, the programme successfully made the switch to online assessment. To improve the validity of the assessment of group projects, the panel recommends structurally adding individual components to at least the design project. The procedures and assessment forms for the final master projects are solid, but could be more transparent. The panel recommends introducing grades for the various subcriteria and provide examiners with a rubric to help them substantiate their assessment. The Board of Examiners fulfils its role in safeguarding the quality of assessment in the programme. The panel recommends more structural checks to determine the quality of course assessment and the final master projects.

The panel concludes that final master projects of the programme are generally of a high quality, and show that the intended learning outcomes of the programme are achieved. Alumni are satisfied with their education, and feel that it has prepared them well for their future career. Graduates of the master's programme continue in approximately equal numbers in nanotechnology-related positions in academics and industry underlining the dual nature of the programme, as well as the high demand for its graduates.

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

Master's programme Nanotechnology

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, Cees Terlouw, and the secretary, Peter Hildering, of the panel hereby declare that all panel members studied this report and that they agree with the judgements laid down in the report. They confirm that the assessment was conducted in accordance with the demands relating to independence.

Date: 11 October 2021

DESCRIPTION OF THE STANDARDS FROM THE ASSESSMENT FRAMEWORK FOR LIMITED PROGRAMME 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

Profile and aims
The master's programme Nanotechnology is an interdisciplinary programme organized by the Faculty of Science and Engineering (TNW) at the University of Twente (UT). The programme aims to educate students that can use nanotechnology to contribute to solving society's grand challenges in a role of researcher, engineer or manager. It is a small-scale master's programme for talented students that typically attracts 15-25 students per year, although there is room for more. Historically, the programme has been strongly tied to MESA+, the nanotechnology research institute within the UT in which multiple disciplines collaborate. Active research groups in the programme come from the disciplines of Applied Physics, Biomedical Engineering, Chemical Engineering and Electrical Engineering. The master's programme Nanotechnology was originally launched in 2004 for students interested in pursuing a combined MSc-PhD programme at MESA+. Since 2016, in response to the recommendations of the previous accreditation committee, the aims and curriculum of the programme were broadened to include more attention to engineering, such as the fabrication and design of nanodevices. The programme has a strong international focus. The majority of students and staff is international. The programme offers an international double degree with the Technical University of Łódź (Poland), where excellent students from the master's programme Nanotechnology in Łódź join the programme at the UT.

The panel has studied the profile and aims of the programme, and concludes that they are fitting for an academic master's programme. It is a unique programme with a strong interdisciplinary character, and it is firmly connected to the MESA+ research institute. The panel is positive on the international character of the programme, and considers the double degree programme with Łódź to be a strong addition.

According to the panel, the recent refocus towards industry and engineering is a sensible choice that adds to the relevance of the programme. The high-tech industry in the field of nanotechnology is rapidly growing and there is a high demand for qualified engineers in the field. From discussions with students, the panel noted that some felt that the programme was in practice still primarily focused on a career in academia rather than engineering and industry. The programme management agreed that this tendency is still visible in the programme, and that the programme is in the process of finding a balance between a research and a professional focus. The panel encourages the programme to continue this process, and to make sure that a PhD trajectory and a career in industry are presented as equally viable options for students. To further strengthen this, the programme could consider setting up an external advisory board consisting of representatives of both career paths. This board could provide the programme with input to align their aims with the demands of academia and high-tech industry. The panel is confident that a dual approach, combined with the interdisciplinary strengths and the facilities of MESA+, will be attractive to prospective students. If the programme is successful in increasing the intake, the programme could consider creating a specific track for students interested in a PhD, for instance by pursuing a 5-year MSc-PhD trajectory.

Intended learning outcomes
The programme translated its goals into seven intended learning outcomes (ILOs) that describe the knowledge, skills and competences that are required of a master's student in Nanotechnology. They are expressed in terms of the seven competence areas of the Meijer's criteria. These criteria were developed by the Dutch technical universities

(4TU) as a translation of the Dublin descriptors for higher education in engineering. The ILOs are included in Appendix 1. To provide a benchmark of its ILOs, the programme compared these to the domain-specific framework of reference (DSFR) of the Applied Physics programmes, as well as to national and international master's programmes or tracks in nanoscience and -technology.

The panel studied the ILOs of the programme, and concluded that they form a convincing and well-structured overview of the main goals of the programme translated into knowledge and skills to be acquired by students. The use of the Meijers criteria in designing the ILOs guarantees that they meet the master's level and academic orientation, as well as comply with general engineering skills required by the academic and professional field. The benchmark with other programmes shows that all essential elements are covered in the ILOs. According to the panel, the interdisciplinary character of the programme could be better expressed in the ILOs. It recommends adding interdisciplinary skills to highlight this important strength of the programme.

Considerations
The profile and aims of the master's programme Nanotechnology are fitting for an academic programme within the field. The programme has a strong interdisciplinary and an international focus and a strong connection to the MESA+ institute. The double degree programme with the Technical University of Łódź is a strong addition. The recent refocus on both research and engineering is sensible with regard to demands of the field, and could appeal to a larger group of students. The panel recommends continuing to work on the balance between the academic and professional focus of the programme. It could consider setting up an external advisory board where both areas are represented. The goals of the programme have been well-translated into a coherent set of intended learning outcomes that are aligned with the requirements of the academic and professional field through the Meijer's criteria and a benchmark with comparable programmes. The panel recommends adding interdisciplinary skills to the ILOs, as this is a distinctive characteristic of the programme.

Conclusion
Master's programme Nanotechnology: 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

Curriculum
The Nanotechnology curriculum (see Appendix 2) consists of a compulsory core (35 EC), programme-specific electives (15 EC), free electives (10 EC), an internship project (20 EC) and the master's final project (40 EC). The *compulsory core* is offered in the first year, and consists of the fundamentals of nanophysics and techniques to fabricate nanostructures, such as lithography, self-assembly methods and nanochemistry. Students learn to understand and use tools and methods for characterizing nanostructures, including scanning probe and electron microscopy, scattering techniques, NMR and various spectroscopy methods. This is offered in the labs of the research groups and the cleanroom facilities of the MESA+. In the design project, students design and fabricate their own nanodevice for use in a practical application. Furthermore, students choose three *programme-specific electives* from a selection of ten courses, divided over the subdomains of solid-state matter, biomolecular matter and soft matter & systems. Students can choose to specialize in a subdomain, but this is not required: students can choose any combination of courses. Students complete their first year with an *internship project*. This is usually an project conducted at an external research centre, university or company, and aims to provide students with job orientation. The *free electives*, pursued in the second year, can be any master's level course, as long as it prepares students for their master's research project or deepens their knowledge of a specific subject. The remainder of the

second year is spent on the *master's final project*, where students perform an individual research projects in one of the research groups affiliated with the programme. Societal embedding and valorization of nanotechnology are integrated in the design and final project, where students are asked to consider and reflect on these aspects as part of their research and design project.

The panel studied the structure and content of the curriculum as well as the content of a selection of courses within the programme, and spoke to the programme management, teaching staff and students. It concludes that the programme’s intended learning outcomes are well incorporated into the curriculum. The *compulsory core* programme provides a strong basis in nanotechnology, including the fabrication and design of nanostructures. The design project adds a clear engineering component to the programme. The courses pay sufficient attention to the training of academic and professional skills, as well as research integrity and reflection in the societal embedding and valorization parts of the design project and the final project.

The programme could consider making the skills education more visible in the curriculum, for instance by creating a separate overview or learning trajectory that shows where the various academic and professional skills are offered. This could also be helpful in the case of future curriculum changes. The panel understood that some students, in hindsight, would have appreciated more help in choosing a coherent curriculum. The panel advises the programme to consider introducing for instance a mentor for each student that helps him or her with curriculum choices based on personal goals. With regard to career orientation, the panel learnt from the interviews and remarks in the self-evaluation report that some students would welcome more opportunities to orient themselves towards industry, in particular larger companies. Most interactions with industry are with start-up companies within the MESA+ ecosystem. The panel recommends investigating more options for students to interact with larger companies, for instance through the internships, guest lectures or company visits.

Students in the double degree programme with the Technical University of Łódź follow an adapted curriculum. The programme is designed for excellent students from Łódź that want to study in Twente. Students are selected based on their results in Łódź (8.0 grade average or higher). After their first semester, they come to Twente and follow a 35 EC selection of core courses and electives complementary to their first semester in Poland, as well as a 30 EC final project. Completed with a R&D project they conduct in Łódź, they receive their diploma from both universities. The panel studied the curriculum of the double degree programme, and concludes that the two universities created a coherent and complementary programme that covers the ILOs of the UT master's programme. It understood from the interviews that students and staff appreciate this variant, and that its students are often among the best of the programme.

Teaching methods

The master's programme Nanotechnology is a small-scale programme that provides interactive, student-driven education. Research and education are closely connected, with students working with researchers and in the labs and cleanrooms. Teaching methods are often interactive sessions, with knowledge sharing based on the student's needs. During the corona pandemic, these interactive sessions were continued online. Students all received a digital drawing board from the Faculty to facilitate interactive communication during the lectures.

Students have a large amount of control over their own learning: in particular the design project, internship and final project can be shaped to the student's own aims and goals. Within the courses, students are often challenged to find their own solutions with the help of teachers. During the final project, students learn by means of a master-apprentice relationship with their supervisor, where students often perform a part of a larger research project where they frequently interact with other researchers.

The panel is positive on the small-scale, intensive and student-driven teaching methods used by the programme, both in face-to-face education as during the online education. By working closely with researchers in the field of nanotechnology, they develop into independent researchers and engineers. According to the panel, this is a very valuable characteristic that the programme should aim to maintain under possible future growth.

Language and internationalization

The programme is offered in English. The field of Nanotechnology in academia as well as industry has a strong international focus, in which the English language is essential. Due to the international context, all teaching staff works and communicates in English on a day-to-day basis. For new staff members, language proficiency is one of the selection criteria for new staff. Additionally, the university offers courses to improve language proficiency of all staff. The panel considers the choice for the use of English to be well motivated. The programme is closely related to the research field, which is fully international. An English language programme prepares students for an internationally oriented field. Students are positive on the quality of the education in English, and there is sufficient attention to the language skills of the teaching staff.

With regard to the language skills of students, the panel learnt that there are sometimes issues with international students with a low proficiency in English. These students usually manage throughout the curriculum, but fellow students report that cooperation in classes and projects with these students can be challenging. The programme management recognized the issue and mentioned to the panel that they are working on improving admission criteria on this aspect. Currently, the programme uses standardized TOEFL tests to assess the language proficiency of prospective students. Nevertheless, the command of English can in practice be significantly lower than the assessment suggests. The programme is planning to introduce live online interviews with prospective students to be able to get a second opinion on their English language skills. The panel supports the planned measures to make admission criteria stricter, and recommends a short-term implementation. Communication between students is important in a small-scale programme, and should not be limited by language barriers.

Feasibility and student support

The programme aims to offer a feasible curriculum for students from various backgrounds. The programme uses the courses in the compulsory core to tackle the variation in the student's entry level with regard to background knowledge. These courses cover the various disciplines that contribute to nanotechnology, bringing students towards a similar level. For some target groups there are specific deficiency courses, such as students without sufficient knowledge of basic quantum mechanics, electronics and instrumentations or MatLab. Students with a foreign and professional (hbo) bachelor's diploma follow a workshop on academic skills. Students with larger deficiencies can enter the programme after following the pre-master's programme. This is a 30 EC programme aimed at bringing students to the required disciplinary and academic level. The content varies depending on the background of the student. During the programme, the study advisor monitors the progress of students, with special attention to students from abroad and with a background in professional education (hbo), and anticipates quickly in the case of suspected issues.

The panel is positive on the attention to a feasible programme for students from different backgrounds. The deficiency courses and pre-master help to bring students to the required level before entering the programme, and the compulsory core brings students to the same level during the programme, with the study advisor in a monitoring role to prevent feasibility issues. From interviews with students as well as the student chapter, the panel understood that the diversity in background cause students to have a very different experience of the workload and level of the programme. According to the panel, this is partly an unavoidable characteristic of an interdisciplinary programme. Nevertheless, the panel recommends keeping track of the deficiencies students experience during the curriculum, and add deficiency courses if the workload for the compulsory core courses for specific groups of students becomes too high.

The average study duration of the programme is 2, 3 years, with 88% of students graduating within three years. Combined with the low drop-out rates (6%), and the positive remarks by students, the panel concludes that the programme is feasible to complete in two years. Students in the double degree programme in Łódź experience no issues when they enter the programme in the second semester. On the contrary, their average grades are higher than that of the single degree students. According to the programme management and teaching staff, the main factor still causing delay in the programme is the duration of the internship and the final project. The programme has recently started monitoring progress of students, and approaches the student in the case of unexplained delay. The panel supports this, and recommends introducing more strict requirements at the start of the projects. It understood from the interviews that sometimes companies require students to spend longer on the internship than the amount of EC justifies. In the case of final projects, it is often the own ambition of the student that stands in the way of timely completion. A more strict system with deadlines and clear arrangements with internship partners could help reducing the risk of delays.

During the corona pandemic, the programme could not use the cleanroom facilities for education. The nanolithography modules therefore had to be postponed. Use of the cleanrooms for research was still possible, so students could continue to work on their final project. The limited contact time available in the academic year 2020-21 was mostly spent on practical work and group projects where students learn to cooperate in teams. In the case of cancelled internships, students worked on a company assignment at the university, or could postpone their internship and start their final project earlier to minimize study delay. The students that the panel interviewed were generally satisfied with the efforts of the programme to minimize the effects of the pandemic on feasibility of the programme. The panel agrees and praises the programme for their efforts to keep the programme feasible during the pandemic without compromising on the quality and level of education.

Several of the programme's students are interested in following a two-master programme, where they combine the programme with another master's programme. The programme management and the Board of Examiners have defined conditions under which a two-master programme is possible. There are detailed arrangements with the master's programmes Applied Physics, Chemical Engineering and Electrical Engineering at the UT for 180 EC two-master programmes that fulfil the requirements of both programmes, with other tailor-made options available upon request. The panel thinks that the two-master programmes are an interesting option for students that are interested in combining a disciplinary with an interdisciplinary master's programme.

Teaching staff

The programme is taught by active researchers in the field of nanotechnology and related disciplines. The sum of expertises spans the entire field of nanotechnology, with teachers coming from various research groups in the faculties TNW or Electrical Engineering, Mathematics and Computer Science (EEMCS). Most are associated with nanotechnology through MESA+. The programme requires all new teaching staff to have obtained or follow the UTQ course. Current staff members have either followed or are following the UTQ course, or received an exemption based on a dossier proving acquired teaching competences. These requirements were recently made stricter by the Faculty. At the moment, 74% of the teaching staff has obtained an UTQ or has an exemption, and this number is expected to rise in coming years.

The self-evaluation documents and interviews during the site visit have given the panel a positive view of the teaching staff of the programme. The programme has a very interdisciplinary teaching staff with all essential expertises, and students describe their teachers as approachable and enthusiastic. The programme has sufficient attention towards professionalization of the staff, and the percentage of teachers with a UTQ has significantly improved since the previous accreditation. The panel encourages the programme to continue these efforts.

Facilities

The programme uses the cleanroom facilities of MESA+ and the laboratories of the research groups associated with the programme. Students can also use the new Homebase area that houses a communal study area, project rooms and the study associations of the programmes Applied Physics, Chemical Science & Engineering and Advanced Technology. The panel had the opportunity to visit the cleanrooms and some of the lab facilities as well as the Homebase, and praises the programme-specific facilities of the programme. The MESA+ cleanrooms and the research labs are state-of-the art. The Homebase area is an excellent new facility designed for and with students, which is very much appreciated by students.

Considerations

The master's programme Nanotechnology has translated the intended learning outcomes into a strong interdisciplinary curriculum in nanotechnology. The curriculum has sufficient attention to engineering skills as well as academic and professional skills. To make this more visible, the programme could consider creating a learning trajectory that describes the skills education throughout the curriculum. The panel also recommends offering students additional assistance in composing a coherent curriculum, and increasing options for students to work with larger companies. The double degree programme with the Technical University of Łódź is well-structured and offers a coherent curriculum covering the programme's ILOs.

The programme successfully uses small-scale interactive teaching methods. Students work closely together with their teachers, who are all active researchers and engineers, as well as with their fellow students with various disciplinary backgrounds. The panel considers this an important strength of the programme. The use of English throughout the programme is well motivated. The English language proficiency of students could be improved in some cases: the panel supports the planned measures to make the admission criteria stricter to prevent language barriers in courses and group projects. The programme is feasible for students from various backgrounds, with sufficient attention to deficiencies. The panel recommends continuing to pay attention to these aspects, and making sure that the workload of the courses stays manageable for all admitted students. Study delays due to the corona pandemic were minimized and issues were sufficiently addressed. The internship and final project are often a source of study delay; the panel recommends introducing stricter rules concerning duration at the start of a project. The expertise of the teaching staff reflects the interdisciplinary character of the programme, and consists of capable and qualified teachers. The panel supports efforts to further improve professionalization of teachers through UTQs. The Homebase area provides students with excellent study facilities, and the programme's lab facilities are state-of-the-art.

Conclusion

Master's programme Nanotechnology: 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 programme has defined an assessment system that aims to assure that assessments are transparent, valid and reliable. The design of assessment in courses is based on constructive alignment, where the assessment methods as well as the teaching methods used in the course are designed with the realization of the intended learning outcomes as a starting point. The programme aims for a balanced mix of assessment methods. Due to the small-scale nature of most master's courses, the assessment methods are often interactive, such as presentations, assignments and projects, next to written exams for the more theoretical courses. The internship is assessed on performance and a report. The academic supervisor functions as examiner, consulted by the external supervisor. From March to September 2020, almost all exams and assignments could be moved to an online setting without substantial changes. The panel is positive on the system of assessment in the programme. The assessment methods fit the learning goals of the courses, and are sufficiently varied. Students are satisfied by the assessment within the programme, both in the regular curriculum and during the online assessments in 2020.

The programme pays extra attention to teamwork, which it deems to be an important skill in an interdisciplinary programme. This is most prominent in the design project. During the site visit, the panel discussed with programme representatives how individual contributions to the project were monitored. The programme leaves it to the lecturers involved to check that all students contribute equally and on the same level to the group project. The panel thinks that this procedure could be improved, and advises the programme to structurally add individual components to at least the design project, which is important to the realization of several skills identified in the programme's ILOs.

Assessment of the final master project

The final master project is assessed by a graduation committee consisting of at least three members: the chair of the group where the assignment was carried out, an external member (full professor) from another group and a third member of choice. Students receive two grades: one for general aspects (including skills and performance) and one for nanotechnological research aspects. If both grades are a 6 or higher, the student can graduate. The graduation committee jointly completes an assessment form on which it substantiates the grade on various criteria, as well as feedback to the students. The assessment form is standardized for all master's programmes in the Faculty TNW. The panel considers the assessment procedures to be well designed. The consistent use of an external member from another research group adds to the validity of the assessment.

As part of its preparation of the site visits, the panel studied 15 final master projects with the accompanying assessment forms. It concludes that the form has useful subcriteria to evaluate the thesis, and the assessors usually provide sufficient feedback. The panel noted that the subcriteria are only assessed qualitatively and are not graded. When discussed during the site visit, the programme management, teaching staff and Board of Examiners explained that they feel that the subcriteria cannot always capture the impression examiners have on the student's performance, and that subgrades and rubrics would reduce the assessment to a scoring card. The panel understands the wish for a qualitative assessment, but also notes that the current grading system is not very transparent. It thinks that a good rubric is not restrictive but can help assessors express their qualitative assessment in a grade. As such, it is the final step in a qualitative process aimed at substantiation of the justification for the final grade. It therefore recommends introducing subgrades and rubrics into the assessment procedures of the final master project to make these more transparent.

Board of Examiners

The programme has its own Board of Examiners, consisting of four members (including the chair) covering different disciplines within the programme, and an external assessment expert. The Board monitors the quality of assessment in the programme through investigation of exams and final master projects. Based on the documents, as well as the interview with the Board of Examiners, the panel concludes that the Board fulfils its role by safeguarding the quality of assessment in the programme. Nevertheless, the panel thinks that the quality assurance of courses and the final projects can be improved. It learnt that the Board usually only checks the assessment of courses and projects when there are anomalies, or in case of negative student feedback. In the regular final project checks, the Board only checks the assessment forms and not the content of the projects. The panel recommends introducing a more structural approach with regular a posteriori checks of course assessment and final project quality, rather than in the case of issues and outliers. This should also include a check on the validity of assessment of group projects with regard to individual contributions, as discussed above.

Considerations

The programme has a valid, transparent and reliable system of assessment in place. The assessment methods are varied and fit the learning goals of the courses. During the corona pandemic, the programme successfully made the switch to online assessment. To improve the validity of the assessment of group projects, the panel recommends structurally adding individual components to at least the design project. The procedures and assessment forms for the final master projects are solid, but could be more transparent. The panel recommends introducing grades for the various subcriteria and provide examiners with a rubric to help them substantiate their assessment. The Board of Examiners fulfils its role in safeguarding the quality of assessment in the programme. The panel recommends more structural checks to determine the quality of course assessment and the final master projects.

Conclusion

Master’s programme Nanotechnology: 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

Prior to the site visit, the panel studied 15 final master projects of the programme, including three students in the double degree programme. The panel concludes that the theses are generally of high or very high quality. They describe state-of-the-art research in nanotechnology, with a wide variety of topics. The panel concludes that the students in both regular and double degree programme realize the learning outcomes.

According to a recent alumni survey, approximately 50% of the graduates continue in a PhD programme: two-thirds at MESA+, and one third elsewhere. The other half continues in industry (or his/her position is unknown to the programme). 95% has his or her first job in a nanotechnology related field. The survey also shows that alumni are generally satisfied with the programme, and feel that it has prepared them well for their first job. The panel concludes that the programme prepares students well for a future career. The 50-50 outflow of students to PhD positions and industry shows that the dual focus of the programme is justified, and fits the future career perspective of graduates. The high number of students in nanotechnology-related jobs shows that the programme is very relevant, and that its graduates are in high demand.

The panel understood that the programme has established an alumni committee, which the panel applauds According to the panel, keeping in contact with its alumni, as such information on the career and performance of its graduates is crucial to keep the programme aligned with the requirements of the field.

Considerations

The panel concludes that final master projects of the programme are generally of a high quality, and show that the intended learning outcomes of the programme are achieved. Alumni are satisfied with their education, and feel that it has prepared them well for their future career. Graduates of the master's programme continue in approximately equal numbers in nanotechnology-related positions in academics and industry underlining the dual nature of the programme, as well as the high demand for its graduates.

Conclusion

Master’s programme Nanotechnology: the panel assesses Standard 4 as ‘meets the standard’.

GENERAL CONCLUSION

The panel assesses all four standards of the programme as ‘meets the standard’.

Conclusion

The panel assesses the *master’s programme Nanotechnology* as ‘positive’.

APPENDICES

APPENDIX 1: INTENDED LEARNING OUTCOMES

The Master's graduate Nanotechnology:

1. *has thorough knowledge of a sub-area of nanotechnology.*
   A graduate NT is familiar with current scientific knowledge and has the competence to extend this knowledge by means of (independent) study.

1a	Has a thorough understanding of the basic knowledge of the relevant disciplines and is versed in the areas of the disciplines that are in the forefront of the knowledge of nanotechnology and underlying disciplines, such as (nano)physics, (nano)chemistry, (nano)devices and materials science (latest theories, methods, techniques and topical questions). [ks]
1b	Actively looks for structure and connections in the relevant disciplines [ksa]
1c	Has the knowledge, skills and attitude to independently, in the context of more advanced ideas or applications in nanotechnology: - develop theories and models, - interpret texts, problems, data and results, - conduct experiments, and collect and simulate data, - make decisions based on the data and the modelling. [ksa]
1d	Has experimental skills in areas of relevant disciplines, such as - nanotechnology: the manufacture of nanomaterials, qualitative and quantitative characterization of chemical and physical properties, including working in a cleanroom. - in one of the research areas: solid state matter, (bio)molecular matter and soft matter combined with components and systems. [ksa]
1e.	Has the ICT skill to create and edit text, data and models. [ksa]
1f.	Is aware of the presuppositions of standard methods and their importance; is able to reflect on these methods and presuppositions; is able to challenge them; is able to propose changes and is able to assess their impact. [ksa]
1g.	Is able to independently identify gaps in their knowledge, and to enhance and extend their knowledge through study. [ksa]

2. *is able to conduct research in one or more sub-areas of nanotechnology.*
   A graduate NT has the competence to acquire new scientific knowledge through research. Research here means: developing knowledge and new insights in a targeted and methodical manner.

2a.	Is aware of the complex nature of the research methodology in nanotechnology. [ksa]
2b.	Is able to independently conduct research at master level, and to - analyse research issues of a complex nature in nanotechnology, - make use of the relevant knowledge base, - define research targets and, if relevant, define suitable hypotheses, - define a research plan, including the required theoretical and experimental steps, assumptions and methods, - carry out the various activities of the research plan, - analyse and evaluate the research results in relation to the defined problem, - assess the scientific value of the research results, - defend these results against others. [ksa]
2c.	Is perceptive and has the creativity and the ability to discover specific connections and new viewpoints and to use these new viewpoints for new applications. [ksa]
2d.	Is able to work at different levels of abstraction and selects the appropriate level for the process stage of the research problem. [ksa]
2e.	Is able to assess the scientific merit of research in nanotechnology, to systematically collect such research, and to analyse and process it. [ksa]
2f.	Is able to and has the attitude to involve other disciplines in their research as and when necessary. [ksa]
2g.	Is able to handle changeability of the research process due to external circumstances or progressive insights. Is able to adjust this process accordingly. [ksa]
2h.	Is able to contribute independently to the development of scientific knowledge of one or more sub-areas of nanotechnology. [ks]

3. *is skilled in designing in one or more sub-areas of nanotechnology.*
Apart from conducting research, many graduates NT will also create designs. This concerns in particular the design of measuring installations, methods, materials or systems that are required for research, but also the design of processes for nano-manufacturing and for the production of nanotechnology products. Designing is a synthetic activity that aims at the realization of new or changed artefacts or systems, with the objective of creating value in conformity with pre-defined requirements and wishes.

3a.	Is able to independently design at master level, and to: - analyse complex design issues in connection with measuring installations, methods, materials or systems. - integrate the relevant knowledge base in a design. - formulate design requirements, objectives and conditions, and takes into account safety, environmental and economic aspects, and describes and translates these requirements into quantitative design parameters. - formulate a design plan on a general and detailed level, including the steps, assumptions and methods. - analyse and evaluate a design and decision steps in a systematic manner with respect to the defined requirements. - make a technical and economic analysis of the selected design. - defend these results against others. [ksa]
3b.	Is able to systematically collect, analyse and process relevant design information from literature, patents, databases and websites, and is able to identify missing information. [ks]
3c.	Is creative and has synthetic skills with respect to design problems. [ksa]

3e.	Is able to handle changeability of the design process due to external circumstances or progressive insights. Is able to adjust this process accordingly. [ksa]
3f.	Is able to and has the attitude to involve other disciplines in their design as and when necessary. [ksa]
3g.	Is able to phrase new research questions on the basis of a design problem. [ks]

4. *takes a scientific approach.*
A graduate NT uses a systematic approach, characterized by the development and use of theories, models and consistent interpretations; has a critical attitude and has insight into the nature of nanoscience and nanotechnology.

4a.	Is able to identify and take in relevant developments. [ksa]
4b.	Uses a systematic approach, characterized by the development and use of theories, models and consistent interpretations and is able to subject these to a critical assessment in the area of their final master's project. [ksa]
4c.	Is in possession of extensive skills in using, developing and validating models; is able to make a considered choice between modelling methods. [ksa]
4d.	Has insight in the nature of science and technology (purpose, methods, differences and similarities between scientific disciplines, nature of laws, theories, explanations, role of the experiment, objectivity, etc.) and is familiar with current discussions. [k]
4e.	Has insight in scientific practice (research system, relationship with clients, publications system, importance of integrity, etc.) and is familiar with current discussions on the subject. [k]
4f.	Is able to adequately document the research results and design, with the purpose to contribute to the development of knowledge within and outside the discipline, and is able to publish the results. [ksa]

5. *has intellectual skills.*
A graduate NT is competent in reasoning, reflecting and forming an opinion. These are skills that are trained and improved in the context of nanotechnology, and that are generally applicable, afterwards.

5a.	Is able to critically and independently reflect on his/her own thinking, decision making, and acting and is able to make adjustments. [ksa]
5b.	Can reflect on their strong and weak points in connection with research, design, organization and teaching/advising activities, and can make adjustments on the basis of this. [ks]
5c.	Is able to reason logically within nanotechnology and is able to recognize modes of reasoning (induction, deduction, analogy, etc.); is able to recognize fallacies, and is able to apply the modes of reasoning. [ksa]
5d.	Is able to ask adequate questions and takes a critical, but constructive attitude when analysing and resolving complex problems in nanotechnology. [ks]
5e.	Is able to achieve a substantiated opinion in case of incomplete of irrelevant data or inaccuracies, taking into consideration the manner in which the data was created. [ks]
5f.	Is able to express a point of view in a scientific argument in nanotechnology and is able to make a critical judgement. [ksa]

6. *is able to cooperate in projects, and communicate with specialists in the chosen track and other stakeholders.* A graduate NT is able to work with and for others. This requires not only adequate interaction, a sense of responsibility, and leadership, but also good communication with colleagues and other stakeholders. He is also able to participate in a scientific or public debate in English.

6a.	Is able to perform project-based work for complex projects: is able to develop a project plan and planning, is able to deal with limited sources, is able to deal with risks. [ks]
6b.	Has insight into, and is able to deal with, team roles and social dynamics; is able to work within an team with disciplinary and cultural diversity; is pragmatic and has a sense of responsibility; is able to make compromises. [ksa]
6c.	Is able to communicate in writing and verbally in English about research and solutions to problems with colleagues, non-colleagues and other involved parties. [ksa]
6d.	Is able to interpret English written scientific literature and textbooks and to understand discussions and scientific debates in English. [s]
6e.	Is familiar with professional behaviour. This includes: reliability, commitment, accuracy, perseverance and independence as well as respect for others irrespective of their age, social economic status, education, culture, philosophy of live, gender, race or sexual nature. [ksa]

7. *takes the current and social context into account.* Nanoscience and nanotechnology do not exist in isolation; they exist in a current and social context. Points of view and methods have their origin in society and, in time, decisions made will have consequences for society. A graduate NT is aware of this and has the competence to integrate these insights in their scientific work.

7a.	Is aware of social, environmental, sustainability and safety aspects of nanotechnology; is able to analyse and understand these aspects and integrates elements of them in his/her scientific work. [ksa]
7b	Has an eye for the various roles of a nanotechnology professionals in society: researcher, designer, manager, adviser/teacher and chooses a professional position in society. [ksa]
7c.	Is able to analyse the social consequences (economic, social, cultural) of new developments in nanotechnology, to discuss the subject with colleagues, non-colleagues, and to integrate the consequences in his/her scientific work. [ksa]
7d.	Is able to analyse the ethical and normative aspects of the consequences and the assumptions of scientific thought and actions within nanotechnology, to discuss the subject with colleagues, non-colleagues (in research, design and applications), and to integrate this in his/her scientific work. [ksa]

APPENDIX 2: OVERVIEW OF THE CURRICULUM

<table>
<tr><th colspan="2">Semester 1</th><th colspan="2">Semester 2</th></tr>
<tr><th>Quarter 1A</th><th>Quarter 1B</th><th>Quarter 2A</th><th>Quarter 2B</th></tr>
<tr><th>Characterisation</th><th>Fabrication</th><th>Design</th><th>Internship</th></tr>
<tr><td>Characterisation of nanostructures
(7.5 EC)</td><td>Fabrication of nanostructures
(7.5 EC)</td><td rowspan="2">Design project
(10 EC)
inclusive:
Technology venturing</td><td rowspan="5">Internship & Job orientation project
(15 of 20 EC)</td></tr>
<tr><td colspan="2">Nano-Lab: Fabrication & Characterization
(5 EC)</td></tr>
<tr><td rowspan="3">Nanoscience
(5 EC)</td><td>SSM: Nanoelectronics</td><td>SSM: Inorg. mat. science</td></tr>
<tr><td>BMM: Nanomedicine</td><td>BMM: Bionanotechn.</td></tr>
<tr><td>SMS: Lab on a chip</td><td>SMS: Nanofluidics</td></tr>
</table>

Legend to colors:

Compulsory courses	Solid State Matter	(Bio)Molecular Matter	Soft Matter & Systems

<table>
<tr><th colspan="2">Semester 3</th><th colspan="2">Semester 4</th></tr>
<tr><th>Quarter 1A</th><th>Quarter 1B</th><th>Quarter 2A</th><th>Quarter 2B</th></tr>
<tr><th>Nano-research</th><th colspan="3">Master's Final Project preparation, evaluation</th></tr>
<tr><td>Internship & Job orientation project
(5 of 20 EC)</td><td colspan="3" rowspan="4">Master's Final Project
(40 EC)
inclusive:
Societal embedding (3rd quarter)</td></tr>
<tr><td>SSM: Nanomat. research
or Nano-optics</td></tr>
<tr><td>BMM: (Bio)mol. C&T</td></tr>
<tr><td>SMS: Advanced colloids & Interfaces</td></tr>
<tr><td>Elective
(5EC)</td><td colspan="3">1 Elective or C.S. research group5 in quarter 2, 3 or 4
(also subject from 1st year are allowed)</td></tr>
</table>

APPENDIX 3: PROGRAMME OF THE SITE VISIT

B Technische Natuurkunde (TN)
M Applied Physics (AP)
M Nanotechnolgy (Nano)

SUNDAY 20 JUNE

16.00	17.30	Preliminary Discussion
17.30	18.15	**Interview Programme Management Nano**
18.30	19.00	Consultation hour

MONDAY 21 JUNE

8.30	9.00	Arrival & Welcome
9.00	9.45	**Interview Student & Alumni Panel Nano**
10.00	10.45	**Interview Teacher Panel Nano**
11.00	11.30	**Interview Board of Examiners Nano**
11.30	12.00	**Tour Nanolab**
12.00	13.15	Internal panel consultation (incl. lunch)
13:15	13.45	**Interview with Faculty Board and Programme Management Nano**
13.45	15:00	Panel Preliminary Findings Nano
15.00	15.30	**Oral report & Wrap up Nano**
16.15	17.00	**Interview Programme Management TN/AP**
17.15	17.45	**Interview Alumni Panel AP**

TUESDAY 22 JUNE

8.30	9.15	**Interview Bachelor Panel TN**
9.30	10.15	**Interview Master Panel AP**
10.30	11.15	**Interview Teacher Panel TN/AP**
11.30	12.00	**Interview Board of Examiners TN/AP**
12.00	12.30	**Tour Homebase**
12.30	13.30	Lunch
13.30	14.00	**Interview Programme Committee TN/AP**
14.00	14.30	Internal panel discussion
14.30	15.00	**Interview Faculty Board + Director of Education TN/AP**
15.00	16.30	Panel preliminary findings TN/AP
16.30	17.00	**Oral report & wrap up**

APPENDIX 4: THESES AND DOCUMENTS STUDIED BY THE PANEL

Prior to the site visit, the panel studied 15 final master projects. Information on the selected theses is available from Qanu upon request.

During the site visit, the panel studied, among other things, the following documents:

- Self-evaluation report Nanotechnology
- Domain-specific framework of reference Applied Physics
- Benchmark of Nanotechnology curricula
- Education and Examination Regulations
- Overview of the curriculum
- Overview of the quality assurance policies at the faculty
- Overview of corona measures in the programme
- Double degree curriculum
- Admission requirements, pre-master's curriculum and overview of deficiency courses
- Annual reports and minutes of the Board of Examiners 2018-2020
- Annual reports of the Programme Committee 2018-2020
- Educational and assessment materials and course evaluations of a selection of courses
- Examples of assessment plans
- Summary alumni survey 2020
- Overview contacts with the professional field