FRAUNHOFER- SOCIETY

CERTIFICATION HANDBOOK AND EXAMINATION REGULATION

Personnel Certification Quantum Computing Professional

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Fraunhofer Personnel Certification Authority
Schloss Birlinghoven
53757 Sankt Augustin
Germany

CERTIFICATION HANDBOOK AND EXAMINATION REGULATION

Personnel Certification
Quantum Computing Professional

Fraunhofer Personnel Certification Authority

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Content

1 Foreword

The certification services of the Fraunhofer Personnel Certification Authority in the field »Quantum Computing Professional« are open for all interested persons. The Certification Authority guarantees the equal treatment of all applicants.

Below the process of the personnel certification in the field »Quantum Computing Professional« will be described according to EN ISO 17024 »General requirements for bodies operating certification of persons« and a uniform certification system will be provided.

The certification handbook serves simultaneously as examination regulation for certification examinations in the field »Quantum Computing Professional«.

2
SCOPE OF APPLICATION

The scope of the present certification handbook includes personnel certifications in the field »Quantum Computing Professional« by the Fraunhofer Personnel Certification Authority.

The personnel certifications in the field »Quantum Computing Professional« refer to the following certification profiles:

- Level A (Basic Level):
  - Certified Quantum Computing Professional Basic Level
  - Certified Quantum Computing Professional specialized in Quantum Machine Learning
  - Certified Quantum Computing Professional specialized in [to be defined]
- Level B (Advanced Level): Certified Quantum Computing Professional Advanced Level
- Level C (Senior Level): Certified Senior Quantum Computing Professional

Each certification profile is independent from the other ones. The requirements of the different certification profiles are listed in this document's annex and are part of the respective personnel certification.

The different certification profiles are developed as independent profiles but complement each other. They differ and complement each other as follows:

At Level A (Basic Level), the title "Certified Quantum Computing Professional Basic Level" is awarded as well as the certificate in specialized area with the title "Certified Quantum Computing Professional specialized in Quantum Machine Learning" and further certification profiles "specializend in .." (which are still to be developed).

The certificate "Certified Quantum Computing Professional Basic Level" in combination with the certificate "Certified Quantum Computing Professional specialized in Quantum Machine Learning" includes a basic qualification in the essential content and methodological aspects of the field. The learning content of "Certified Quantum Computing Professional specialized in Quantum Machine Learning" builds on "Certified Quantum Computing Professional Basic Level".

Level B (Advanced Level) is completed with the title "Certified Quantum Computing Professional Advanced Level" and includes the application of methods from the field of Quantum Computing in everyday work. The certificate is awarded after acquiring the "Certified Quantum Computing Professional Basic Level" plus one of the specializations "Certified Quantum Computing Professional specialized in …" as well as proof of at least one year of professional experience in the field of Quantum Computing.

At Level C (Senior Level), the title "Certified Senior Quantum Computing Professional" is awarded if, in addition to several years of professional experience, the "Certified Quantum Computing Professional Advanced Level" certificate can be proven and a project documentation as well as a presentation have been completed.

The following figure shows the relationships between the individual certification profiles.

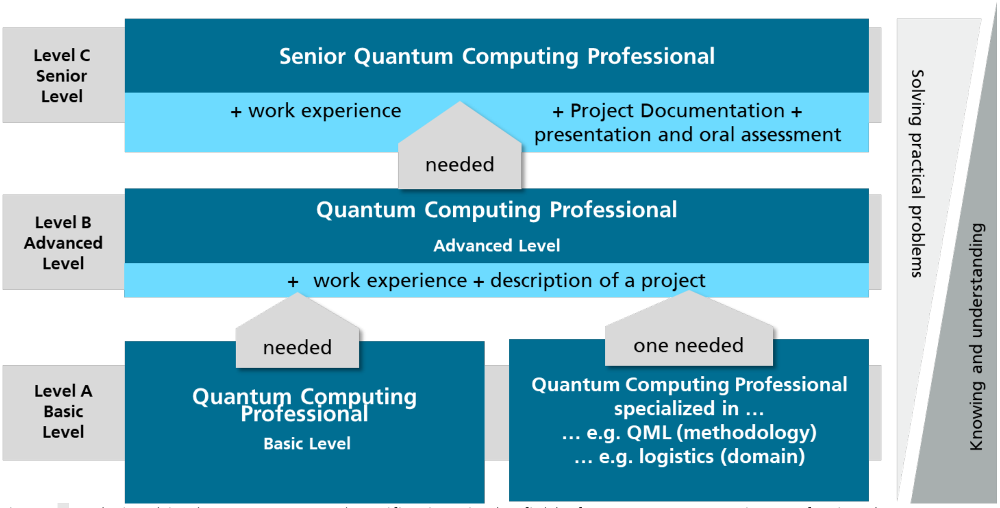

Figure 1: Relationships between personal certifications in the field of Quantum Computing Professional

Figure 1 shows how the present and perspective certification profiles fit in a certification system that includes a basic (Level A), advanced (Level B), and senior level (Level C).

The requirements of the specific certification profiles are listed in the annexes to this document and are part of the respective certification of persons.

3
GENERAL TERMS

- **Fraunhofer Personnel Certification Authority**
  Authority in the Fraunhofer Society that organizes certificates of the conformity of normative specifications and the actual personnel qualification.

- **Examiner (E)**
  Experts acting on behalf of the Fraunhofer Certification Authority to examine persons. They are independent in terms of their examination tasks. It is guaranteed that the examiners know the complete course content.
- **Examination Observer (EO)**
  People who are acting on behalf of the Fraunhofer Certification Authority in order to support the examiners during the exams. They are responsible to the examiners.

- **Expert Committee (EC)**
  Committee of experts that is appointed by the Fraunhofer Personnel Certification Authority. The tasks of the committee are the following: verification and validation of examination content, creation of examination questions, responsible authority for professional requests and consulting of the Fraunhofer Personnel Certification Authority in terms of the professional quality of the examiners. Full particulars in terms of the tasks and competences can be found in the »internal rules of procedure of the expert committee«. An expert committee will be formed for each certification profile.

- **Term »know«**
  The term »know« can be found in the first and second level of the six-level scale of the Bloom's Taxonomy of Educational Objectives (Taxonomy of educational objectives, 1974, 5. Auflage. Beltz Verlag, Weinheim 1976). It includes the ability to replicate terms on call by using keywords. The required skills for this are knowledge, recognition, and imitation.
  The goal of »know« in the examination of the »Quantum Computing Professional« certification includes different contents for each certification profile. These will be described in the annex.

- **Term »apply«**
  The term »apply« is used to describe the third and fourth level of the Bloom's Taxonomy of Educational Objectives. The learner should be able to convert and order the content. The distinctive skills for this are understanding, reaction and practice.
  The goal of »apply« in the examination of the »Quantum Computing Professional« certification includes different contents for each certification profile. These will be described in the annex.

- **Term »evaluate«**
  The term »evaluate« is used to describe the fifth and sixth level of the Bloom's Taxonomy of Educational Objectives which are called »transfer« and »problem-solving competence«. It is characterized by the transfer of basic principles to new and similar tasks. Distinct abilities are the application, evaluation, coordination, and problem-solving, and automation.
  The goal of »evaluate« in the examination of the »Quantum Computing Professional« certification includes different contents for each certification profile. These will be described in the annex.

4 SPECIFICATIONS FOR THE CERTIFICATION PROCEDURE

In the following section the specifications for the certification procedure will be described.

4.1 Goal

The certification serves to examine qualification characteristics according to defined qualification profiles and to attest the quality of those through a certificate of competence.

4.2 Application

Applicants may be certified after successfully completing the examination fulfilling the requirements stated in § 1.
Applicants who wish to take or retake the examination shall apply to the Fraunhofer Personnel Certification Authority in writing. The application must include the following information of the applicant:

- Name, date of birth, private address.
- Workplace with address (if any)
- Occupation
- Relevant certification profile
- Statement, whether the application concerns an initial certification, a retake or a recertification.

Eligible for certification are all persons that have successfully passed an examination of the Fraunhofer Personnel Certification Authority in the field of »Quantum Computing Professional« and that meet the defined admission requirements according to the annex of this certification handbook.

The examination dates will be determined by the Fraunhofer Personnel Certification Authority.

4.3 Examination procedure

The examination procedure is described below.

The examinations at Level A (Basic Level) for the "Certified Quantum Computing Professional Basic Level" are written exams which consist of a theoretical and practical examination, both of which are taken in writing.

The examinations in the specialized area with the title "Certified Quantum Computing Professional Specialized in Quantum Machine Learning" are also conducted in writing and consist of a theoretical examination section with practical parts that are completed in writing.

There is no separate examination for certification at Level B. The certificate is awarded after acquiring and holding the valid certificate "Certified Quantum Computing Professional Basic Level" and at least one valid certificate "Certified Quantum Computing Professional specialized in …" as well as proof of at least one year of professional experience in the field of Quantum Computing.

For certification at Level C, a valid certification on level B and a proof of professional experience of at least 2 years are necessary as well as a documentation of a (real) project and its presentation in an oral assessment is required.

Recertification is only required for the certificate at the highest level achieved.

4.3.1 Compilation and allocation of the examination documents and assignment of the examiners

The Fraunhofer Personnel Certification Authority compiles the examination questions for the written certification examination based on a catalogue of questions which is confirmed by the expert committee. The allocation of the examination questions must be protected from unauthorized access.

The head of the Fraunhofer Personnel Certification Authority authorizes the examiners for the examination.

4.3.2 Execution of the written and practical examinations

The written examinations are usually conducted as face-to-face examinations but can also be conducted as online-proctored examinations. The Fraunhofer Personnel Certification Authority decides whether face-to-face or online-proctored examinations are to be conducted and on which dates.

The face-to-face examinations take place at a location approved by the Fraunhofer Personnel Certification Authority that meets the conditions specified by the Fraunhofer Personnel Certification Authority.

To avoid attempts at deception, the online-proctored examinations take place with the aid of suitable software in premises selected by the participants and in compliance with the specifications defined by the Fraunhofer Personnel Certification Authority. The specifications to be observed will be made available to the participants in writing in good time before the examination.

The written examinations last 3 hours.

The designated language of the examinations is usually English and, upon request, German.

The examination questions/tasks of a written examination are to be answered by hand in the case of face-to-face examinations and by keyboard in the case of online-proctored examinations. It is ensured that enough time is available for answering the theoretical examination questions. For this purpose, the responsible technical committee already checks the approximate time required to answer the questions when the questions are designed.

Auxiliary means are not allowed.

Individual exceptions are made for participants who are unable to take the examination as planned due to an impairment.

4.4 Examination questions and tasks

The catalogue of examination questions is different for each certification profile. The same is valid for the number of questions asked per subject area.

The questions are clearly assigned to the different certification profiles and subject areas. Questions may only be asked to participants with the corresponding qualification profile.

4.5 Evaluation of the examination

The participants must achieve a minimum degree of performance of 67 % in the examination. If this is not the case, no certificate will be issued.

If participants fail, the examination may be repeated up to maximal two times.

Participants will be given the opportunity to review the exam within four weeks of being notified of the exam results. The examination is always inspected on site at the Fraunhofer Personnel Certification Office. The examination documents are not sent out and cannot be viewed online via video conference. If the participant is not able to review the examination on site, an individual arrangement can be made with the certification body in exceptional cases.

For each question and task, the examiners will be provided with sample solution which will be used as guideline for the evaluation of the question at hand. Additionally, the expert committee fixes the achievable scores for each question or task.

4.6 Certification

Upon successful completion of the examination a certificate will be handed to the candidate by the Fraunhofer Personnel Certification Authority.

4.7 Recertification

The certificates of all certification profiles need to be renewed before they expire three years minus one day after the last part of the certification examination.

Recertification is only needed for the highest level of certification achieved.

4.7.1 The aim of the recertification

The aim of the recertification is to proof that the required level of knowledge and expertise (state of the art) as a "Certified Quantum Computing Professional Basic Level", “Certified Quantum Computing Professional specialized in Quantum Machine Learning", “Certified Quantum Computing Professional Advanced Level” or “Certified Senior Quantum Computing Professional” is consistently maintained by the person applying for recertification.

4.7.2 Evidence to be provided for recertification

For a recertification the following requirements must be proven:

- proof of at least 1.5 years of professional experience in the field of the profile to be recertified during the three years prior to recertification
- proof of participation in a subject-specific further training event while the certificate is still valid. The further training event has to include demonstrably up-to-date information regarding the competences mentioned in the Certification Handbook Quantum Computing or other current topics in the context of Quantum Computing.

Events of professional further trainings are eligible here if:
The event has a duration of at least two days and is organized by a member of an approved professional organization.
The certificate of attendance must clearly state a subject of the course that is relevant for Quantum Computing.
For individuals who conduct training in Quantum Computing as instructors that meet the above-mentioned requirements, this training activity will also be recognized.

4.7.3 Procedure for recertification

The person holding the certificate must formally apply for recertification within the period of two years minus one day after the final examination (or the last partial examination) up to 2.5 years minus one day after the final examination (or the last partial examination) (This means.: from 2 years up to 2.5 years after certification at the latest; or up to six months before the certificate expires) and provide evidence of both professional experience and participation in a further training event.

The head of the Fraunhofer Personnel Certification Authority decides on the recognition of the professional experience as well as the further training event.
In exceptional cases, professional experience and participation in a further training event can also be recognized within the last six months before the certificate expires. This must be applied for and justified in writing to the Fraunhofer Personnel Certification Authority up to 2.5 years minus one day after the final examination or the last partial examination. The head of the Fraunhofer Personnel Certification Authority shall decide on the granting of this exemption on a case-by-case basis.

If the recertification requirements are not met, the validity of the certificate shall expire on the date of expiry. The certificate must be reacquired (see initial certification).
In justified exceptional cases, a deferment of a maximum of six months may be granted (e.g. in the event of serious illness or parental leave). This deferment must also be requested in writing and justified. The decision to grant a deferment is made by the management of the Fraunhofer Personnel Certification Authority.
However, if the submitted documents are handed in in time but are not accepted for recertification, the certificate holder will get the possibility to hand in other evidence within a period of six months.

4.7.4 Proof of professional experience and participation in a further training course

Proof of professional experience may be provided, for example, by means of a certificate from the employer.
Proof of participation in the further training course is provided by a certificate of attendance from the further training provider and the submission of an agenda indicating the subject-specific topics that were dealt with.

4.7.5 Recognition of further training courses

For the recognition of a further training course, the course must be organized by a member of a recognized professional association in the field of Quantum Computing and deal with specialized topics.
Other training activities may also be recognized, with appropriate justification for the quality of the event and its relevance to the field of Quantum Computing, provided that

- the above-mentioned requirement of a two-day event is fulfilled.
- the participation in the entire event is evidenced by a personalised certificate of attendance from the organiser (no self-disclosure is permitted for the entire event)
- in addition, the participation in individual parts of the event (lectures, workshops, tutorials) is certified by the organiser or in exceptional cases by self-declaration with reference to the program,
- a description of the extent to which the attended events (lectures, workshops, tutorials) are related to the certification program.

This recognition is granted on a case-by-case basis by the Fraunhofer Personnel Certification Authority in consultation with the Expert Committee Quantum Computing.

If the recertification requirements are met, the respective certificate is renewed for another three years minus one day.
If the recertification requirements are not met, the validity of the respective certificate expires.

5 RIGHTS AND OBLIGATIONS

The rights and obligations of the Certificate Holder are described below.

5.1 Preliminary information

Upon written request (e.g., from potential clients of a Certificate Holder), the Fraunhofer Personnel Certification Authority may provide information on whether this person is legally holding the certificate by stating the certificate number. The name, date of birth and place of birth of the Certificate Holder are stored for identification purposes. With the registration, participants declare by their signature their intention to accept these regulations in the event of the certificate being issued. The Fraunhofer Personnel Certification Authority is bound by the provisions of the German Federal Data Protection Act.

5.2 Rights

Within the scope of his/her occupation in "NAME OF CERTIFICATE", the Certificate Holder is entitled to

- refer to his/her certification on letterheads, on the internet in connection with their person and other printed documents in connection with their person in the following way: certified "NAME OF THE CERTIFICATE", approved by the Fraunhofer Personnel Certification Authority" or certified "NAME OF THE CERTIFICATE". By using Alternative 1, he/she shall check that the designation of "approved by the Fraunhofer Personnel Certification Authority" does not appear bigger than the name of the certified person.
- use the certificate as a whole referring to the certification
- view the document "Certification Handbook" of the respective certification profile, which explains the certification system of the Fraunhofer Personnel Certification Authority (which is freely available on the webpage of the Fraunhofer Personnel Certification Authority).

  Further details: cf. section 5.3 below.

5.3 Obligations

The following principles must be complied with by the Certificate Holder while performing the tasks in the area of the respective certification profile:

5.3.1 Diligence

The certificate holder shall exercise his/her occupation in accordance with the "State of the Art".

The actions of the certificate-holder are characterized by the principle of always achieving an error-free and high-quality work result.

The Certificate Holder is obliged to not use the certification in an improper manner and to not make any statements that must be considered misleading or unauthorized by the Fraunhofer Personnel Certification Authority.

5.3.2 Independence

The Certificate Holder shall act without regard to official relations within the company and/or its employees or their desired results (personal independence).

5.3.3 Personal performance

The certificate holder shall perform all required services with regards to preparation, execution and evaluation of projects in the field of the respective certification profile in person. He/she shall not use the deed of the certification falsely or in any misleading way.

5.3.4 Permitted use of certificates

The following regulations shall also apply for the use of certificates:

- The certificate shall be granted to the Certificate Holder. The actual certificate/document shall remain the property of the Fraunhofer Personnel Certification Authority.
- Only valid certificates shall be used.
- The certificate shall not be abused inappropriately.
- The certificate shall be returned to the Fraunhofer Personnel Certification Authority
    - after expiration of the certificate,
    - after the Certificate Holder has been informed by the Fraunhofer Personnel Certification Authority about the withdrawal.
- In case of suspension, withdrawal or lapse of the certification, the Certificate Holder shall immediately cease the use of the certificate. References of the Certificate Holder to the certification and/or the Fraunhofer Personnel Certification Authority shall be removed immediately. In this event letterhead or other printed material shall be destroyed immediately or in case of suspension shall not be used during suspension.
- The use of the certificate or references to it are only permitted within the scope of the certificate.
- The certificate may only be used in connection with the person who is mentioned as certified in the certificate.
- The use of the certificate and references to it are only permitted if the observer explicitly recognizes who has been examined and certified.
- By using the certification or making references to it he/she shall not give the impression that the certified person is an employee of Fraunhofer-Society or that he/she acts on behalf of Fraunhofer-Society.
- The Certificate Holder is responsible for the correct use of the Certificate. Doubts shall be the responsibility of the Certificate Holder.

5.3.5 The Use of Fraunhofer-Logo

The certificate of the Fraunhofer Personnel Certification Authority contains the Fraunhofer-Logo. The Logo shall exclusively be used as a part of the certificate in that way that the certificate may be copied or made available on the internet as proof of the issuing Fraunhofer Personnel Certification Authority for e.g., clients or employers. Any further use beyond this of the Fraunhofer-Logo or the use of the name Fraunhofer as a trademark is expressly prohibited. In case of violation the Fraunhofer Society is entitled to apply for injunctive relief or damage claims.

5.3.6 Duty to give Notice

The Certificate Holder shall notify the Fraunhofer Personnel Certification Authority without delay of:

- any changes of name (e.g., in case of marriage),
- any change of place of residence,
- the loss of the certificate.

In addition, the Certificate Holder must inform the Fraunhofer Personnel Certification Authority immediately of any matters that may affect their ability to continue to fulfil the certification requirements (e.g. newly occurring physical limitations).

5.3.7 Duty to Disclose

Upon request of the Fraunhofer Personnel Certification Authority, the Certificate Holder shall disclose and furnish all necessary particulars and documents regarding the monitoring of activities and compliance with the aforementioned duties within a set deadline and without compensation.

He/she may refuse to provide self-incriminating information or such information that may incriminate his/her relatives.

5.4 Violation to Duties as Certificate Holder

Depending on the gravity of the violation of a duty stated in this document the certification may be suspended or revoked, which is communicated to the Certificate Holder in written form. For the duration of the suspension or after the certification has been revoked, the Certificate Holder is no longer entitled to refer to his/her certification and the Fraunhofer Personnel Certification Authority.

Annex A: »CERTIFIED QUANTUM COMPUTING PROFESSIONAL BASIC LEVEL«

A 1 Reference to other norms and documents

- EN ISO 17024

A 2 Profile of qualification

A 2.1 Determination

The qualification profile of a »Certified Quantum Computing Professional Basic Level« results from the characteristics and description of his or her field of work.

A »Certified Quantum Computing Professional Basic Level«:

- is able to explain and apply the general concepts of Quantum Mechanics and Linear Algebra necessary for Quantum Computing (QC)
- knows in which application areas quantum computing could be applied and have an overview of well-known algorithms (e. g. Shor and Grover)
- translates a simple problem into a Quantum Circuit and design it by using a Quantum Toolkit such as Qiskit.
- knows how to make a simple quantum circuit, transpiling it and running it in a simulator and real backend, e.g., IBM's quantum computers
- is able to program the basic QC algorithms such as Deutsch algorithm or Quantum Fourier Transformation (QFT) in Jupyter notebooks with the help Quantum Toolkit such as Qiskit.
- is able to program other algorithms such as Quantum Phase Estimation and Quantum Amplitude Amplification by using a Quantum Toolkit such as Qiskit
- is familiar with error mitigation methods and can explain them for simple examples

A 2.2 Entrance requirements

A 2.2.1 Previous education

A »Certified Quantum Computing Professional Basic Level« must have:

A successfully completed study at

- a German scientific university,
- a German state or state-recognized university of applied sciences, or
- a foreign university recognized as equivalent by the competent authority of the state

or

- at least one year of work in the field of Software Engineering, Data Science, Quantum Computing Science or Technology Scout.

Note:
In special cases the applicant has the possibility to prove missing entrance requirements within one year after taking the examination.

After examination of the submitted documents, the Fraunhofer Personnel Certification Authority will decide on the requirements. If entry requirements are not fulfilled, the Fraunhofer Personnel Certification Authority will directly communicate the decision to the applicant.

In principle, the Fraunhofer Personnel Certification Authority may in well-founded and justifiable exceptions accept varying evidence. These evidence, documents and decisions of the Fraunhofer Personnel Certification Authority have to be documented.

A 2.2.2 Additional education, entitlement and practical experience

A »Certified Quantum Computing Professional Basic Level« does not have to prove any additional education, entitlement, or practical experiences.

A 2.2.3 Personal requirements

None.

A 2.3 Required competences (learning goals)

Basis for the examination to become »Certified Quantum Computing Professional Basic Level« are the following competences (learning goals):

Topic	Competences (Learning Goals)	know	apply	evaluate
Introduction to Quantum Mechanics and Quantum Computing				
Introduction	Identifying and contrasting crucial differences between classical bits and quantum bits (Qubits)	X		
	Designating different application areas for quantum computing	X		
	Naming and explaining DiVincenzos criteria for universal quantum computers	X		
	Designating current challenges in hardware and software development for quantum computing	X		
	Naming various aspects of quality assurance for quantum computing	X		
Fundamentals of Quantum Mechanics + Discussion	Describing the relationship between the quantum states of an atom and the states of a qubit	X		
	Transferring the axioms of quantum mechanics to quantum computing	X		
	Designating basic aspects of entanglement	X		
Mathematical Foundations of Quantum Mechanics + Interactive Exercise	Explaining what a Hilbert space is	X		
	Describing key differences between classical and quantum states	X		
	Using the Bra-Ket formalism/Dirac notation to mathematically formalize single qubit states	X		
	Explaining superposition of quantum states	X		
	Describing how quantum states are manipulated and how this can be described mathematically	X		
	Geometrically representing and interpreting qubit states and qubit transformations on the Bloch sphere	X		
	Explaining measurements of quantum states and resulting challenges	X		

Topic	Competences (Learning Goals)	know	apply	evaluate
Linear Algebra for QC + Interactive Excercises + Virtual Lab	Handling (complex-valued) matrices and vectors and belonging operations such as summation, multiplication and computing the adjoint	X		
	Classifying complex-valued matrices as unitary or Hermitian	X		
	Using the Bra-Ket/Dirac notation to represent adjoint operations on matrix-vector products for computing probabilities and expectation values	X		
	Explaining and computing eigenvalues and eigenvectors	X		
	Describing composite quantum systems via the tensor product and Kronecker product	X		
	Using the separability criterion to distinguish between entangled and non-entangled pure quantum states	X		
Introduction to Quantum Circuit Model and Quantum Toolkits				
Creating and understanding simple quantum circuits.	Describing important quantum gates and explaining their basic principles	X		
	Explaining the effects of important gates on a Bloch sphere	X		
	Defining and applying the bra-ket notation		X	
	Designating and explaining the mathematical definition of entanglement	X		
	Explaining the meaning of entanglement for quantum advantage		X	
	Describing the conditions for universal quantum computers		X	
Understanding and ability to explain limitations of NISQ devices in terms of quantum circuits	Naming limitations and identifying the potential of quantum computing	X		
	Naming differences between quantum computing technologies	X		
	Describing the motivation for hybrid algorithms	X		

Topic	Competences (Learning Goals)	know	apply	evaluate
Fundamentals of Quantum Programming & Software Engineering				
Fundamentals of Quantum Programming + Interactive Exercise + Virtual Lab	Simulating measurement results and the state vector using built-in simulator backends (e.g. from Qiskit)	X		
	Transpiling a quantum circuit to a target backend with different optimizations	X		
	Explaining crucial aspects of quantum circuit transpilation	X		
	Sending a job to a publicly available Quantum Computing backend (e.g., IBM) and retrieving the belonging counts	X		
	Writing functions for automatically generating simple quantum circuits based on certain input parameters	X		
Basics of Quantum Algorithms	Explaining the historic development of important quantum algorithms until Shor's algorithm	X		
	Identifying different quantum algorithms classes and describing the differences between them	X		
	Identifying suited quantum algorithms for different application areas	X		
	Naming current challenges in the algorithm design and implementation	X		
Quantum Fourier Transform + Virtual Lab + Practical Applications	Graphically interpretating of QFT	X		
	Naming important application areas of the classical fourier transform	X		
	Explaining the QFT in a simplified but intuitive manner	X		
	Explaining the mathematics behind QFT	X		
	Implementing a simple QFT example within a graphical web interface (e.g., the IBM Quantum Experience Web Interface)	X		
	Identifying the quantum gates needed to implement QFT		X	

Topic	Competences (Learning Goals)	know	apply	evaluate
	Implementing a general implementation of QFT in a quantum programming framework (e.g. Qiskit)		X	
	Naming different application areas of QFT	X		
Basic Quantum Algorithms				
Quantum Phase Estimation + Virtual Lab	Defining QPE	X		
	Naming examples of QPE applications	X		
	Naming the subroutines of QPE	X		
	Describing what affects the precision of QPE	X		
	Implementing and running QPE routines in a quantum programming framework (e.g. Qiskit)		X	
Shor Algorithm + Virtual Lab	Explaining the popularity and importance of Shor's algorithm	X		
	Operating with modular arithmetic operations	X		
	Describing the classical and quantum parts of Shor's algorithm	X		
	Implementing Shor's algorithm with predefined functions from a quantum programming framework		X	
	Analyzing the implementation with respect to important parameters such as gate count, qubit count, circuit depth		X	
	Sketching future applications of Shor's algorithm		X	
Grover's Algorithm + Virtual Labs + Practical applications	Explaining the initial problem statement for Grover's algorithm as well as further applications in cryptography and optimization	X		
	Explaining the query complexity of Grover's algorithm and compare it to the complexity of classical linear/sequential search	X		
	Differentiating between query complexity and oracle generation complexity	X		

Topic	Competences (Learning Goals)	know	apply	evaluate
	Explaining the effects of each step in the algorithm (superposition, oracle, diffusion operator, iterations, readout)	X		
	Sketching a simplified quantum circuit for Grover's algorithm	X		
	Picturing the geometrical interpretation for Grover's algorithm		X	
Quantum Amplitude Amplification, Error Corrections and Mitigation + Practical exercises in Virtual Lab				
Quantum Amplitude Amplification (QAA)	Explaining the Idea of Quantum Amplitude Amplification (QAA)	X		
	Naming an example of QAA applications	X		
	Naming the required components of the canonical QAA algorithm	X		
	Naming the idea of the oracle in the context of QAA	X		
	Naming the QAA- or Grover-operator	X		
	Describing the intuition behind the QAA algorithm	X		
	Explaining the influence of the number of amplifications	X		
	Naming the potential benefit of QAA vs. a classical algorithm	X		
	Implementing and running QAA in a quantum computing framework (e.g., Qiskit)		X	
Quantum Error Correction (QEC) and Quantum Error Mitigation (QEM)	Stating the purpose of QEC	x		
	Naming the tree main steps of an error correction code	X		
	Sketching how QEC changes the probability of error	X		
	Explaining the idea of concatenation in the context of QEC	x		
	Explaining how concatenation changes the probability of error	x		
	Explaining the meaning of fault tolerance	x		
	Stating the quantum threshold theorem	x		
	Sketching the Shor Code	x		

Topic	**Competences (Learning Goals)**	**know**	**apply**	**evaluate**
	Describing *discretization* and *digitization* of errors	X		
	Explaining the idea of CSS codes and providing an example	x		
	Explain the idea of stabilizer codes and providing an example	x		
	Implementing and running the 3-qubit bit flip, 3-qubit phase flip and Shor codes in a quantum computing framework (e.g., Qiskit)		X	
	Explaining the key difference between QEC and QEM	x		
	Naming and describing examples of QEM methods	x		

ANNEX B: » CERTIFIED QUANTUM COMPUTING PROFESSIONAL SPECIALIZED IN QUANTUM MACHINE LEARNING«

B 1 Reference to other norms and documents

- EN ISO 17024
- Certification Handbook "Data Science" of the Fraunhofer Personnel Certification Authority.

Note:
The certification profile "Certified Quantum Computing Professional specialized in Quantum Machine Learning" is equivalent to the certificate "Data Scientist specialized in Quantum Machine Learning" of the certification program "Data Science" of the Fraunhofer Personnel Certification Body. The learning objectives and examination content are the same for both certification profiles. If a person obtains one of the two certificates, this certificate is therefore automatically recognised for the respective other certification program.

B 2 Profile of qualification

B 2.1 Determination

The qualification profile of a »Certified Quantum Computing Professional specialized in Quantum Machine Learning« results from the characteristics and description of his or her field of work.

A »Certified Quantum Computing Professional specialized in Quantum Machine Learning«:

- programs an application example on the topic of quantum optimization with the help of quantum toolkits in the Virtual Lab
- is able to understand the approach of variational quantum algorithms and to create quantum clustering algorithms, such as quantum k-Means, with the help of a quantum toolkit and to apply them in practical exercises
- knows quantum principal component analysis and quantum support vector machine methods and uses them in use cases
- programs quantum neural networks using quantum toolkits for simple use cases and identifies potential applications and benefits

B 2.2 Entrance requirements

B 2.2.1 Previous education

A certified »Certified Quantum Computing Professional specialized in Quantum Machine Learning« must have:

A successfully completed study at

- a German scientific university,
- a German state or state-recognized university of applied sciences, or
- a foreign university recognized as equivalent by the competent authority of the state

or

- at least one year of work in the field of Software Engineering, Data Science, Quantum Computing Science or Technology Scout.

and

- basic knowledge of machine learning and basic knowledge of quantum computing

Note:
In unusual cases the applicant has the possibility to prove missing entrance requirements within one year after taking the examination.

After examination of the submitted documents, the Fraunhofer Personnel Certification Authority will decide on the requirements. If entry requirements are not fulfilled, the Fraunhofer Personnel Certification Authority will directly communicate the decision to the applicant.

In principle, the Fraunhofer Personnel Certification Authority may in well-founded and justifiable exceptions accept varying evidence. These evidence, documents and decisions of the Fraunhofer Personnel Certification Authority have to be documented.

B 2.2.2 Additional education, entitlement and practical experience

A »Certified Quantum Computing Professional specialized in Machine Learning« does not have to prove any additional education, entitlement, or practical experiences.

B 2.2.3 Personal requirements

None.

B 2.3 Required competences (learning goals)

The Certified Quantum Computing Professional specialized in Quantum Machine Learning exam is based on the knowledge areas and skills listed below.

Topic	Competences (Learning Objectives)	know	apply	evaluate
Machine Learning/Data Science and Basics				
Machine Learning/Data Science	Explaining what data is	X		
	Explaining methods for data preprocessing (integration, reduction, cleaning, transformation, enrichment)	X		
	Explaining the concept of feature spaces	X		

Topic	Competences (Learning Objectives)	know	apply	evaluate
	Implementing a data transformation method and a suitable feature representation		X	
	Explaining what a learning problem/algorithm is	X		
	Explaining the difference between supervised and unsupervised learning	X		
	Explaining the three different learning tasks classification, regression and clustering	X		
	Implementing an algorithm for solving the clustering learning task		X	
	Explaining the validation and evaluation of a model	X		
	Explaining different statistical evaluation metrics for learning tasks (accuracy, recall, RMSE, MAE, Silhouette value)	X		
	Explaining the concepts of theoretical complexity in machine learning models	X		
	Evaluating results with reasonable metrics and investigate validity of solution	X		
Quantum Computing	Explaining the difference between a bit and a qubit (superposition)	X		
	Explaining that multiple qubits can be described as a quantum state, which can represent a probability distribution	X		
	Explaining that quantum states can be manipulated/transformed with quantum gates	X		
	Stating the unitary matrix form of the most important quantum gates (X, Y, Z, H, CX, etc.)	X		
	Describing the bell states and why there are interesting	X		
	Explaining quantum circuit diagrams	X		
	Implementing a quantum circuit consisting of multiple quantum gates, which corresponds to an implementation of an algorithm		X	

Topic	Competences (Learning Objectives)	know	apply	evaluate
	Explaining that there exist quantum algorithms which are (complexity wise) proven to be faster than classical counterparts	X		
	Recollecting the QFT algorithm for computing the discrete Fourier transform and the corresponding complexity advantage	X		
	Explaining the paradigm of adiabatic quantum computing	X		
	Explaining the applicability and potential advantages of adiabatic quantum computing for solving quadratic unconstrained binary optimizations (QUBOs)	X		
	Implementing a small QUBO (clustering) example and find the solution		X	
Introduction to Quantum Clustering Algorithms				
Classical Clustering Algorithms	Explaining the difference between hard and soft clustering	X		
	Expressing the fundamental principle of classical k-Means in one sentence	X		
	Naming clustering models	X		
	Stating disadvantages of k-Means compared to other clustering methods	X		
	Explaining the elbow method for choosing the optimal number of clusters in the k-Means algorithm	X		
	Explaining what is the k-Means algorithm sensitive to	X		
Grover Algorithm	Sketching the simplified circuit of the Grover algorithm	X		
	Naming the most important steps of Grover's algorithm	X		
	Comparing the query complexity of Grover's algorithm and sequential search algorithm	X		
	Sketching the intuition of Grover's algorithm geometrically	X		
Quantum k-Means	Explaining the fundamental principle of quantum k-Means in one sentence	X		

Topic	Competences (Learning Objectives)	know	apply	evaluate
Algorithm	Describing the weakness of quantum k-Means in the current NISQ-era	X		
	Recalling the steps of quantum k-Means algorithm	X		
	Describing the core principle of SWAP-test	X		
	Expressing the role of the SWAP-test in the quantum k-Means algorithm	X		
	Expressing the role of Grover's algorithm in the quantum k-Mean algorithm	X		
Parameterized Quantum Circuits (PQCs)				
Parametrized quantum circuits	Showing how gates act as rotations on quantum states		X	
	Matching a quantum state to the according visualization on a bloch-sphere	X		
	Producing and explaining a parameterized rotation gate		X	
	Illustrating how to use multiple gates (e.g. in layers) to build more complex circuits	X		
	Reciting that quantum machine learning (QML) is about utilizing the complex space, accessible by quantum computers, not only about speed-ups	X		
Data encoding	Paraphrasing that data can be mapped to quantum states	X		
	Listing Base Encoding, Amplitude Encoding, Angle Encoding	X		
	Explaining the concept of Angle Encoding and sketching a simple circuit using Angle Encoding	X		
	Reciting that data characteristics can be encoded in PQCs (e.g. symmetries)	X		
	Outlining how expressivity can be increased using repeated input encoding (e.g. data reuploading)	X		
Analyzing parametrized quantum circuits	Identifying and modifying redundant gate-combinations	X		
	Reciting or paraphrasing that the quantum Fischer information (QFI) can be used to find redundancies automatically	X		

Topic	Competences (Learning Objectives)	know	apply	evaluate
Introduction to Quantum Kernels				
Describing the basic concepts of the classical kernel method and support vector machines	Describing what the classical kernel methods are used for	X		
	Explaining the classical kernel trick	X		
	Describing the advantages of support vector machines for classical machine learning	X		
Implementing a kernel matrix using quantum feature maps by using a relevant tool (e.g. Qiskit) and solve a classification problem with it	Describing the currently available quantum feature maps	X		
	Implementing a circuit of currently available quantum feature maps		X	
	Implementing a custom parametrized circuit feature map		X	
	Calculating the quantum kernel matrix of a given training and test dataset		X	
	Describing the structure of the quantum kernel matrix	X		
	Solving a simple classification task using the quantum kernel matrices in a classical support vector machine		X	
Training quantum kernels with gradient based optimization	Describing the idea of kernel alignment	X		
	Implementing a kernel-target alignment to see how well the quantum kernel reproduces the similarities of the data		X	
	Constructing a gradient descent optimization for improving the kernel target alignment		X	
Comparing the quantum circuit evaluations required in a kernel based versus variational training	Explaining the idea behind quantum kernel support vector machine function	X		
	Investigating the number of executions needed for a quantum kernel support vector machine using a relevant function (e. g. PennyLane's function)		X	
	Summarizing the number of executions using a kernel based method and the number of executions needed for a similar example using variational training		X	
Quantum Neural Networks				

Topic	Competences (Learning Objectives)	know	apply	evaluate
Neural Networks Basics	Recalling and defining what neural networks are and their significance in machine learning and artificial intelligence	X		
	Recognizing and describing the basic components of neural networks, such as neurons, layers, and activation functions	X		
	Summarizing the training process in neural networks, including the fundamental concepts like backpropagation and gradient descent	X		
Practical Session on Neural Networks	Recalling and Demonstrating the process of constructing a basic feedforward neural network using a deep learning framework (e.g., TensorFlow or PyTorch)	X		
	Describing how training techniques, such as backpropagation and gradient descent, can optimize their neural network models effectively	X		
	Applying the comprehension to choose appropriate evaluation metrics and describing the performance of their neural network models on a given dataset		x	
Introduction to Quantum Neural Networks	Recalling and providing a clear definition of Quantum Neural Networks and understanding how they differ from classical neural networks	X		
	Recognizing practical applications and domains where Quantum Neural Networks can offer advantages over classical approaches	X		
	Summarizing the potential quantum advantage that Quantum Neural Networks (QNNs) can bring to various problem-solving scenarios. Participants can also explain, why backpropagation is not possible on the quantum hardware	X		

Topic	Competences (Learning Objectives)	know	apply	evaluate
Practical Session on Simple Quantum Neural Networks (QNNs)	Recalling and demonstrating the process of creating a simple Quantum Neural Network (QNN) model using available quantum programming tools or frameworks	X		
	Explaining the concept and significance of quantum gates in quantum computing and their potential applications within Quantum Neural Networks	X		
	Demonstrating the behavior of their Quantum Neural Network model on a quantum simulator and describing the results effectively	X	x	

Note:
The competences (learning objectives) described here correspond to the learning objectives of the "Data Scientist specialized in Quantum Machine Learning" of the "Data Science" certification profile.

ANNEX C: »CERTIFIED QUANTUM COMPUTING PROFESSIONAL ADVANCED LEVEL«

This level is currently under development.

ANNEX D: »CERTIFIED QUANTUM COMPUTING PROFESSIONAL SENIOR LEVEL«

This level is currently under development.