Uddannelses- og Forskningsministeriet

Prækvalifikation af videregående uddannelser - Quantum Technologies and Engineering

Udskrevet 22. december 2024

Kandidat - Quantum Technologies and Engineering - Aarhus Universitet

Institutionsnavn: Aarhus Universitet
Indsendt: 15/09-2021 09:04
Ansøgningsrunde: 2021-2
Status på ansøgning: Godkendt
Afgørelsesbilag
Download den samlede ansøgning
Læs hele ansøgningen

Ansøgningstype
Ny uddannelse

Udbudssted
Aarhus

Informationer på kontaktperson for ansøgningen (navn, email og telefonnummer)
Astrid Gad Knudsen, agk@au.dk, Tlf. 51371429

Er institutionen institutionsakkrediteret?
Ja

Er der tidligere søgt om godkendelse af uddannelsen eller udbuddet?
Nej

Uddannelsestype
Kandidat

Uddannelsens fagbetegnelse på dansk
Quantum Technologies and Engineering

Uddannelsens fagbetegnelse på engelsk
Quantum Technologies and Engineering

Angiv den officielle danske titel, som institutionen forventer at bruge til den nye uddannelse
Master of Science (MSc) in Quantum Technologies and Engineering

Angiv den officielle engelske titel, som institutionen forventer at bruge til den nye uddannelse
Master of Science (MSc) in Quantum Technologies and Engineering

Hvilket hovedområde hører uddannelsen under?

Naturvidenskab

Hvilke adgangskrav gælder til uddannelsen?

Følgende bacheloruddannelser er adgangsgivende:

- Alle danske bachelorgrader i fysik.
- Internationalt anerkendte bachelorgrader i fysik.

Udvælgelsen af kandidater følger EU-retningslinjer inden for Erasmus Mundus-programmet.
Der er ingen "retskravsbachelorer", da dette er et Erasmus Mundus-program.
Ansøgere skal dokumentere, at de har et tilstrækkeligt højt engelskniveau. Dette skal dokumenteres med en IELTS-test med en minimumscore på 6,5 og minimum 6,0 i hver disciplin. Dette svarer til en TOEFL-test med en score omkring 600 paper-based/250 computer-based/95 internet-based.

Er det et internationalt samarbejde, herunder Erasmus, fællesuddannelse el. lign.?

Ja

Hvis ja, hvilket samarbejde?

Ja, en EU-ansøgning om Erasmus Mundus Master i Quantum Technologies and Engineering (QuanTEEM) er indsendt i samarbejde med:

- University of Burgundy, Dijon, France (Primær EU-ansøger)
- University of Kaiserslautern, Germany
- Moscow Institute of Physics and Technology, Russian Federation

Aarhus Universitet orienterer Styrelsen om afgørelsen på EU-ansøgningen, når en sådan foreligger i løbet af efteråret 2021.

Hvilket sprog udbydes uddannelsen på?

Engelsk

Er uddannelsen primært baseret på e-læring?

Nej, undervisningen foregår slet ikke eller i mindre grad på nettet.

ECTS-omfang

120

Beskrivelse af uddannelsens formål og erhvervssigte. Beskrivelsen må maks. fylde 1200 anslag

Formålet med QuanTEEM er at gå sammen om at uddanne en ny generation af studerende, som vil tage udfordringen op på et erhvervsområde, hvor kvantemekaniske fænomener udnyttes i den teknologiske udvikling.
Quantum Technology forventes at spille en vigtig rolle i den fremtidige økonomiske udvikling. Dette bekræftes nationalt, internationalt og via talrige finansieringsinitiativer. Intet universitet har samlet ekspertisen for alle områder af Quantum Technology. Derfor vil færdiguddannede kandidater fra QuanTEEM, hvor ekspertisen fra fire universiteter forenes, være særdeles velegnet til at klare denne udfordring.
Alle fire institutioner bidrager med deres særlige ekspertise inden for kvanteteknologi så de studerende får en afstemt og komplet uddannelse og mulighed for at skabe et netværk på tværs af landegrænser.
Uddannelsens kandidater vil være rustet til at løse problemer inden for rammerne af et flerkulturelt miljø. Deres unikke kombination af færdigheder fra uddannelsen i Dijon, Kaiserslautern, Moscow og Aarhus giver dem mulighed for ansættelse ved en lang række af virksomheder, som anvender kvanteteknologier i Danmark (se bilag 7).

Uddannelses struktur og konstituerende faglige elementer

Et detaljeret kursusprogram er indsendt i en EU-ansøgning den 17/6-2021.
Vi har skræddersyet vores curriculum til at omfatte alle aspekter af kvanteteknologien (QT) med et bredt spektrum af avancerede kurser med fokus på de fire kvantesøjler: Quantum computation, quantum simulation, quantum information & communication og quantum sensing. Herudover vil være et supplement af andre tværfaglige kurser og seminarer, herunder sociale og samfundsmæssige udfordringer med QT, quantum computing til sundheds- og biovidenskab, quantum computing for finansielle tjenester samt et solidt kommunikationsnetværk.
Programmet er nøje udvalgt med det sigte at tilbyde en både bred og specialiseret viden om kvanteteknologien og dets applikationer, og udarbejdet på baggrund af en behovsanalyse med partnerlaboratorier og private virksomheder (bilag 1). Programmet sigter mod at uddanne studerende på et højt niveau, med kompetencer til (i) at påbegynde et ph.d.-forløb ved både universiteter og i private virksomheder (R&D-afdelinger) overalt i verden, (ii) som direkte rekruttering eller (iii) start-up-initiativer. Programmet sigter mod en grundlæggende læring i sammenspil med avanceret teknologisk laboratoriepraktik i de bedst tilgængelige faciliteter, som konsortiet tilbyder.
Kursets opbygning er skitseret i bilag 4. Efter et fælles første semester på UBFC med grundlæggende kurser, vil QuanTEEM-studerende blive tilbudt rigelige muligheder for mobilitet, med udgangspunkt i deres individuelle studieplaner. At flytte mellem de fire universiteter er obligatorisk (inklusive sommerkurser), og de studerendes individuelle planer vil blive organiseret i løbet af det første semester. De studerende får mulighed for at specialisere sig inden for to områder, ud over det obligatoriske speciale på 4. semester, som er placeret i konsortiet eller et andet sted i verden, hvis konsortiet anser det for passende.

Konsortiets specialiseringer inkluderer:
Specialisering 1: Photonics, nanophotonics, and enabling technologies.
Specialisering 2: 2D quantum materials and nanostructures.
Specialisering 3: Many-body quantum physics.
Specialisering 4: Integrated quantum optics.
Specialisering 5: Platforms for quantum technologies.

Specialisering 1,2 og 3 tilbydes på andet semester, mens specialisering 4 og 5 ligger på tredje semester. Specialisering 3 og 5 er mere - dog ikke udelukkende – teoretisk orienteret og indeholder dybere begreber i QT, mens specialisering 1,2 og 4 er mere - dog ikke udelukkende - teknologisk. Mere teoretiske eller mere teknologiske (eller endda kombinerede) specialiseringer kan tilvælges af de studerende i henhold til deres færdigheder og ønsker. Både teoretiske og teknologiske komponenter har vist sig at være nyttige til tværsektorielle applikationer.

Undervisningsformerne for vores program inkluderer forelæsninger, selvstudie, seminarer og laboratorieundervisning, i form af supervision af mindre grupper og individuelle forløb.
Hvert forløb bedømmes separat; bedømmelsesmetoderne inkluderer skriftlige eksaminer, mundtlige og skriftlige rapporter om praktisk-/projektarbejde, multiple choice-spørgsmål, mundtlige og grafiske præsentationer af projektarbejdet.

Kompetenceprofil

Formålet med kandidatuddannelsen er at udvikle de studerendes videnskabelige og personlige kompetencer i et internationalt miljø baseret på en forudgående bacheloruddannelse. Dette vil gøre de færdiguddannede kandidater i stand til at

- opnå kvalifikationer, der giver adgang til ansættelse i private virksomheder såvel nationalt som internationalt, hvor der kræves sagkundskab på højt niveau inden for kvanteteknologi.

- erhverve de nødvendige forudsætninger for videre studier, herunder til ph.d.-uddannelse inden for forskningsområder, som er relateret til de vigtigste områder af kvanteteknologi.

- udvikle egne ideer eller virksomhed baseret på det kvanteteknologiske indhold af uddannelsen.

Gennem uddannelsen opnår kandidaten kompetencer inden for følgende overordnede kompetencemål:

- Kandidaten har en T-formet kompetenceprofil kendetegnet ved en bred viden om fysik og en dybdegående viden om kvanteteknologi. Derudover er kandidatens kompetencer yderligere specialiserede inden for metoderne og teorierne på det valgte specialiseringsområde i kvanteteknologi.

- Kandidaten kan vurdere anvendeligheden af teoretiske, eksperimentelle og praktiske metoder til analyse og løsning af fysikfaglige spørgsmål og i særdeleshed inden for kvanteteknologi

- Kandidaten kan selvstændigt planlægge, lede og gennemføre projekter og anvende resultaterne af disse i en faglig relateret beslutningsproces.

- Kandidaten har en solid baggrund inden for iværksætteri og kender de væsentligste trin i produktudvikling.

- Kandidaten kan selvstændigt og kritisk strukturere egen kompetenceudvikling.

- Kandidaten kan formidle og kommunikere faglige spørgsmål og problemstillinger i såvel et videnskabeligt som et alment forum.

- Kandidaten har forståelse for og indsigt i kvantefysikkens sammenhæng med andre fagområder og har kvalificeret viden om fysikkens samspil med det omgivende samfund, herunder med særlig fokus på de strukturelle forandringer der forventes inden for kvanteteknologi.

I EU-ansøgningen er uddannelsens kompetenceprofil specificeret i forhold til læringsmål jf. Dublin-deskriptorerne, se Bilag 8.

The program:
The first semester S1 (September – January) is based on core courses at UBFC. The foundation of the Master programme will be laid. The courses will be conducted in collaboration with the existing international Master on Physics, Photonics and Nanotechnology[1] coordinated by UBFC. To make sure that a joint level is reached by the diverse group of students, 30 ECTS points will be mandatory (including the first part of the winter school in February):

- Advanced quantum theory I (including atomic and molecular physics, introduction to quantum optics, quantum control and optimal control) (4 ECTS)
- Quantum Computation and Information, including laboratory courses (non-linear optics: second-harmonic generation, quantum sensing by diamond magnetometer, photon entanglement, quantum cryptography, quantum computation on IBM Q-network) (4 ECTS)
  Condensed-matter physics (4 ECTS)
- Advanced computational methods, including machine learning (4 ECTS)
- Signal processing (4 ECTS)
- French language and culture (2 ECTS)
- Soft skills (2 ECTS)
- Business & Entrepreneurship (2 ECTS)

Winter school (at UBFC, first half of February) in collaboration with MIPT partner focuses on interdisciplinary courses (4 ECTS) including applications of QT for societal challenges:

- secure communication networks
- big data handling
- quantum machine learning for materials
- quantum sensing for healthcare
- green quantum chemistry

The second semester S2 at UBFC (February – June) offers a specialization in photonics, and nanophotonics, complemented by an introduction to nanotechnology:

- Guided optics (4 ECTS) or nonlinear optical technologies: fundamentals and materials (4 ECTS)
- Laser technology (4 ECTS)
- Optical communications, fiber photonics and networks (4 ECTS)
- Nanophotonics and nanoscale processing (4 ECTS)
- Nanotechnologies (4 ECTS)
- Semester project (10 ECTS)

The second semester S2 at Kaiserslautern (March-July), provides a deeper theoretical understanding and advanced laboratory courses will be offered through the specialization in many-body quantum physics. The courses will be conducted in collaboration with the existing “International Master’s programme on Advanced Quantum Physics”.[2] This will also give the students an opportunity to choose a more theoretical specialization in S2, through the choice of elective courses.

The mandatory courses are:

- Advanced Quantum Mechanics II (8 ECTS)
- Quantum Gases and Quantum Simulations (4 ECTS)
- Quantum Field Theory I+II (8 ECTS)
- German language and culture (2 ECTS)

In addition, 8 ECTS electives can be chosen from the following courses:

- Advanced quantum physics III (quantum gases, superconductivity, quantum field, topological systems)

- Femtosecond science - from concepts to applications

The third semester S3 at Kaiserslautern, still in collaboration with the master programme in advanced quantum physics will propose a specialization in integrated quantum optics

- Quantum optics I+II (8 ECTS)
- Seminar on optical integration, Quantum Sensing and Metrology (3 ECTS)
- Advanced Laboratory course (single photon interference, quantum correlations and communication) (9 ECTS)
- German language and culture (2 ECTS)

In addition, 8 ECTS electives will be chosen.

The third semester S3 at Aarhus University (September – January) is devoted to applications of quantum systems and concepts in future technology with a focus on the diverse platforms (ultracold atoms, trapped ions, cavity quantum electrodynamics, superconducting qubits, complex and hybrid quantum systems).

The mandatory courses are:

- Advanced Atomic, molecular and optical physics II - 10 ECTS
- Engineering of Complex Quantum Systems - 5 ECTS
- Methods of Quantum Technology - 5 ECTS

In addition, 10 ECTS electives can be chosen from the following courses:

- Electronics and Data Acquisition - 10 ECTS

- Advanced Data analysis - 5 ECTS
- General relativity - 5 ECTS
- Surface and Semiconductor-Physics - 10 ECTS
- Magnetic Resonance Physics - 5 ECTS
- Advanced Particle Physics - 10 ECTS

Final summer school (organization alternating between TUK, AU and UBFC, hosting the final exam / master thesis defence) oriented towards industrial applications, such as:

- information technology & computer industy
- quantum for financial services
- molecular simulation for Chemistry/Materials/Energy
- chemical industry applications in quantum computing
- quantum for advanced manufacturing
- quantum & healthcare / life sciences: exploration of new solutions

[1] https://blog.u-bourgogne.fr/master-ppn/
[2] https://www.physik.uni-kl.de/quantum-master

Begrundet forslag til takstindplacering af uddannelsen

Uddannelsen er en naturvidenskabelig uddannelse, hvor omkostningerne til uddannelsen vil være de samme som for andre naturvidenskabelige uddannelser, herunder den almindelige kandidat i fysik. Derfor ansøges der om, at uddannelsen tildeles takst 3.

Forslag til censorkorps

Censorkorpset for Fysik og Astronomi

Dokumentation af efterspørgsel på uddannelsesprofil - Upload PDF-fil på max 30 sider. Der kan kun uploades én fil

Følgebrev og bilagssamling.pdf

Kort redegørelse for det nationale og regionale behov for den nye uddannelse. Besvarelsen må maks. fylde 1800 anslag

Quantum Technology vil i fremtiden være en vigtig faktor inden for den økonomiske udvikling. Forventningen udspringer delvist af det nyligt lancerede EU Quantum Flagship-initiativ, ligesom danske investeringsfonde indset betydningen og potentialet på området og investerer i det.
Quantum Technology er en væsentlig del af den danske industri, fx hos virksomheder som NKT Photonics og OFA Fiber Solutions (se bilag 7). Antallet af medarbejdere i sektoren forventes at vokse, og specialiserede internationale medarbejdere vil være efterspurgte. Med en Master in Quantum Engineering vil kandidater være godt rustet til at bestride disse stillinger.
Med henblik på afklaring af behovet for uddannelsen, har hele QuanTEEM gennemført en kvantitativ spørgeskemaundersøgelse blandt aftagere og interessenter. Sammenfattende peger tilbagemeldinger på, at uddannelsen opfylder et behov, som eksisterende uddannelser ikke tager højde for.
EU finansierer ca. 20 pladser om året og yderligere studerende (også fra EU) dækker selv deres studiegebyrer. Erfaringer viser, at vi kun kan forvente i alt 20 studerende om året for hele uddannelsen. Heraf forventes 7 studerende at deltage ved AU. Det vurderes, at en del af disse studerende vil fortsætte deres arbejdsliv i Danmark efter endt uddannelse, og på baggrund forventer vi, at ca. 3 færdiguddannede kandidater vil være tilgængelige for det danske arbejdsmarked årligt.

Sprog

Det europæiske Erasmus Mundus-program henvender sig til studerende fra hele verden. EU opfordrer til, at alle kontinenter er repræsenteret blandt de optagne. Uddannelsen gennemføres i de fire involverede lande (Frankrig, Tyskland, Rusland og Danmark). Derfor er det obligatorisk, at kurserne gennemføres på engelsk.

Uddybende bemærkninger

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Underbygget skøn over det nationale og regionale behov for dimittender. Besvarelsen må maks. fylde 1200 anslag

Behovsundersøgelsen er baseret på følgende:

1. Spørgeskema rundsendt internationalt (bilag 1)

2. Spørgeskema rundsendt nationalt i Danmark (bilag 2)

3. Analyse af opslåede stillinger for perioden 2020-2021 (bilag 3)

4. Analyse af ledighed (bilag 6)

Den internationale aftagerundersøgelse (bilag 1) viser, at aftagerne anså uddannelsen for meget relevant og ser et klart behov for uddannelsen.
I den danske undersøgelse (bilag 2) angiver 76% af respondenterne, at de på nuværende tidspunkt kan bruge mindst en dimittend årligt – og på sigt flere. Ift. det totale behov svarer 62% af respondenterne at de på nuværende tidspunkt ser et behov for mindst 8 dimittender årligt, og 76%, at der på sigt vil blive behov for mindst 10 dimittender om året.
Derudover viser en gennemgang (bilag 3), at 53 stillingsannoncer fra juli 2020-21 efterspørger kompetencer inden for kvanteteknologi.
En undersøgelse af ledigheden inden for beslægtede uddannelser (bilag 6) viser en ubetydelig ledighed, hvilket også underbygger, at al tilgængelig arbejdskraft på området er udnyttet.
På denne baggrund vurderes det, at 3 kandidater årligt til det danske arbejdsmarked er passende, ligesom området er i vækst.

Hvilke aftagere har været inddraget i behovsundersøgelsen? Besvarelsen må maks. fylde 1200 anslag

I forbindelse med den internationale behovsafdækning (bilag 1) var der fokus på relevante aftagere i både små og mellemstore virksomheder. Aftagere fik tilsendt et elektronisk spørgeskema med en uddannelsesbeskrivelse. Den kvantitative spørgeskemaundersøgelse havde dels til hensigt at få estimeret behovet for kommende dimittender og dels at få konkrete input til uddannelsen.
Derudover er gennemført en behovsanalyse på det danske arbejdsmarked. Potentielle arbejdsgivere i Danmark (bilag 7) er kontaktet med et tilsvarende spørgeskema (bilag 2), for at anslå den forventede efterspørgsel på området i de kommende år. Respondenterne har fået indsigt i det planlagte kursusprogram og beskrivelsen af de forventede kvalifikationer. Input fra behovsanalysen og kompetenceprofilen bruges til at finjustere programmet til efterspørgslen i Danmark og de andre deltagerlande.

International undersøgelse

Spørgeskemaet blev besvaret af 51 aftagere fra i alt 23 brancher. Respondenterne påpeger overordnet, at det er unikt, at uddannelsen er internationalt orienteret og har fokus på kvanteteknologier.

National undersøgelse

Spørgeskemaet blev besvaret af 21 aftagere fra i alt 13 brancher.

Hvordan er det konkret sikret, at den nye uddannelse matcher det påviste behov? Besvarelsen må maks. fylde 1200 anslag

Undersøgelserne (bilag 1 og 2) gav input ift. hvilke kvalifikationer der efterspørges i branchen. Disse kvalifikationer bliver indarbejdet i kurserne rettet mod Erasmus Mundus-studerende.
Respondenterne pegede på kernekompetencer, der er efterspurgte i erhvervslivet, herunder blev kunstig intelligens, machine learning og entreprenørskab fremhævet som komplementære kompetencer, der bør indgå i uddannelsen. Desuden påpegede respondenterne, at mange brancher i fremtiden forventes at kunne profitere på kvanteteknologi.
For at evaluere behovet for en skræddersyet uddannelse i den internationale undersøgelse blev respondenterne spurgt, hvor stort behovet for en uddannelse på området er for erhvervslivet. Her svarede 61% "meget stærkt", mens ingen svarede ”temmelig svagt" eller ”meget svagt”. Respondenterne blev bedt om at bedømme eksisterende kandidatuddannelsers relevans for kvanteteknologi i fremtiden. Disse blev i vid udstrækning vurderet ”ikke relevante” og hele 68% angav dem som værende ”temmelig irrelevante” (bilag 1).
Der nedsættes et eksternt internationalt advisory board for at kvalitetssikre uddannelsen årligt, herunder for at uddannelsen understøtter de efterspurgte kompetencer.

Beskriv ligheder og forskelle til beslægtede uddannelser, herunder beskæftigelse og eventuel dimensionering. Besvarelsen må maks. fylde 1200 anslag

Uddannelsen vil give en klar forståelse af kvanteteknikkens nuværende betydning og teknologiske fremskridt. Denne forståelse opnås ved at kombinere grundlæggende kurser og valgfag på de deltagende universiteter på en endnu uset, men optimal måde. Dette vil føre til en stærkere målretning ift. den faglige profil, da den sædvanlige mulighed for valgfrihed i kurser på fx AU begrænses. Der opnås altså en mere målrettet kandidatgrad, der samtidig indeholder de grundlæggende kurser, som er obligatoriske for en kandidatgrad i Fysik på alle danske universiteter.
Eksisterende nationale og beslægtede internationale kandidatuddannelser (bilag 5) tilbyder en bred vifte af valgmuligheder, men dækker ikke alle relevante aspekter inden for kvanteteknologien på et tilstrækkeligt avanceret niveau. Samtidig er nogle af de internationale kandidatuddannelser betydeligt mere specialiserede på specifikke områder uden de grundlæggende kurser. Således er QuanTEEM unik i sin sammensætning af den ekspertise, hvormed kvanteteknologien bliver dækket.
De foreslåede nye elementer i uddannelsen opnås hovedsageligt gennem en kombination af eksisterende kurser og via ekspertise på de deltagende universiteter.

Uddybende bemærkninger

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Beskriv rekrutteringsgrundlaget for ansøgte, herunder eventuelle konsekvenser for eksisterende beslægtede udbud. Besvarelsen må maks. fylde 1200 anslag

Erasmus Mundus-programmet er internationalt anerkendt, og det er et centralt rekrutteringsinitiativ på EU-niveau. Desuden inkluderer programmet fuld støtte for et begrænset antal studerende (ca. 20 årligt). Studerende derudover har mulighed for at deltage med egen finansiering. Af samme grund har de igangværende Erasmus Mundus-programmer på AU de sidste år modtaget et stort antal internationale ansøgninger. Baseret på denne erfaring forventer vi at modtage over 300 ansøgninger om året, hvilket giver mulighed for en streng udvælgelsesproces.
Erfaringerne med Erasmus Mundus-programmer på AU viser også, at ansøgerne kommer fra hele verden, tiltrukket af den høje standard som Erasmus Mundus-programmet tilbyder. Med det forholdsvis lille optag forventes det ikke, at kurset får indflydelse på rekrutteringen til andre kandidatuddannelser i Fysik i Danmark.

Beskriv kort mulighederne for videreuddannelse

Der vil være mulighed for videreuddannelse på området ved at tage en ph.d. i en af forskningsgrupperne, som har fokus på quantum engineering.

Forventet optag på de første 3 år af uddannelsen. Besvarelsen må maks. fylde 200 anslag

Vi forventer 20 studerende årligt fra hele verden. Disse finansieres af EU og registreres ved University Bourgogne Franche-Comté. Vi forventer at ca. 7 studerende årligt vil deltage i kurserne på AU.

Hvis relevant: forventede praktikaftaler. Besvarelsen må maks. fylde 1200 anslag

Øvrige bemærkninger til ansøgningen

Hermed erklæres, at ansøgning om prækvalifikation er godkendt af institutionens rektor

Ja

Status på ansøgningen

Godkendt

Ansøgningsrunde

2021-2

Afgørelsesbilag - Upload PDF-fil

A5 - Godkendelsesbrev KA Quantum Technologies and Engineering AU.pdf

Samlet godkendelsesbrev - Upload PDF-fil

AARHUS
UNIVERSITET

Uddannelses- og Forskningsstyrelsen
Haraldsgade 53
2100 København Ø

Ansøgning om prækvalifikation og godkendelse af nye uddannelser og udbud – september 2021

Hermed godkendes, at Aarhus Universitet fremsender ansøgning samt bilag om prækvalifikation og godkendelse af nye uddannelser med frist 15. september 2021. Det drejer sig om følgende nye uddannelse:

Kandidatuddannelsen Quantum Technologies and Engineering (Erasmus Mundus)

Aarhus Universitet står gerne til rådighed med yderligere oplysninger.

Venlig hilsen

Berit Eika
Prorektor

Rektoratet

Berit Eika

Prorektor

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Bilagssamling

Ansøgning om prækvalifikation
Erasmus Mundus Joint Masters Degree - QuanTEEM

Indhold

Bilag 1: International study to identify quantum workforce skills

Requirements for an Erasmus Mundus Joint Master Degree (EMJMD) in quantum technologies

Study to identify skills future quantum workforce will need

Dear participant,
This questionnaire aims at identifying specific training needs in quantum technologies at master's level. The questions will help us to get an overview about what might be important to teach to master students during their studies, and about different points of view and priorities from industry, society, sciences, education, or other perspectives.
This survey consists of 10 questions, organized in four sections. Your collected opinions will be used for our EMJMD proposal only.

I. Quantum technologies: the core and complementary subjects

1) What are the necessary knowledge and subjects needed to train master's level students to become experts in quantum technologies?

Answer: Quantum theory, atomic and molecular physics, atomic and molecular spectroscopy, optics & photonics, quantum optics, condenser-matter physics, quantum information processing (computation, communication, cryptography, information theory, simulations), quantum sensing, quantum imaging, quantum control, optimal control, computational methods, signal processing.

2) What complementary subjects would add a strong value to the expertise in quantum technologies?

Answer: Artificial intelligence, machine learning, quantum chemistry, 2D materials, materials science, nanostructure, communication & security, financial techniques, entrepreneurship, laser technologies, nano-optics, nano-photonics, quantum gases, femtosecond science, semiconductor physics, 2D materials.

II. Quantum technologies: applications, markets, society and industry

3) Which markets are benefiting or expect to benefit in the near future from quantum technologies?

Answer:

- Telecommunication: secured communication, user authentication, secure transactions,
- Healthcare and Biotechnology: Imaging beyond classical imaging limitations
- Security and Defense: Cryptography
- Information technologies and computer industries: machine learning, artificial Intelligence, cognitive computing, big data handling and storage
- Civil engineering: natural resource exploitation, precise positioning
- Mobility industry: autonomous driving, quantum sensing
- Logistics and Supply Chain

4) What are the emerging new directions of quantum technologies beyond the mainstream?

Answer: Quantum finance & financial modeling, improved artificial intelligence capabilities, accelerated business intelligence, increased productivity and efficiency, autonomous driving

5) Identify short-term (0-5 years), mid-term (5-10 years) and long-term (>10 years) applications.

Answer:

short-term (0-5 years) applications

- Develop quantum signal repeaters that work with cryptography capability and enabling long-distance point-to-point quantum-secure links.
- Realise a quantum simulator to address problems relevant to chemical processes and the design of materials.
- Develop more precise atomic clocks that can be used for synchronisation of future smart networks, such as for energy and telecommunications.
- Improve the control and robustness of superconducting qubit.
- Integrate a functional quantum circuit with high-speed cryogenic control hardware.
- Develop quantum sensors for special-purpose applications, such as gravity sensors for defence, oil and gas and space, quantum clocks for timing applications and magnetic sensors for medical use and imaging.
- Discover new algorithms, protocols and fields of application for quantum simulators, computers and communication networks.
- Develop quantum processor executing quantum algorithms and the operation of a logical qubit protected by quantum error correction in atomic, solid-state or superconducting platforms.
- Develop the supply chain of components like cryogenic or electronic amplifiers and components, or laser sources. These are fundamental to building quantum devices, as well as to numerous spin-off applications.

mid-term (5-10 years) applications

- Realise versatile simulators of material magnetism and of such electronic properties as superconductivity, supporting the development and design of new materials with superior properties.
- Simplify quantum sensors so that they can be produced at lower cost for larger-volume applications such as manufacturing, automotive, construction and geosurveying.
- Enable secure communication between distant cities via quantum networks, which enhance information security and prevent eavesdropping.
- Solve problems in chemistry and materials science with special-purpose quantum computers operating at high speeds beyond one hundred physical qubits.
- Develop handheld quantum navigation devices precise to 1 mm/day and able to function indoors.
- Engineer quantum devices to improve their manufacturability and reliability, reduce their cost and make them available for more mainstream markets.
- Demonstrate ground-to-satellite quantum cryptography.

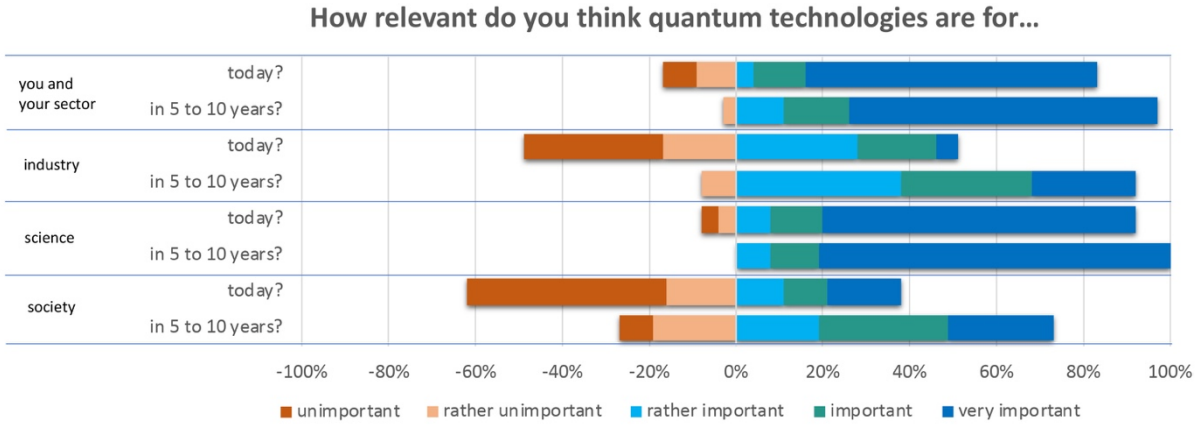
long-term (>10 years) applications

- Create a secure and fast quantum internet connecting the major cities in Europe using quantum repeaters running quantum communication protocols.
- Design new materials with tailored properties (e.g. electric conductivity or magnetism) using special-purpose quantum hardware.
- Build a quantum computer able to demonstrate the resolution of a problem that, with current classical techniques on a supercomputer, would take longer than the age of the universe (quantum supremacy).
- Develop quantum computers to model physical and chemical problems and to solve chemical reaction problems faster and more accurately than is possible with the fastest supercomputer. For instance, for the development of novel catalysts and for drug design.

- Develop on-chip quantum sensor devices that can integrate within mobile phones, etc., to allow quantum information and sensing applications within multiple consumer applications.
- Correlate measurements from an array of gravity sensors to create gravity images.
- Integrate quantum sensors with consumer applications, such as integrated photonic or solid-state devices for mobile devices.
- Develop other applications like quantum credit cards and quantum keys, as well as unanticipated discoveries and applications.

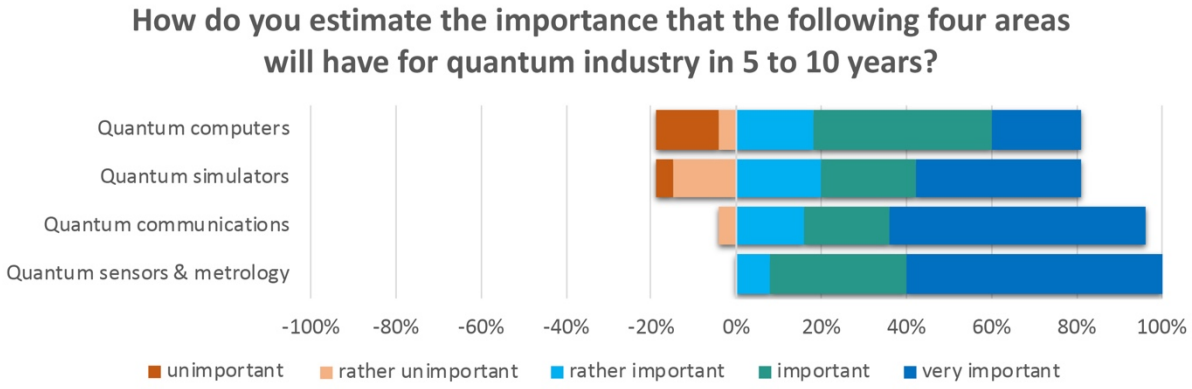
6) The relevance of Quantum Technologies in different sectors.

Answer:



7) How do you estimate the importance that the following four areas will have for quantum industry in 5 to 10 years?

Answer:



III. Relevance of the existing educational programmes and expected needs

8) How do you estimate the need of master & engineering programmes in quantum technologies with a stronger orientation towards industry?

Answer:

very strong: 61%, strong: 28%, rather strong: 11%, rather weak: 0%, very weak: 0%

9) How do you estimate the appropriateness of the existing master programmes for the near future of quantum technologies?

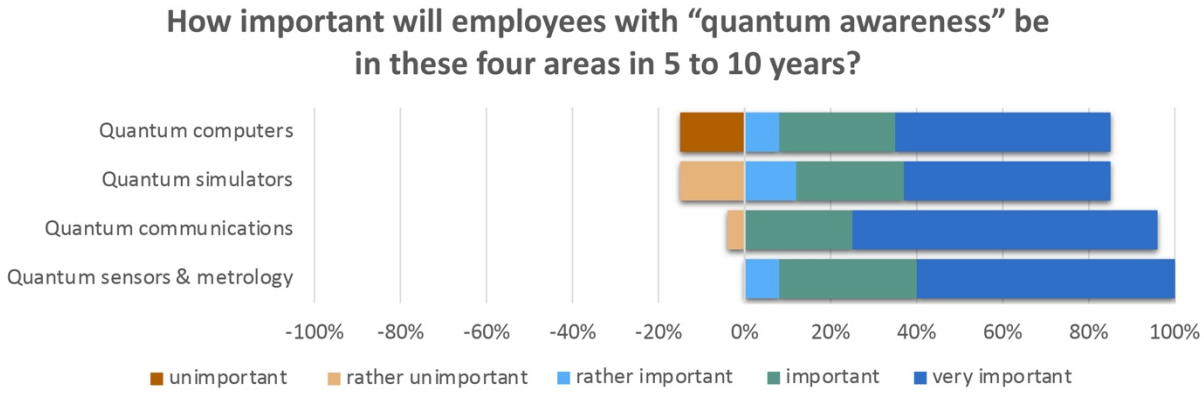
Answer:

fully appropriate: 3%, rather appropriate: 16%, rather inappropriate: 68%, fully inappropriate: 13%,

IV. Quantum awareness for non-specialists

10) How important will employees with quantum awareness be in these four areas in 5 to 10 years?

Answer:



Bilag 2: Study conducted in Denmark

Dear participant,

This questionnaire will help us to identify the requirements for a new international Master's degree course in quantum engineering and technology.

Your answers will provide us with input to the content of the course and with an estimate of the need for the graduates in Danish industry.
The survey is anonymous and all data will be handled confidentially.

The proposed course was designed within the frame of an EU "Erasmus Mundus" proposal and is called "Quantum Technologies and Engineering Erasmus Mundus Master" (QuanTEEM). It includes the following participating institutions:

- Department of Physics and Astronomy - Aarhus University – Denmark (AU)
- University Bourgogne Franche-Comté – Dijon – France (UBFC)
- Technische Universität Kaiserslautern – Germany (TUK)
- Moscow Institute of Physics and Technology - Russia Federation (MIPT)

The consortium of QuanTEEM was chosen due to their complementary strengths supplemented by industrial associated partners.

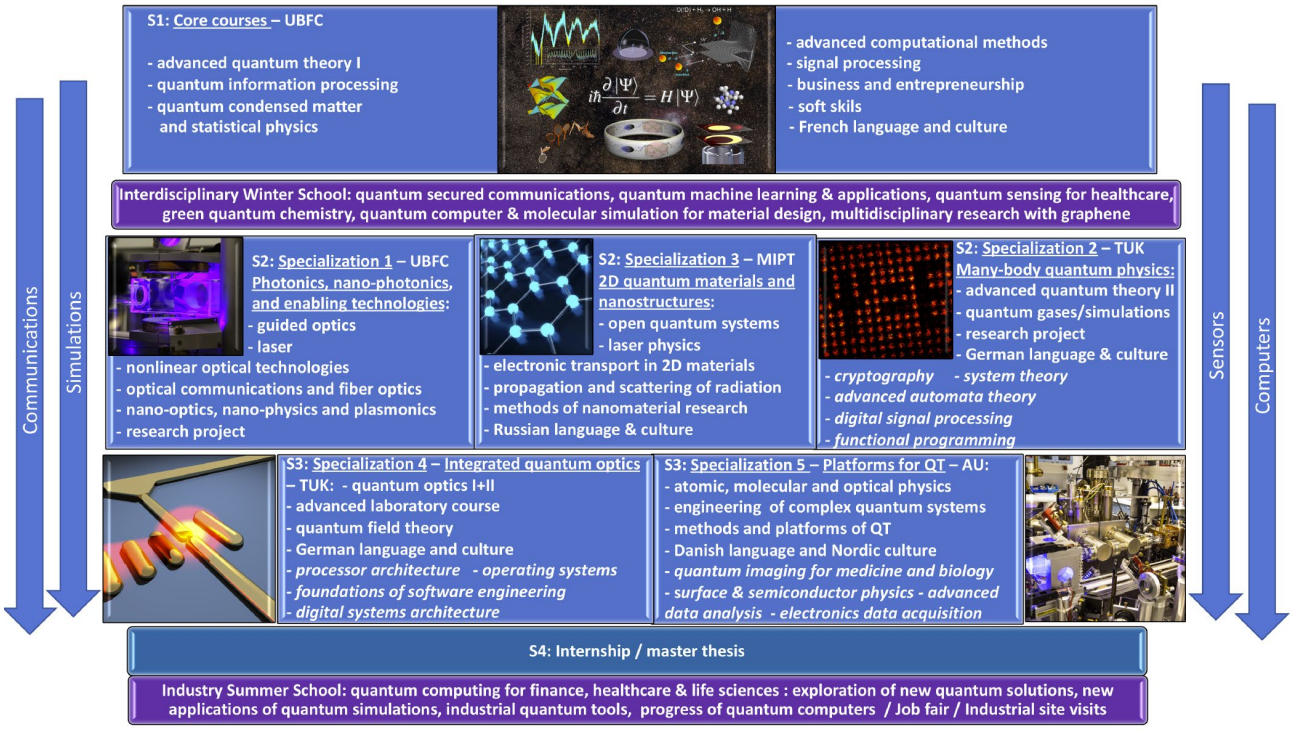
1. QuanTEEM courses

QuanTEEM will establish a unique joint master's degree in the emerging field of quantum technology based on interdisciplinarity, internationalisation and innovation. The programme is based on the established quantum pillars:

- quantum communication,
- quantum simulation,
- quantum sensing,
- quantum computation,
- quantum information sciences.

It addresses aspects ranging from basic research to major grand challenges such as energy, materials, health, security and environment, to which quantum technology has started to apply.

The diagram below gives an overview of the programme where the four semesters are labelled S1 to S4:



The programme also includes five specialization paths:

- Photonics, nano-photonics and enabling technologies
- 2D quantum materials and nanostructures
- Many body quantum physics
- Integrated quantum optics
- Platforms for quantum technology

1.1 What is your general impression of the content of the proposed master's course? (based on the course overview shown above)

- Impressive
- Great idea to focus on photonics and nanostructructures since they are industrially relevant.
- My impression is good - the content seems both ambitious and interesting.
- It is difficult for me to know exactly what the content is, but it seems to cover a broad aspect of relevant quantum technologies, which is good. Although, I think it seems too focused on AMO physics, and I do miss a few subjects (see below).
- The proposed course looks quite impressive, covering a broad range of topics.
- highly ambitious course program with a world class spectrum of opportunities for the students combined with many courses aimed at industry transferable skills
- I believe the structure for these master's courses would serve as a great template for new physics students to get pick a cohesive path for their education and the field of speciality.
- Great new initiative.
- The outlined content covers a broad range of exiting topics. I had expected a larger explicit emphasis on sensing, though many of the subjects are obviously closely related to sensing.
- The general idea sound really awesome. The idea of having the master's degree somewhat specialized into something (hopefully) worthwhile for the industry sounds cool.

I am also not really sure what the 4 arrows on the sides should symbolize? Is it to say doing this master's you will master these four things?

- no strong disagreements
- It seems highly interesting from an academic point of view and will create a firm basis for graduate students with in the field
- The content is good, but I think there is simply too much going on. It is confusing too read some many things packed into one 'poster'.
- The proposed course covers the major topics in quantum technology, so very good.
- The impression is good. It is highly relevant that Business and entrepeneurship is part of the core courses.
- I don't understand why is it important to have language and culture as part of the different areas of specialization ? Could you not do 2D quantum materials without learning about Russian culture?
- But in general the topics that is chosen seems all relevant, however one could also imaging to have 5 pillars like the quantum flagship and use them as the ways of organizing the specialization.
- Seems overall to target the trends and needs!
- I can only comment on the Photonics specialisation path, and I think it is a very good idea. We are missing employees with a knowledge of laser building and a quantum background.
- Not sure about the relevance of "French/German/Danish/Russian language and culture" in this program. Could/Should you replace them by more quantum tech courses?

1.2 How do you evaluate the choice of specializations and their applicability? (based on the course overview shown above)

- Very good
- I like the inclusion of engineering to increse industrial relevance. The languages and cultures seems strange to include due to their narrow scope of future relevance for the student.
- The specializaiton "platforms for quantum technology" is unclear to me. Aren't the other four specializations examples of such platforms? So how is this specialization different?
- I think it would be nice to have a specialization in superconducting platforms, if this is not already included in the list above.
- I am not working with quantum technology today, so it is hard for me to comment on specific topics.
- excellent. The specializations allow the students to achieve specialized knowledge, while keeping the importance of a holistic education in mind
- Specifically I believe that there are quite some good combinations to pursue with these options, whether you start out with a more theoretical or experimental background. My impression is that theory, modeling and applied physics are generally well represented in these paths and offers quite some options for weighing these differently depending on your preference.
  I am quite happy to see that there are some connection between quantum technique/disciplines and the industri/health/finance, which I believe is important to apply acquired knowledge from the field of physics into engineering.
- Very applicable in industry.
- The should provide students with a broad skill set that will allow them to successfully work within technological sectors.
- It sounds cool with the different specializations, however it seems to me that it might be a lot in every specialization, I hope it is not too cramped.
  Also I don't really get why the different language and culture parts are a part of a master's degree in physics.
- Hard for me to give a good answer

- I am not super familiar with the directions within quantum technology and therefore not capable of rating these directions
- Each of the choices come with a long list of things. I would recommend that this list becomes shorter and more focused.
- Very good
- The course specialization looks good.
- The specializations are targeting the research at AAU, but maybe you could think of making it more general and again this could be achieved by making 5 completely general specializations, quantum computing, quantum sensing/metrology, quantum communication and so on .....
- The areas of specialization seem well-considered, they target important areas, and appear to result in comparable work loads for the candidates.
- That looks great, but it seems that there is not much "engineering" involved. Only for specialization 5. The industrial aspect does not seem to be represented either.

1.3 Which other relevant topics should be included to educate experts in the field of quantum technology?

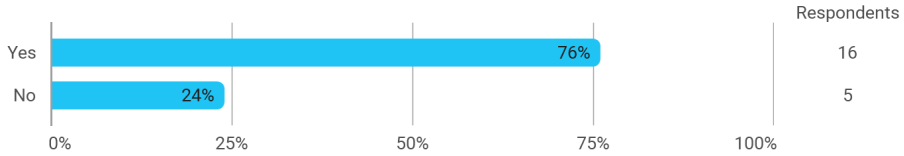
- Topics covered
- No ideas.
- Quantum computation is listed as one of the "established quantum pillars", but I do not see quantum computation in any of the listed courses in the diagram. I'm not an expert on emerging quantum technologies, but the field of quantum computation strikes me as quite relevant and should perhaps be covered more explicitly.
- It is not clear to me how much superconducting circuits and quantum computing with superconducting qubits is covered. This is a highly relevant topic and used widely in academia and industry alike (Google, IBM, Alibaba, Rigetti ect). I think this should be one of the cornerstones of the master's program.
- I think that a technology degree should have as many applications as possible, showing how the technology is and can be applied to solve real problems in industry and other areas beyond research. For example: what business problems are being solved today with quantum computing? What problems become accessible as the technology matures?
- transferable skills e.g. project management, scientific writing or dissemination of knowledge through seminars
- The topics I could come up with I believe are contained within the topics stated here.
- A course on electronics should possibly be included both as a required tool for practical work in the field of quantum technology and to give a perspective on where QT is advantageous over classical devices and vice versa.
- Is there enough emphasis on theoretical side and performing simulations?
- Pretty much everything is already mentioned so I do not see any other topics of relevance. BUT there are also too many topics there in my opinion.
- It might be relevant to include a (small) topic on the requirements for bringing quantum technology from the lab into industrial applications. Credible measurement and validation techniques are essential in order to ensure global acceptance of new quantum products. International standards are required for unique specification of interfaces between various quantum products. Standardization activities for quantum technology have already been initiated. New techniques will have to be developed to measure quantum properties of new products in a reliable way - here we cannot rely on the well-developed metrology for the 'classical physics world'.

- I think it would be helpful for the education that the students have to have a course in electrical engineering. This is an essential core competence, for a successful quantum technology innovation.
- I think the topics are well defined, and I guess things like non-classical light, squeezing, entanglement, photonic computation, error code corrections, and so on is already thought about?
- A good knowledge of instrumentation and the setting up of experiments make a significant difference when it comes to harvesting results. Perhaps a screening of candidates would be required, or perhaps it would be an idea to introduce an add-on course?
- Metrology in general should be a bigger part of the laser and quantum educations because understanding the concepts of noise measurement is something largely missing, and something critical to understand the laser subsystems for quantum systems.

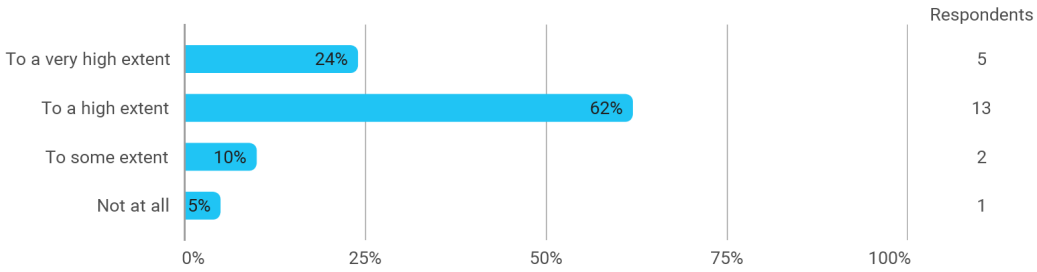
2. Requirement analysis

QuanTEEM will provide a combination of strong research, excellent teaching, novel didactics, and strong industrial involvement.
Thus the students will obtain a multifaceted qualification, who will have the ability (i) to be recruited in private companies, (ii) to embark on a PhD programme or (iii) to create a start-up.

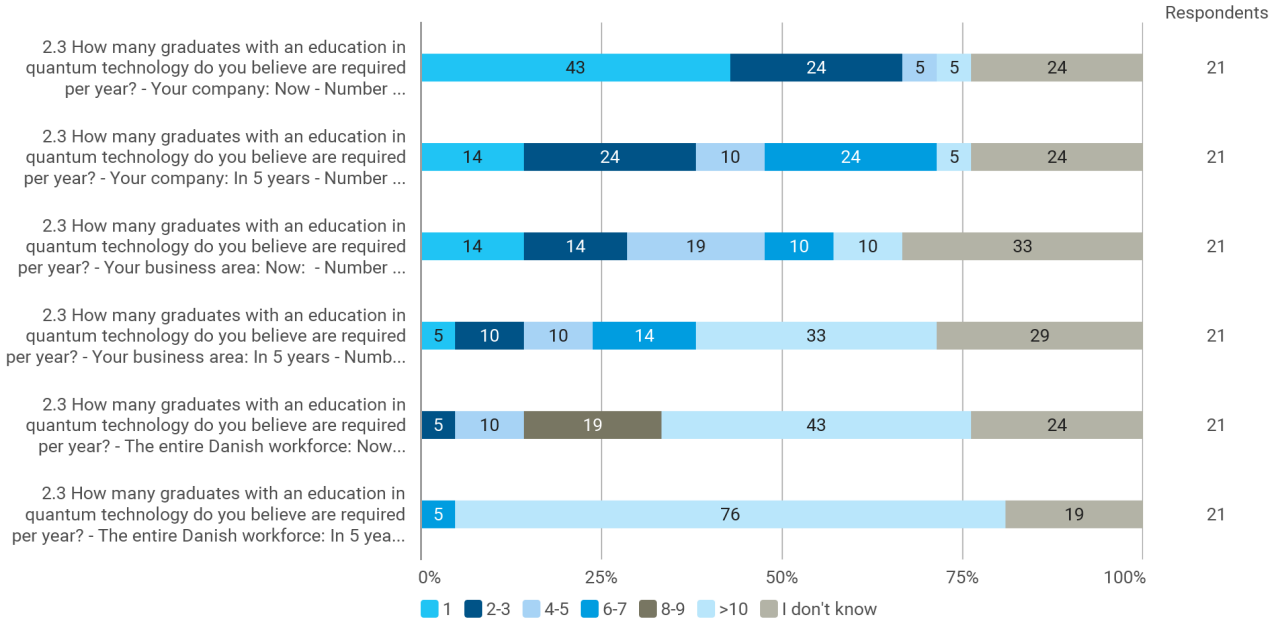
2.1 Does the education outlined above fill a need on the in Danish industry?



2.2 Do you think that the proposed master's degree in quantum technology will equip the students with additional competences with respect to these related programs?

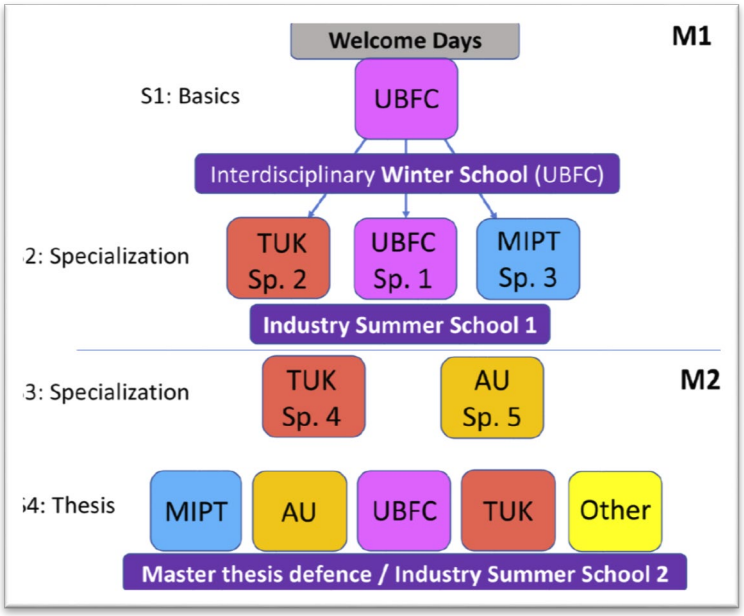


2.3 How many graduates with an education in quantum technology do you believe are required per year?

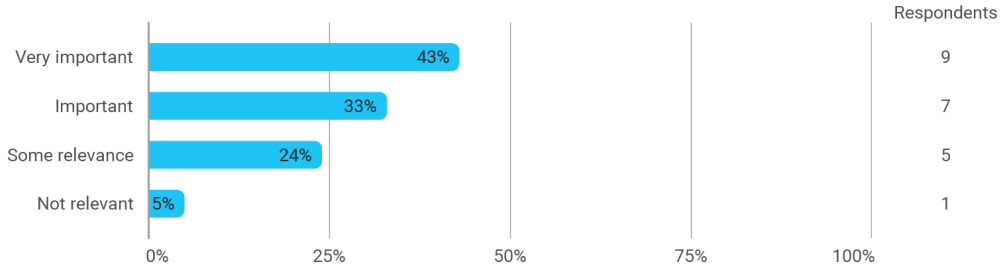

Respondents
2.3 How many graduates with an education in quantum technology do you believe are required per year? - Your company: Now - Number ...
43
24
5
5
24
21
2.3 How many graduates with an education in quantum technology do you believe are required per year? - Your company: In 5 years - Number ...
14
24
10
24
5
24
21
2.3 How many graduates with an education in quantum technology do you believe are required per year? - Your business area: Now: - Number ...
14
14
19
10
10
33
21
2.3 How many graduates with an education in quantum technology do you believe are required per year? - Your business area: In 5 years - Numb...
5
10
10
14
33
29
21
2.3 How many graduates with an education in quantum technology do you believe are required per year? - The entire Danish workforce: Now...
5
10
19
43
24
21
2.3 How many graduates with an education in quantum technology do you believe are required per year? - The entire Danish workforce: In 5 yea...
5
76
19
21
0%
25%
50%
75%
100%
1
2-3
4-5
6-7
8-9
>10
I don't know

3. QuanTEEM mobility plan

QuanTEEM offers numerous possibilities of mobility between the partners combined with fives specializations: photonics, quantum materials, many-body quantum physics, integrated quantum optics and platforms for quantum technologies.



3.1 How do you evaluate the requirement of mobility and international experience in QuanTEEM?



4. Information about your company

4.1 Name of the company where you are employed (optional):

- IBM
- R&D Engineering Solutions
- Patentgruppen A/S
- Halfspace
- Ørsted
- Vestas
- Kamstrup
- Trescal Group
- Kamstrup A/S
- AU

- Ørsted
- Danish Fundamental Metrology A/S
- Apparateq ApS
- NKT Photonics
- UV Medico A/S

This field was left blank in a number of answers.

4.2 Number of employees in Denmark: <10, 10-20, 20-30, >30

- <10 – 1%
- 10-20 – 9%
- 20-30 – 9%
- >30 – 81%

4.3 Number of employees internationally: <10, 10-20, 20-30, >30

- <10 – 35%
- 10-20 – 5%
- 20-30 – 10%
- >30 – 50%

4.4 In which business area is the company?

- IT
- Mechanical, electrical and software engineering
- Patent consultancy
- Data, analytics and AI
- Energy
- Metrology (classical & quantum), R&D, consultancy
- Wind Turbine Generator Manufactoring
- Education
- Sensoring, metering and services to water and energy utilities
- Metrology
- Selling meter and services to utilities world wide
- Water industry
- R&D
- Energy
- Metrology
- Fundamental Metrology and Quantum metrology
- research and development (calibration and validation)
- Electronics for science and research
- Photonics
- ultraviolet lighting and sensing

5. If you have additional comments please add them here:

- Looks very good.
- I personally find it difficult to assess the need for experts of emerging quantum technologies in the Danish workforce.
  Being educated in quantum physics myself, I use very little of my deep knowledge of physics in my daily work. Nevertheless, my studies also equipped me with transferable skills which I use every day, I'm sure that people educated through the proposed master's degree will also learn skills which are broadly applicable.
- I think the partnership between universities is really interesting, and the requirement for the students to move around is great. We need much more coorporation in Europe within the area of quantum technology, and I hope this program can strengthen the bonds!
- I see the most immediate possible applications of quantum technology within my own business area in applying quantum computing to optimisation problems. But I am curious to see what other possibilities the future brings.
- An exceptional opportunity to strengthen international collaboration in education and research, and educate the next generation of quantum scientists and engineers.
- To 2.1
  I was unemployed for 6 months after I graduated, and I didn't see any jobs asking for any expertise in Jutland. My impression is that it might be different in Copenhagen, but the industry in Aarhus seems lacking in this regard.
  To 2.3
  I would have answered 0 instead of don't know.
- Having such a narrow focus on quantum technology is likely not a very good selling point towards industry, but the compentences you learn during your education is what is needed in the private sector. I think the program will be good, but the selling point towards industry is weak.
- I general I think at that a standard physics education where the students can pick freely between all the aspects of physics is a better way of producing the best candidates. Then they will pick what they find relevant and if you provide a wide spectrum of interesting courses quantum technology will also be some students merit.
  In most cases for the industry we do not need/use specific courses followed during the education, but the entire skill set acquired during 5 years of study.
  In my company we are more than 25 physicist and more of 50 % of these have phds as well. I do not think that any of us uses specific knowledge acquired in a course very often
- The initiative is really appreciated!!
- Your proposal looks great! I'd like to mention that at the ECE department of AU, there are funded projects (Innovation Fund Denmark, Grand Solutions) to work on photonic *quantum technologies* and we teach about them at the MSc level (see e.g. the course entitled "Photonic Devices"). From what you shared about your proposal, I think these activities could be quite synergetic. Maybe we can imagine a closer collaboration if this program is funded?

Bilag 3: Job marked in Denmark

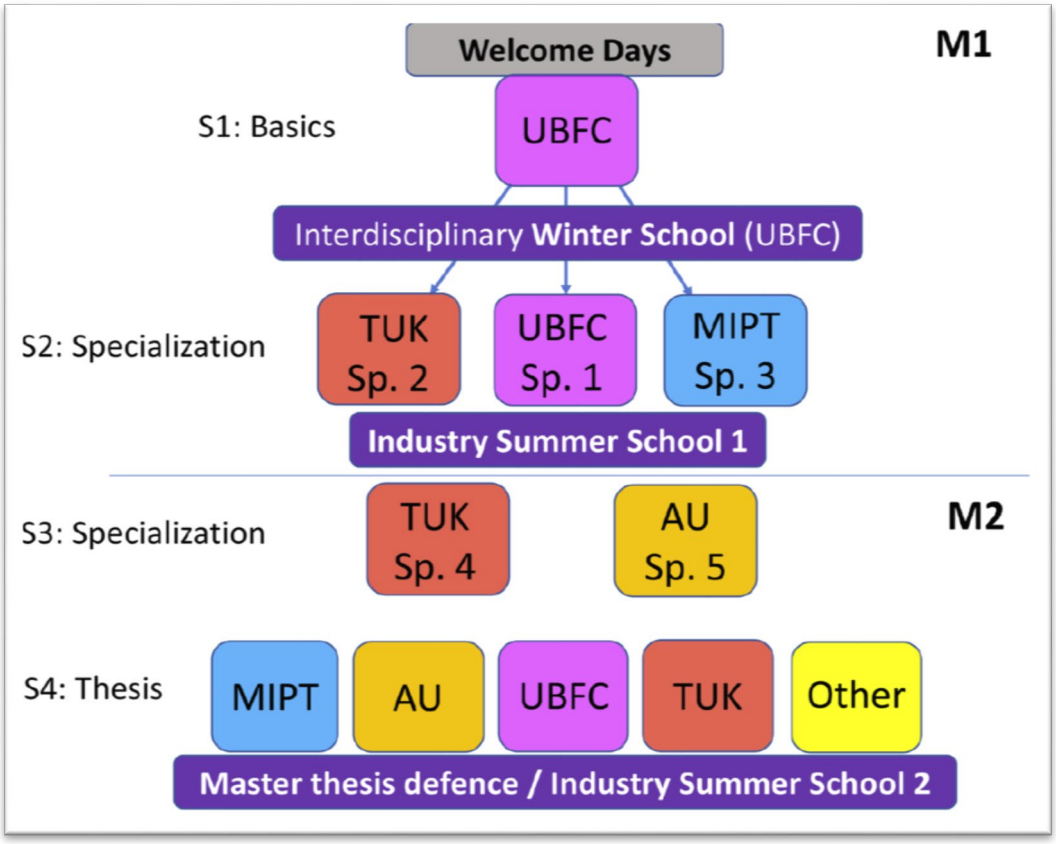
The following list shows an analysis of the positions posted in Denmark in the time interval from July 2020 to July 2021 requiring skills related to quantum physics. All university-based positions (such as PhDs and permanent research positions) have been removed to show the need solely based on industry based positions.

The total list comprises 53 positions showing the considerable the need for skills in quantum based technologies both related to hardware and software (quantum computation).

Job title	**Company**	**Posting time**
Associate crypto udvikler	IBM Client Innovation Center	2020-01-07 14.48.45
Quantum Site Manager	Microsoft	2020-01-09 16.40.15
Nanofabrication Engineer	Microsoft	2020-01-13 18.46.08
Nanofabrication Engineer	Microsoft	2020-01-15 20.02.44
Data & Applied Scientist	Microsoft	2020-01-28 05.23.21
Nanofabrication Engineer	Microsoft	2020-01-29 06.25.36
Associate Crypto Developer - IBM CIC	IBM	2020-02-07 04.01.46
Senior GUI Developer	Synopsys Northern Europe Ltd	2020-02-11 17.28.04
Quantum Researcher	Microsoft	2020-02-17 15.59.34
Quantum Researcher	Microsoft	2020-02-17 16.01.07
Senior Fabrication Engineer	Microsoft	2020-02-20 18.01.14
Senior Hardware Program Manager	Microsoft	2020-02-24 20.10.50
Site Program Manager	Microsoft	2020-03-06 02.42.23
Associate Crypto Developer - IBM CIC	IBM	2020-03-20 14.43.22
Associate Crypto Developer	IBM Client Innovation Center	2020-03-24 10.15.56
Associate Crypto Developer	IBM Client Innovation Center	2020-03-24 10.27.18
Senior Embedded Software Engineer	Angoka	2020-03-27 05.18.09
Scientific Software Developer	Synopsys Northern Europe Ltd	2020-04-28 17.00.13
Senior Embedded Software Engineer	Angoka	2020-05-07 05.18.04
Associate Crypto Developer	IBM Client Innovation Center	2020-05-14 14.46.17
Scientific Specialist in molecular dynamics and materials simulations	Synopsys Northern Europe Ltd	2020-06-03 20.00.08
Associate Crypto Developer	IBM Client Innovation Center	2020-06-04 12.17.37
Associate Crypto Developer - IBM CIC	IBM	2020-07-01 00.00.44
High end Server Channel Executive for Nordic Markets	Atos IT Solutions and Services	2020-07-10 13.06.08
High end Server Channel Executive for Nordic Markets	Atos IT Solutions and Services	2020-07-14 13.35.34
Senior Software Developer Engineer-Quantum team	Microsoft	2020-08-10 23.15.21
Senior Applications Engineer	Synopsys Northern Europe Ltd	2020-08-15 02.00.12

Senior Applications Engineer	Synopsys Northern Europe Ltd	2020-08-15 02.00.13
Scientific Software Developer	Synopsys Northern Europe Ltd	2020-09-01 03.25.07
Site Program Manager	Microsoft	2020-09-24 16.24.31
Data Engineer - NewTech	KPMG Denmark	2020-09-26 11.50.13
High-Performance Computing Specialist	Synopsys Northern Europe Ltd	2020-10-02 08.01.16
Principal Materials Scientist	Microsoft	2020-12-09 15.45.33
IPaper - Senior Backend Developer	Kold+Partners	2020-12-24 10.35.14
IPaper - Senior Frontend Developer	Kold+Partners	2020-12-24 10.35.15
Lead Backend Developer (Python, PostgreSQL)	Molecular Quantum Solutions (MQS)	2021-01-04 05.18.12
Lead UI Front-end Developer (React)	Molecular Quantum Solutions (MQS)	2021-01-04 05.18.12
Quantum Simulation Engineer	Microsoft	2021-02-03 08.58.59
Lab Manager Quantum	Microsoft	2021-02-11 13.05.27
Ultra-high vacuum Hardware Engineer Quantum Team	Microsoft	2021-02-11 13.05.55
Konsulent til areal- og rettighedserhvervelse	Energinet	2021-02-27 15.17.05
Research Assistant - TECH	Copenhagen Capacity	2021-03-05 13.21.34
Sektionschef til ny teknologisk forsknings- og vidensenhed	Forsvarets Efterretningstjeneste	2021-03-27 00.35.17
Molecular Beam Epitaxy Engineer - Quantum Team	Microsoft	2021-03-31 05.47.34
Quantum Hardware Researcher	Microsoft	2021-04-09 16.53.35
Structural Characterization Engineer	Microsoft	2021-04-09 17.15.09
Center for Cybersikkerhed søger tekniske kandidater til virksomheds ph. d	Forsvarets Efterretningstjeneste	2021-04-24 07.34.17
Center for Cybersikkerhed søger tekniske kompetencer til ny sektion	Forsvarets Efterretningstjeneste	2021-04-24 07.34.21
Medical Operations Coordinator	Merck Group	2021-05-30 03.21.32
Medical Operations Coordinator	Merck Group	2021-06-01 04.43.26
Medical Operations Coordinator	Merck Group	2021-06-03 09.27.15
Medical Operations Coordinator	Merck Group	2021-06-05 12.41.37
Medical Operations Coordinator	Merck Group	2021-06-07 15.31.34

Bilag 4: Studiediagram



Bilag 5: Oversigt over beslægtede uddannelser

Beslægtede uddannelser, nationalt

Master´s degree	Place	QT	Specialty
Fysik	Aarhus Universitet, AU	related, broad	• Astrofysik • Atomic, molecular and optical physics • Particle physics • Faststoffysik • Kernefysik
Fysik	Københavns Universitet, KU	related, broad	• Astrofysik • Geofysik • Kvantefysik • Bio- og medicinsk fysik • Computational Physics
Fysik	Syddansk Universitet, SDU	related, broad	• Computational Physics • Quantum Optics • Particle Physics and Cosmology • Soft Matter and Statistical Physics
Fysik	Aalborg Universitet, AAU	related, broad	• Kvantefysik • Materialefysik • nanooptik.
Fysik	Roskilde Universitet, RUC	related, broad	• Fysik + Environmental Biology • Fysik + Filosofi og Videnskabsteori • Fysik + Kemi • Mathematical Physical Modelling • Physics + Chemistry • Physics + Computer Science (Datalogi)
Nanoscience	INano, Aarhus Universitet, AU	related, very broad	• Nanomaterialer • Biomedicinsk • Nanoteknologi • strukturbiologi og biofysik • organsk nanokemi/bløde materialer

Nanoscience	Københavns Universitet, KU	related, broad	mange valgfrie kurser, men ingen specialiseringer.
Fysik og teknologi/Teknisk videnskab (civilingeniør) i fysik og teknologi	Syddansk Universitet, SDU	related, broad	• avanceret optik • kvantefysik • materiale- og molekylefysik • nanofysik • samt fremstilling af nanostrukturer
Fysik og nanoteknologi/Teknisk videnskab (civilingeniør) i fysik og nanoteknologi	Danmarks Tekniske Universitet, DTU	related, broad	• Biofysik og sundhedsteknologi • Nanoskala materialefysik • Nanosystemer • Optiske metamaterialer og komponenter • Fysik og nanoteknologi • Kvantesystemer
Master of Science in Physics and Nanotechnology i samarbejde med udenlandske universiteter.	Danmarks Tekniske Universitet, DTU	related, broad	• Biological and medical physics • Energy Physics (including plasma physics and nanostructured materials for energy applications) • Nano-scale materials physics • Nanosystems Engineering • Optics, Photonics and Light Science • Quantum Engineering.
Elektroteknologi	Aarhus Universitet, AU	related, broad	• Photonics • Wearable Devices • Wireless Communication • Signal Processing • Integrated Circuits
Fotonik/Teknisk videnskab (civilingeniør) i fotonik	Danmarks Tekniske Universitet, DTU	related, broad	• Fotoniske materialer og strukturer • Komponenter til optisk kommunikation • Biofotonik og sensorer • Lasere og lyskilder

Beslægtede uddannelser, internationalt

Master's degree name or Department	Place	QT related or focussed	Speciality and limitations
Advanced Quantum Physics	**TUK** (consortium member)	related	Quantum physics
Applied Physics	TU Delft	focussed	Quantum devices and quantum computing
Center for Integrated Quantum Materials	Harvard & Howard Universities/MIT	focussed	Quantum materials
Graduate School Quantum Science and Nanomaterials	University of Strasbourg	related	Nanomaterials
Nanoscience and Quantum Engineering	Stanford University	related	Nanoscience
Optoelectronics & Quantum Technology	University of Bristol	related	Optoelectronics for QT/ 1 year
Photonics	Polytechnical University Catalunya	related	Photonics
Physics, Photonics & Nanotechnology	**UBFC** (consortium member)	related	Photonics & nanotechnology
Physics	University of Copenhagen	related	Quantum Physics
Quantum Engineering	ETH Zurich	focussed	Oriented to information technology and electrical engineering
Quantum Engineering	Julius-Maximillians-Universität Würzburg	focussed	Oriented to material synthesis, characterisation, spectroscopy and modelling
Quantum Photonics and Nanomaterials	University of Sheffield	related	Quantum photonics and nanomaterials/ 1 year
Quantum Science & Technology	Munich Universities: TUM and LMU	focussed	QT
Quantum Technologies	University College London	focussed	Lacking nanophotonics/ 1 year
Quantum Technology	Australian National University	focussed	QT
Quantum Technology	University of Sussex	focussed	Platforms and devices for QT/ 1 year
Quantum Technology	University og Glasgow	focussed	Nanotechnology/ 1 year

Bilag 6: Ledighedsstatistik for beslægtede uddannelser

Master´s degree	Place	Ledighed nyuddannede (%)	Ledighed 10 år efter endt uddannelse (%)
Fysik	Aarhus Universitet, AU	8	1
Fysik	Københavns Universitet, KU	7	2
Fysik	Syddansk Universitet, SDU	6	1
Fysik	Aalborg Universitet, AAU	9	-
Fysik	Roskilde Universitet, RUC	17	5
Nanoscience	INano, Aarhus Universitet, AU	12	1
Nanoscience	Københavns Universitet, KU	13	1
Fysik og teknologi/Teknisk videnskab (civilingeniør) i fysik og teknologi	Syddansk Universitet, SDU	12	-
Fysik og nanoteknologi/Teknisk videnskab (civilingeniør) i fysik og nanoteknologi	Danmarks Tekniske Universitet, DTU	3	0
Master of Science in Physics and Nanotechnology i samarbejde med udenlandske universiteter.	Danmarks Tekniske Universitet, DTU	-	-
Fotonik/Teknisk videnskab (civilingeniør) i fotonik	Danmarks Tekniske Universitet, DTU	0	-

Bilag 7: Liste over potentielle arbejdsgivere i Danmark

The table below provides a list of possible employers in Denmark which have been identified as developers or users of quantum technology in a wide sense.

Company	QT profile
Anton Paar Nordic	Developer
C2Wind	User
Danfoss	User
Danfysik	Developer
Danmarks Meteorologiske Institut	Developer
Dansk Center for Partikelterapi	Developer
Danske Bank	User
DHI	User
DNV GL	Developer
FOSS	Developer
GPower	User
Netcompany	User
Grundfos Holding	User
Haldor Topsoe	Developer
IBM	Developer
IHFood	User
Inspicos	User
Kamstrup	Developer
Koheras	Developer
National Oilwell Vargo	User
NKT Photronics	Developer
NNE	User
Nokia	User
Odense Universitetshospital	User
OFS Fitel Denmark	Developer
Oxford Instruments	Developer
Patentgruppen	User
QIAGEN	User
R&D - Engineering Solutions & Consulting	User
Rigshospitalet	User
SICK	User
Siemens Gamesa	User
Teknologisk Institut	Developer
TERMA Group	Developer
Unisense	Developer
Vejle Hospital	User
Vestas	User
Ørsted	User
Aarhus Universitetshospital	User

Bilag 8: Qualification according to the Dublin descriptors

Qualification according to the Dublin descriptors	Intended learning outcomes in QuanTEEM	Implementation in QuanTEEM
Knowledge and understanding > have demonstrated knowledge and understanding that is founded upon and extends and/or enhances that typically associated with the bachelor's level, and that provides a basis or opportunity for originality in developing and/or applying ideas, often within a research context	> Acquire a comprehensive up-to-date knowledge of the field of QT > Be able to identify and formulate R&D questions related to QT	> Advanced core courses: > Quantum physics, quantum information and communication, quantum computation and simulation, quantum sensing
Applying knowledge and understanding > can apply their knowledge and understanding, and problem-solving abilities in new or unfamiliar environments within broader (or multidisciplinary) contexts related to their field of study	> Acquire a comprehensive up-to-date knowledge of the field of QT > Acquire a comprehensive up-to-date knowledge of the field of QT > Be able to solve a problem in a blurred context > Be able to implement a project management strategy > Be able to formulate an optimization problem with multiple criteria (technological or not) > Be able to propose hierarchized solutions	> Implementation of problem-based learning: case/challenge-based modules > Case/challenge topics proposed by industrials or societal actors > Multidisciplinary/intersectoral supervision of cases/challenges > Project management tools in the specific context of QT
Making Judgements > have the ability to integrate knowledge and handle complexity, and formulate judgements with incomplete or limited information, but that include reflecting on social and ethical responsibilities linked to the application of their knowledge and judgements	> Able to bridge knowledge, research results coming from different horizon > Able to dialog with specialist of other disciplines than their own > Able to critically examine results, solutions from the literature > Able to adopt a holistic point of view	> Broad education on sciences directly related to QT (in addition to core courses in physics): Information technology, computer science, material science, nanotechnologies. A large spectrum of breadth courses is proposed, including courses for opening mind to social, societal, human, and economy outcomes > Outcomes of the challenge-based module > Outcome of the master thesis
Communication > can communicate their conclusions, and the knowledge and rationale underpinning these, to specialist and nonspecialist audiences clearly and unambiguously	> Able to collaborate in a project of R&D, even with specialists coming from different horizons > Able to present results in international audiences in their own area of specialization and to present convincingly in English (both orally and in writing) > Able to transfer the knowledge to a large public > Able to operate in intercultural environment	> Case/challenge-based modules > Presentation of the case/challenge during an oline meeting + pitch in the summer session (written report, oral presentation by team) > Master thesis writing and defence in front of a large multidisciplinary/intersectoral panel > Public awareness training, actions towards schools and young pupils > Working in an international team (students, teachers) and language & culture courses
Learning skills > have the learning skills to allow them to continue to study in a manner that may be largely self-directed or autonomous	> Be able to learn by their own > Be able to keep abreast of the latest development in their own field	> Be in contact with top-class researchers (and face learning research-based methods) > Be placed in top class research environment > Autonomous work in the case/challenge

Uddannelses- og Forskningsstyrelsen

Aarhus Universitet
E-mail: au@au.dk,

Godkendelse af ny uddannelse

Uddannelses- og forskningsministeren har på baggrund af gennemført prækvalifikation af Aarhus Universitets ansøgning om godkendelse af ny uddannelse truffet følgende afgørelse:

Godkendelse af (Erasmus Mundus) kandidatuddannelse i Quantum Technologies and Engineering

Afgørelsen er truffet i medfør af § 20, stk. 1, nr. 1, i bekendtgørelse nr. 1558 af 2. juli 2021 om akkreditering af videregående uddannelsesinstitutioner og godkendelse af videregående uddannelser med senere ændringer af 5. september 2021.

Det er en forudsætning for godkendelsen, at uddannelsen og dennes studieordning skal opfylde uddannelsesreglerne, herunder bekendtgørelse nr. 247 af 13. marts 2015 om universiteternes internationale uddannelsesforløb (international uddannelsesbekendtgørelse) og bekendtgørelse nr. 35 af 13. januar 2022 om adgang til universitetsuddannelser tilrettelagt på heltid (universitetsadgangsbekendtgørelsen).

Da Aarhus Universitet er positivt institutionsakkrediteret gives godkendelsen til umiddelbar oprettelse af uddannelsen.

Set i lyset af uddannelsens fagområde henstiller Uddannelses- og Forskningsstyrelsen til, at AU fremadrettet er opmærksomme på de retningslinjer for internationalt forsknings- og innovationssamarbejde, som Udvalg om retningslinjer for internationalt forsknings- og innovationssamarbejde (URIS) har udarbejdet og offentliggjort den 25. maj 2022.

Ansøgningen er blevet vurderet af Det rådgivende udvalg for vurdering af udbud af videregående uddannelser (RUVU). Vurderingen er vedlagt som bilag.

Hovedområde:
Uddannelsen hører under det naturvidenskabelige hovedområde.

Titel:
Efter reglerne i den internationale uddannelsesbekendtgørelses § 26, stk. 1 fastlægges uddannelsens titel til:

Engelsk: Master of Science (MSc) in Quantum Technologies and Engineering

Udbudssted:
Aarhus.

1.juni 2022
Uddannelses- og Forskningsstyrelsen
Uddannelsesudbud og Optag

Haraldsgade 53
2100 København Ø
Tel. 7231 7800

www.ufm.dk

CVR-nr. 3404 2012

Sagsbehandler
Kevin Gønge
Tel. +45 72 31 78 51
kevg@ufm.dk

Ref.-nr.
21/30464-5

Styrelsen har noteret sig, at uddannelsen er en Erasmus Mundus uddannelse, som udbydes af AU, University of Burgundy – primær ansøger (Frankrig), University of Kaiserslautern, Tyskland.

Sprog:
Ministeriet har noteret sig, at uddannelsen udbydes på engelsk.

Normeret studietid:
Ministeriet har noteret sig, at uddannelsen normeres til 120 ECTS-point.

Takstindplacering:
Uddannelsen indplaceres til: Takst 3
Aktivitetsgruppekode: 8137

Koder Danmarks Statistik
UDD: 8115
AUDD: 8115

Censorkorps:
Ministeriet har noteret sig, at uddannelsen tilknyttes censorkorpset for fysik og astronomi.

Adgangskrav:
Efter det oplyste er følgende uddannelser adgangsgivende til kandidatuddannelsen, jf. § 28, stk. 3, i bekendtgørelse nr. 35 af 13. januar 2022 om adgang til universitetsuddannelser tilrettelagt på heltid (universitetsadgangsbekendtgørelsen) og § 36 om krav til engelskkundskaber:

- Alle danske bachelorgrader i fysik og internationalt anerkendte bachelorgrader i fysik.

Udvælgelsen af kandidater følger EU-retningslinjer inden for Erasmus Mundus-programmet. Der er ingen retskravsbachelorer, da dette er et Erasmus Mundus-program.

Ansøgere skal dokumentere, at de har et tilstrækkeligt højt engelskniveau. Dette skal dokumenteres med en IELTS-test med en minimumscore på 6,5 og minimum 6,0 i hver disciplin. Dette svarer til en TOEFL-test med en score omkring 600 paper-based/250 computer-based/95 internet-based.

Med venlig hilsen
Kevin Gønge

Nr. A 5 - Ny uddannelse – prækvalifikation (efterår 2021)			**Status på ansøgningen:** Godkendt	
Ansøger og udbuds-sted:	Aarhus Universitet, Aarhus			
Uddannelsestype:	Kandidatuddannelse. Erasmus Mundus Master.			
Uddannelsens navn (fagbetegnelse):	Quantum Technologies and Engineering			
Den uddannedes titler på engelsk:	-Master of Science (MSc) in Quantum Technologies and Engineering -			
Hovedområde:	Naturvidenskab		**Genansøg-ning:** *(ja/nej)*	Nej
Sprog:	Engelsk	**Antal ECTS:**	120 ECTS	
Link til ansøgning på http://pkf.ufm.dk:	http://pkf.ufm.dk/flows/a9d3df8f35ee8df1d02183ce571105bc			
RUVU's vurdering på møde d. 12. oktober 2021:	RUVU vurderer, at ansøgningen opfylder kriterierne som fastsat i bekendtgørelse nr. 1558 af 2. juli 2021 bilag 4 med senere ændringer om akkreditering af videregående uddannelsesinstitutioner og godkendelse af videregående uddannelser RUVU bemærker, at der er tale om en specialiseret uddannelse, som bidrager til rekrutteringsgrundlaget inden for relevante forskningsområder, hvor der forventes en vækst i de kommende år. Det er også sandsynliggjort, at uddannelsens indhold og sigte ikke dækkes fuldt ud af andre beslægtede uddannelser. Da uddannelsen er et Erasmus Mundus samarbejde, og således indebærer et internationalt samarbejde, finder RUVU det underbygget, at der er behov for at udbyde uddannelsen på engelsk.			