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Dept. 3302 • 1000 E. University Avenue
Laramie, WY 82071
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This form is to be used with all new degree/certificate proposals as outlined in the process on the Academic Affairs website at https://www.uwyo.edu/acadaffairs/degrees. Departments shall use this form to provide documentation of collaboration and support for any courses and/or resources that will be contributing to the new degree/certificate that are not within the home department.

Date: October 20, 2023

Name of Proposal: MS in QISE

Department: EECS, A&P, SoC

College: CEPS

The above-named degree/certificate proposal has been reviewed by the following departments/colleges and all appropriate courses and resources have been discussed prior to proposal submission:

Bryan Shader, EECS	
Department Head	Signature
Jinke Tang, Physics & Astronomy	
Department Head	Signature
Gabrielle Allen, School of Computing	
[redacted] Director	Signature
Cam Wright, CEPS	
Dean	Signature

Submitted on: 10/20/2023 (date)

By: Bryan Shader

Feasibility Study for Quantum Information Science & Engineering (QISE) Master's degree program

Executive Summary

Degree Title: Quantum Information Science & Engineering (QISE) Master's degree program
Level of Degree or Certificate: Masters
Delivery Mode(s): Hybrid
Estimated Startup Cost of Degree: None; existing resources will be utilized to start the program
Anticipated Launch Date: Fall 2024
Description:
The Quantum Information Science & Engineering (QISE) Master's degree program will be a postgraduate program that focuses on the theoretical and practical aspects of quantum computing and quantum information processing. It is designed to equip students with a deep understanding of the fundamental principles of quantum mechanics and their applications in information processing, cryptography, communication, and computation.

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1 A. Overview and Description of Degree

The Master of Science in QISE program consists of two years of coursework, thesis research, research projects, and practical applications of QISE. The program will offer both Plan A and Plan B degrees, comprising 30 required credits. The Plan A degree program will comprise 24 required coursework credits, two seminar credits, and four thesis research credits (XX5960). Students must complete an accepted research thesis for the Plan A degree program approved by the student's graduate committee. The Plan B degree program, a non-thesis option, will comprise 28 required coursework credits and two seminar credits. A student pursuing the Plan B degree program as part of the 28 required coursework credits can do an independent study project at the graduate level of a maximum of three credits. It's important to note that the specific structure and curriculum of this QISE Master's program may vary among students based on discipline-specific QISE and broader QISE advancements.

Coursework includes

- **Core Courses (12 credits):** The program begins with foundational courses that cover essential topics in QISE, such as Quantum-based courses in Mechanics, Computing, Information Theory, Algorithms and Applications, and Hardware and Technology.
- **Elective Courses (12 credits for Plan A and 16 credits for Plan B):** Students can choose from various elective courses based on their interests and career goals. These courses may include specialized topics like discipline-specific application, Depth Sequencing, quantum error correction, quantum machine learning, quantum simulations, or quantum cryptography.
- **Research Projects for Plan B Students.** Throughout the Plan B degree program, students are involved in research projects supervised by faculty members or industry experts. These projects provide hands-on experience in designing and implementing AI systems, conducting experiments, analyzing data, and addressing real-world AI challenges. Research projects often culminate in a final research paper.
- **Seminar Courses (2 credits):** Regular seminars and workshops will be organized to expose students to the latest research advancements, emerging trends, and challenges in QISE. Experts from academia, industry, and government will deliver talks and engage in discussions, allowing students to broaden their perspectives and stay updated with the evolving QISE landscape. The SoC, EECS, and Physics will host, co-host, or support tech talks, colloquia, or speaker series with discipline specific and broad QISE foci.

B. Program Purpose

The purpose of a Quantum Information Science & Engineering academic program is to provide students with a comprehensive education in the field of quantum information science, with a focus on quantum computing, quantum communication, and quantum information theory. Overall, the purpose of a Quantum Information Science & Engineering academic program is to foster the growth of knowledge, skills, and innovation in the field, preparing students to make significant contributions to the development and application of quantum technologies in the future. The program aims to achieve the following purposes:

1. Education and Training: The program aims to educate and train students in QISE theoretical foundations, practical applications, and experimental aspects. Students gain a

deep understanding of quantum mechanics, quantum computing algorithms, quantum information theory, and quantum communication protocols.
2. Knowledge Development: The program seeks to advance knowledge in QISE by conducting cutting-edge research and scholarly activities. Faculty members and students contribute to developing new theories, algorithms, technologies, and applications within QISE.
3. Skill Development: The program aims to develop students' skills in critical thinking, problem-solving, mathematical modeling, and computational analysis. Students learn to apply these skills to solve complex problems in QISE, such as developing efficient quantum algorithms or designing quantum communication protocols.
4. Innovation and Advancement: By fostering a culture of innovation, the program aims to contribute to advancing quantum technologies. It encourages students and researchers to explore new ideas, propose novel approaches, and push the boundaries of what is currently possible in QISE.
5. Interdisciplinary Collaboration: QISE is an interdisciplinary field that draws upon concepts from physics, mathematics, electrical engineering, and computer science. The program promotes collaboration and interaction between students and researchers from diverse backgrounds, fostering a multidisciplinary approach to problem-solving and knowledge creation.
6. Industry Relevance: The program recognizes the growing importance of quantum technologies in various industries. It aims to equip students with the skills and knowledge required to contribute to developing and applying QISE in sectors such as computing, cryptography, telecommunications, materials science, finances, and pharmaceuticals.
7. Ethical Considerations: The program emphasizes the importance of ethical considerations in developing and using quantum technologies. Students are encouraged to consider the societal impact, privacy, security, and ethical implications of their research and applications.
8. Career Preparation: The program prepares students for careers in academia, research institutions, industry, and government agencies. Graduates are equipped with the necessary knowledge, skills, and research experience to pursue advanced research, development, and leadership roles in the rapidly evolving field of QISE.

C. Program Strategic Overlay

The MS in QISE supports UW's Strategic Plan by

- Enhancing student success and preparing students for life and adaptation to a new quantum world.
- Providing a highly sought-after degree in a fast-growing workforce sector that will help grow both domestic and international enrollments.
- Raise UW's Scholarly capacity and profile nationally and internationally in QISE and its applications; and strengthen UW's relationships with external partners and stakeholders in the quantum technological and quantum computational sectors.

- Serve the State of Wyoming by providing Quantum Technology-savvy graduates for our businesses, agencies, and educational institutes.
- Grow educational opportunities for Wyoming around the transformational area of Quantum Technology.

The MS in QISE is a critical component of the EECS department's goal of developing a research program that is nationally and internationally competitive and relevant to Wyoming by focusing on a few specific areas that have significant anticipated funding growth and economically disruptive technologies. Those areas are (a) modern power grid data analysis and modeling, (b) Quantum machine learning, (c) Quantum security and Internet, and (d) Quantum financing.

The MS in QISE is also central to the aims of the School of Computing and Physics department to provide University of Wyoming students, faculty and staff, and Wyoming businesses and citizens with the quantum computational tools, skills, and approaches to drive transformation and innovation in the state.

2. Learning Outcomes

These learning outcomes aim to prepare graduates for various QISE-related career paths, including research, development, implementation, and strategic decision-making in organizations leveraging QISE technologies. The specific learning outcomes of the program may be altered based on the student's goals, faculty expertise, and the evolving needs of the QISE industry.

- **Understanding the Fundamentals of Quantum Mechanics:** Graduates will have a comprehensive understanding of the fundamental principles of quantum mechanics, including wave-particle duality, superposition, entanglement, and quantum measurement.
- **Proficiency in Quantum Computing:** Students will acquire a strong foundation in quantum computing, including knowledge of qubits, quantum gates, quantum circuits, and quantum algorithms. They will be able to design and analyze quantum algorithms for various applications.
- **Expertise in Quantum Information Theory:** Graduates will possess a deep understanding of quantum information theory, including concepts such as quantum entropy, quantum entanglement, quantum teleportation, quantum cryptography, and quantum communication protocols.
- **Proficiency in Quantum Hardware and Technology:** Students will learn about different types of quantum hardware platforms, their underlying technologies, and their associated challenges. They will be familiar with the advancements and limitations of current quantum technologies.
- **Ability to Conduct Research:** Graduates will have the skills to conduct independent research in quantum information science & engineering. They will be able to formulate research questions, design experiments or simulations, analyze data, and draw meaningful conclusions.
- **Communication and Presentation Skills:** Graduates will be adept at effectively communicating complex concepts and research findings related to quantum information

science & engineering. They will be able to present their work to both technical and non-technical audiences, including academic conferences, industry settings, or public outreach events.

- **Ethical and Responsible Conduct:** Students will gain an understanding of the ethical considerations associated with quantum technologies, including issues related to privacy, security, and the responsible use of quantum computing power. They will be able to critically evaluate the ethical implications of their work and make informed decisions.
- **Collaboration and Teamwork:** Graduates will develop strong collaborative skills and the ability to work effectively in interdisciplinary teams. They will be able to contribute to collaborative research projects, communicate ideas, and engage in productive scientific discussions.
- **Lifelong Learning:** Students will develop a continuous learning mindset and stay updated with the latest advancements in quantum information science & engineering. They will be prepared to adapt to the rapidly evolving field and contribute to its future growth and development.

3. Curriculum Map and Program Structure

This curriculum map provides a general overview of courses to include in the QISE Master's program. The sequencing and specific courses may differ based on specialization tracks or allow for content-specific course selection/substitution flexibility. Additionally, practical projects, internships, or industry collaborations may be integrated into courses to provide hands-on experience and real-world applications of QISE concepts. UW currently offers several courses this program would require, but this collaborative feature would distinguish students and opportunities in this program.

Year 1

Fall

- Quantum Mechanics for Non-Physicists* – Being developed for a Minor in QISE, Physics Dept
- EE 5885 - Introduction to Quantum Computing, Offered in Fall 2021, Fall 2022, and Spring 2024.
- Elective*

Spring

- Quantum Information Theory*
- Quantum Algorithms and Applications*
- Elective – EE5885 - Quantum Optimization and Machine Learning* – To be offered in Fall 2024

Year 2

Fall

- Quantum Hardware and Technology*
- Research Methods*
- Elective*

Spring

- EE 5960 Thesis Research: Credits: 4; Designed for students involved in research for their thesis project. It is also used for students whose coursework is complete and who are writing their thesis.

*** - New Courses to be developed or under development**

4. Course Descriptions

- Quantum Mechanics for Non-Physicists*: This course provides a comprehensive understanding of the mathematical formalism and fundamental principles of quantum mechanics. It explores wave-particle duality, superposition, entanglement, and quantum measurement.
- EE5855 - Introduction to Quantum Computing: This course focuses on the principles and algorithms of quantum computing. It covers qubits, quantum gates, quantum circuits, quantum algorithms (e.g., Shor's algorithm, Grover's algorithm), quantum error correction, and quantum simulation.
- Quantum Information Theory*: This course introduces students to the mathematical foundations of quantum information theory. It covers topics such as quantum entropy, quantum entanglement, quantum teleportation, quantum cryptography, and quantum communication protocols.
- Quantum Algorithms and Applications*: This course delves deeper into the practical applications of quantum computing. It explores various quantum algorithms for database searching, optimization, machine learning, and chemistry simulations.
- Quantum Hardware and Technology*: This course provides an overview of the different types of quantum hardware platforms, such as superconducting circuits, trapped ions, topological qubits, and photonic systems. It covers the challenges and advancements in building and scaling quantum computers.
- EE5885 - Quantum Optimization and Machine Learning*: This course delivers topics on variational quantum circuits for optimization and quantum machine learning.

5. Assessment Plan

The MS in QISE degree aims to prepare graduates for various roles in Quantum Computing and technology research, development, implementation, and strategic decision-making. The program focuses on eight key learning outcomes: foundational knowledge, technical skills, research capabilities, ethical considerations, communication, domain-specific applications, and a commitment to lifelong learning. Below, we detail assessment strategies for each of these learning outcomes.

- **Understanding of Quantum Mechanics Fundamentals:**
  Assessment Methods: Written examinations, assignments, and projects.
  Evaluation Criteria: Demonstration of knowledge in qubits, superposition, and entanglement.
- **Proficiency in Quantum Computing Techniques and Tools:**
  Assessment Methods: Practical coding assessments, project submissions, and hack-a-thons.
  Evaluation Criteria: Proficiency in Python programming language, usage of Quantum computing frameworks such as IBM Qiskit, Google CIRQ, etc.

- **Ability to Design and Implement Quantum Algorithms:**
  Assessment Methods: Project-based assessments, case studies, and presentations.
  Evaluation Criteria: Capability to analyze real-world cryptography problems, select appropriate Quantum algorithms, and implement solutions for performance and accuracy.
- **Research and Critical Thinking Skills:**
  Assessment Methods: Research proposals, literature reviews, and experimental design projects.
  Evaluation Criteria: Demonstrated ability to identify research problems, review relevant literature, design experiments, analyze data, and draw evidence-based conclusions.
- **Ethical and Responsible Practices:**
  Assessment Methods: Ethical case studies, project evaluations, and reflective essays.
  Evaluation Criteria: Understanding and application of ethical considerations in Quantum Computing, ability to identify privacy concerns and social implications, and making informed decisions for responsible Quantum Computing practices.
- **Communication and Collaboration:**
  Assessment Methods: Presentations, reports, and group projects.
  Evaluation Criteria: Effectiveness in communicating Quantum concepts to technical and non-technical stakeholders and ability to collaborate with professionals from diverse backgrounds.
- **Discipline-Specific Applications:**
  Assessment Methods: Domain-specific projects, case studies, and industry collaborations.
  Evaluation Criteria: Ability to understand domain-specific challenges, apply Quantum Computing techniques appropriately, and develop solutions tailored to specific disciplines such as finance, cryptography, chemistry, and medicine.
- **Lifelong Learning:**
  Assessment Methods: Continuous professional development plans, self-assessment, and reflective journals.
  Evaluation Criteria: Demonstrated commitment to staying updated with Quantum computing and technology advancements, adaptability to new technologies and techniques, and a proactive approach to professional growth beyond the program.

Successful completion of the program requires satisfactory performance across all learning outcomes, demonstrating a well-rounded preparation for diverse QISE-related career paths.
Regular feedback will be provided to students through assessments, and faculty will use this feedback to improve the program continuously. Additionally, periodic program reviews will be conducted to ensure alignment with industry needs and the evolving landscape of QISE.

6. Degree Program Evaluation

We will employ a combination of methods to evaluate the program's formative stages. We will create a comprehensive data set to help evaluate the degree program at the end of five years. The evaluation will value well-rounded assessment from different perspectives, hopefully leading to informed program enhancement and development decisions.

Program evaluation will be informed by the following.

- **Exit Surveys of Graduates:**
  This will include questions about the quality of instruction, curriculum relevance, resources provided, and their preparedness for real-world applications.
- **Employer Surveys:**

Questions will focus on the graduates' performance, ability to apply knowledge in practical scenarios, and the program's relevance to industry needs.

- **Annual Feedback through Focus Groups of our students**
  These discussions will identify areas for enhancement, address challenges, and gauge the ongoing effectiveness of the curriculum.
- **Alumni Tracking:**
  An alumni network will be established to track the career paths and achievements of graduates over the years to provide insights into the program's long-term impact.
- **Assessment of Learning Outcomes:**
  This data will gauge the program's academic rigor and effectiveness.
- **Industry Partnerships and Advisory Boards:**
  Regular feedback from these external stakeholders will guide adjustments to the program to keep it aligned with industry trends.
- **Review of Research Output:**
  The quality and impact of research output, publications, and contributions will be used to measure the program's academic strength.

7. New Resources Required

The need for new resources for this program's initialization is minimal. Sustainability and growth costs will need to be determined during program review periods. Self-sustaining funding will be encouraged. Strategic funding for other QISE initiatives that work with this program may be addressed in different venues.

- Faculty and instructional staffing
  EECS, Physics, and Math programs have faculty already teaching the core and suggested elective courses. **Currently, a total of ten faculty members exist across the EECS[3], Physics[6], and Mathematics[1] departments who can offer courses in QISE. EECS has a new faculty starting in Fall 2024 in the area of Quantum Security**. The SoC is planning to hire new faculty to help develop/teach other suggested elective course offerings.
- Program administration and staff support
  The SoC director and EECS department head have been working closely on related initiatives and this program development and will continue to do so to ensure program success. The SoC has a program coordinator and adequate staff support to ensure the appropriate scheduling of courses.
- Technology
  UW is currently one of the Arizona State University (ASU) Quantum Hub members through which access to the IBM Quantum Computers is available for faculty and students for education and research. Future technological needs will be determined along with content developments. Program administration will encourage using research funding sources to maintain program technology that supports success.

Library and digital resources

See the above technology considerations that will be applied equally to needed resources here.

Marketing

The SoC has a marketing coordinator to advocate for adequate resource use to promote, recruit, and maintain program enrollment. The SoC and EECS leads will work with Institutional Marketing to develop an appropriate and affordable marketing plan for all external resource needs.

Support

Total projected additional revenues due to added course requirements, assuming a minimum of 10 students per year, is calculated below. We are not including indirect costs due to the wide variability in graduate student needs.

- Per resident student in the program at $311/graduate credit X 30 credits = $9,330
- Per non-resident students in the program at $930/graduate credit * 30 credits = $27,900
- Estimate: 5 resident students and 5 non-residents each year = $186,150 additional tuition

8. Substantive Change Determination

Higher Learning Commission (HLC), UW's regional accrediting agency, must approve all substantive changes to UW's offering. HLC considers substantive change as the addition of a program (degree or certificate/credential level) not previously included in the institution's accreditation, usually judged to be a program that is a significant departure from normal offerings, the addition of a program with 50%+ new coursework required, or the addition or change to an existing program which will be delivered 50%+ through alternative (hybrid, online) delivery. Substantive change may also be defined as a new program that does not meet the above guidelines but which requires a significant amount of financial investment to be made. Please contact the HLC Accreditation Liaison Officer (currently Steve Barrett, steveb@uwyo.edu) to make this determination.

9. Executive Summary of Demand Statistics*

The Office of Online & Continuing Education generated a market analysis from Gray Associates' data (see the attached appendix) in August 2023. Below, we briefly summarize the demand, projected enrollment, equality evaluation, and graduate employability presented in the report.

- This is an emerging and growing field.
- The report concludes that an MS program focusing on QISE will provide students with a new pathway into computing careers and will be attractive to graduates from regional schools and international students.
- Student demand for this program is strong nationally. The University of Colorado in Boulder and the University of New Mexico are the only regional or semi-regional higher education institutions that have entered this arena. This presents an opportunity for the University of Wyoming.

Pro forma budget

	Fiscal Year			
	1	**2**	**3**	**4**
Revenue				
Enrollment in program in given Fiscal Year	10	20	20	20
NEW Resident enrollment (# of new students entering the program each year)	5	5	5	5
NEW Non Resident Enrollment (# of new students entering the program each year)	5	5	5	5
Total Resident credit hours generated	**75**	**150**	**150**	**150**
Total Non Resident credit hours generated	**75**	**150**	**150**	**150**
Per Credit Tuition (with 4% annual growth)				
Resident (Posted Tuition Rate)	$358	$372	$387	$403
Nonresident (Posted Tuition Rate)	$1,074	$1,117	$1,162	$1,208
Prior Year's Non Resident Discount Rate (updated annually by the budget office)	30%	30%	30%	30%
Estimated Actual Non Resident Per Credit Tuition	$752	$782	$813	$846
Total Resident Tuition in NEW Program	$26,850	$55,848	$58,082	$60,405
Total Non Resident Tuition in NEW Program	$56,385	$117,281	$121,972	$126,851
Total Tuition from NEW Enrollment	**$83,235**	**$173,129**	**$180,054**	**$187,256**
Fees				
Mandatory Fee (Per Full Time Student)	$827.96	$827.96	$827.96	$827.96
Mandatory Fee Revenue	$6,900	$13,800	$13,800	$13,800
Total New Revenue Generated	**$90,135**	**$186,929**	**$193,854**	**$201,056**
New Program Expense Assumptions				
Compensation and benefits				
Faculty	**$0**	**$0**	**$0**	**$0**
Other administrative staff				
Graduate Assistants				

Supplies				
Travel				
Marketing	$0	$0	$0	$0
Capital expense	0	0	0	0
Projected Financial Results for New Program	**FY1**	**FY2**	**FY3**	**FY4**
Total Expenses	$0	$0	$0	$0
Total New Revenues Remaining with Program	$90,135	$186,929	$193,854	$201,056
New Program's Total Surplus or Deficit	**$90,135**	**$186,929**	**$193,854**	**$201,056**
Operating margin (surplus or deficit / revenues)	**1.00**	**1.00**	**1.00**	**1.00**

TO	School of Computing, Judy Ann Yates
FROM	Jayne Pearce
DATE	18 September 2023
SUBJECT	Master of Science, Quantum Computing

Request from School of Computing:

*Executive Summary of Demand Statistics**

Describe and outline:

1. *Market area and primary target markets.*
2. *Educational market and student demand statistics, including peer comparisons of the size of enrollment, completions, and size trajectory (growth, decline) of comparator programs.*
3. *Employment trends and projections given core competencies of the degree or certificate.*
4. *Graduate salary trends and other post-completion trends.*

**available from Gray Associates data subscription*

Caveats:

- Gray Associates database uses approximately twelve different data sources to determine results. Slightly lagging data from the United States Department of Education, United States Department of Labor, and United States Federal Statistical System as well as current data from Google, job/employment market (Indeed, Monster, public state job postings, etc…), and various web pages and proprietary partnership resources to determine higher education institutional marketing costs, international student interest, completions, program interest, etc… There are approximately 14,000 different CIP (Classification of Instructional Programs) Codes and Gray will determine results for each code, within different markets (National, Wyoming…), and at the various award levels (undergraduate certificate, bachelor, post-baccalaureate certificate, master, post-master certificate, and doctoral). To my knowledge it is still a one of a kind (sole source) product that Online & Continuing Education subscribes to and if you would like access and training just let me know. All data in this report is from Gray Associates unless otherwise noted.
- Higher education institutions do make mistakes when reporting to the United States Department of Education just as people falsely alter their income, occupation, and other data collection attributes when answering the American Community Survey or US Census.
- Programs reported as online adhere to the below definition. According to the United States Department of Education, IPEDS (Integrated Postsecondary Education System):
    - Distance education (DE) is education that uses one or more types of technology to deliver instruction to students who are separated from the instructor and to support regular and substantive interaction between the students and the instructor synchronously or asynchronously. The following types of technology may be used for distance instruction: a) Internet; b) Satellite or wireless communication; and c) Audio and video conferencing. A Distance Education program for which all the required coursework for program completion can be completed entirely via Distance Education courses. https://nces.ed.gov/ipeds/use-the-data/distance-education-in-ipeds

Currently the Office of Online & Continuing Education is advocating for:

- Changes to the program approval process. Such as: An Accelerated New Program Proposal-a new program that does not require new resources and 50% (*or some percentage*) of the courses are already offered at the University for academic credit.
- Promotion and increases in Dual Enrollment courses and or programs. Dual enrollment are college courses taught by college instructors; these courses are taught on campus, at statewide locations or through distance learning technology (*web-conferencing-e.g. Zoom*). The University of Wyoming can offer dual enrollment courses only, per state statute.
- Adjusting the current tuition and fee structure and split to advocate for more dollars flowing to departments that offer online programs
- Transitioning degree completion bachelor programs to complete bachelor programs
- Hiring professional staff members to guide and increase instructional design, marketing, and recruitment of online programs.

- ***Best Practice to attract the adult learner***
    - 100% asynchronously delivered
    - 7-8 week courses
    - Carousel course rotation (courses offered to meet student demand as they step in and out or attempt to move quickly)
    - Interactive and engaging courses (note: instructional design professionals coming soon)
    - Targeted marketing (Office of Online & Continuing currently developing marketing strategy, currently has one professional marketing staff member and will be hiring a second soon)
    - Specific Program Recruitment-new staff position about to be posted
    - Market tuition rates per program
        - In most cases the adult learner asks themselves: Will this degree allow me to earn more money? Increase my employment opportunities? Get a promotion with my current employer? etc..
        - The adult learner willingly pay more in tuition for convenience (100% asynchronously delivered-anytime anywhere education).

Definitions:

Quantum Computing

A. Quantum computers are computers that consist of quantum bits, or "qubits," that play a similar role to the bits in today's digital computers. The laws of quantum mechanics allow qubits to encode exponentially more information than bits. By manipulating information stored in these qubits, scientists can quickly produce high-quality solutions to difficult problems. This means quantum computing may revolutionize our ability to solve problems that are hard to address with even the largest supercomputers. Scientists have demonstrated these quantum speedups in several applications, including database searches. The race is now on to find others. **https://www.energy.gov/science/doe-explainsquantum-computing**

B. **Quantum computing** is a process that uses the laws of quantum mechanics to solve problems too large or complex for traditional computers. Quantum computers rely on qubits to run and solve multidimensional quantum algorithms. https://builtin.com/hardware/quantum-computing.

National Center for Education Statistics (NCES), Classification of Instructional Programs (CIP) Code Definitions, https://nces.ed.gov/ipeds/cipcode/browse.aspx?y=55

There is not a CIP code definition for ***Quantum Computing***, the below 4 CIP Codes will be used to determine market analysis.

Computer Science 11.0701
A program that focuses on **computer** theory, computing problems and solutions, and the design of **computer** systems and user interfaces from a scientific perspective. Includes instruction in the principles of computational **science**, **computer** development and programming, and applications to a variety of end-use situations.
Computer Engineering 14.0901
A program that generally prepares individuals to apply mathematical and scientific principles to the design, development and operational evaluation of computer hardware and software systems and related equipment and facilities; and the analysis of specific problems of computer application to various tasks.
Physics 40.0801
A general program that focuses on the scientific study of matter and energy, and the formulation and testing of the laws governing the behavior of the matter-energy continuum. Includes instruction in classical and modern physics, electricity and magnetism, thermodynamics, mechanics, wave properties, nuclear processes, relativity and **quantum** theory, quantitative methods, and laboratory methods.
Mathematics 27.0101
A general program that focuses on the analysis of quantities, magnitudes, forms, and their relationships, using symbolic logic and language. Includes instruction in algebra, calculus, functional analysis, geometry, number theory, logic, topology and other mathematical specializations.

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1) Market area and primary target market.

a) Bachelor award level market analysis for this report will focus on completion numbers in computer science 11.0701, computer engineering 14.0901, physics 40.0801, and mathematics 27.0101. This is not a finite arena as Applied Mathematics, Computational Mathematics and other CIP codes could have been included.

b) Wyoming residents:

  i) In 2018 26 Wyoming residents attained a bachelor's degree in a computer related field online from an institution other than UW.

  ii) In 2019 34 Wyoming residents attained a bachelor's degree in a computer related field online from an institution other than UW.

  iii) In 2020 42 Wyoming residents attained a bachelor's degree in a computer related field online from an institution other than UW.

c) Regional bachelor award market (4-year + universities in Colorado, Nebraska, South Dakota, North Dakota, Montana, Idaho, and Utah)

i) In 2021 there were regionally 5,424 undergraduate completions in computer science, computer engineering, physics and mathematics and therefore potential enrollments in a master of Quantum Computing.
ii) Below are 3-years of completions by regional higher education institution undergraduates in computer science, computer engineering, physics and mathematics. Potential enrollment/market for Master of Science in Quantum Computing

Bachelor Completions	2019 Online	2019 Onground	2019 Total	2020 Online	2020 Onground	2020 Total	2021 Online	2021 Onground	2021 Total
11.0701 Computer Science									
Colorado	156	802	958	185	967	1,152	227	1,023	1,250
Nebraska	41	252	293	42	268	310	56	269	325
South Dakota	19	122	141	22	122	144	27	147	174
North Dakota	15	153	168	2	168	170	12	153	165
Montana	0	0	145	1	134	135	0	0	122
Idaho	121	208	329	114	281	395	85	265	350
Utah	16	772	788	135	784	919	459	764	1,223
Regional Total	**368**	**2,309**	**2,822**	**501**	**2,724**	**3,225**	**866**	**2,621**	**3,609**
Utah's Western Governors University	*16*	*0*	*16*	*135*	*0*	*135*	*459*	*0*	*459*
14.0901 Computer Engineering									
Colorado	4	106	110	4	59	63	2	50	52
Nebraska	0	0	43	0	0	40	0	0	43
South Dakota	0	0	15	0	0	15	0	0	8
North Dakota	0	0	25	0	0	33	0	0	35
Montana	0	0	20	0	0	24	0	0	21
Idaho	0	0	19	0	0	29	0	0	44
Utah	0	0	108	0	0	131	0	0	113
Regional Total	**4**	**106**	**340**	**4**	**59**	**335**	**2**	**50**	**316**
40.0801 Physics									
Colorado	0	162	162	0	198	198	0	203	203
Nebraska	0	44	44	0	40	40	0	49	49
South Dakota	0	10	10	0	14	14	0	14	14
North Dakota	0	14	14	0	7	7	0	15	15
Montana	0	22	22	0	23	23	0	28	28
Idaho	0	49	49	0	54	54	0	47	47
Utah	0	100	100	0	88	88	0	108	108
Regional Total	**0**	**401**	**401**	**0**	**424**	**424**	**0**	**464**	**464**
27.0101 Mathematics									

Colorado	0	418	418	0	422	422	0	454	454
Nebraska	6	161	167	6	188	194	14	175	189
South Dakota	0	54	54	0	49	49	0	64	64
North Dakota	1	51	52	4	50	54	7	48	55
Montana	0	74	74	0	68	68	6	48	54
Idaho	0	60	60	0	54	54	5	41	46
Utah	0	168	168	0	161	161	0	173	173
Regional Total	**7**	**986**	**993**	**10**	**992**	**1,002**	**32**	**1,003**	**1,035**

d) National bachelor award market for all programs within the 2-digit CIP Code 11 Computer and Information Sciences and Support Services:

Bachelor Completions	2019 Online	2019 Onground	2019 Total	2020 Online	2020 Onground	2020 Total	2021 Online	2021 Onground	2021 Total
All 2-digit CIP Codes 11 Computer and Information Sciences and Support Services	**14,646**	**78,038**	**92,684**	**15,895**	**85,856**	**101,751**	**18,556**	**91,280**	**109,836**

e) The Office of Online & Continuing Education and the School of Computing could establish a marketing and recruitment plan in a 'geo' specific areas. We would be happy to discuss

f) Tuition discussion:

   (1) With the assistance of the School of Computing a market tuition analysis could be performed. Best practice for online tuition setting is to evaluate the market and determine a flat or the same rate for residents and non-residents. This program may also require specific technology or material costs that may need to accompany the required budget of a new program proposal.

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2) **Educational market and student demand statistics, including peer comparisons of the size of enrollment, completions, and size trajectory (growth, decline) of comparator programs.**

a) Below is a list of higher education institutions that have a related academic program, institute/center, grant funds, and interest in quantum computing. This is not a complete list (accomplished via google searches)

Institution	Program Title, Center Title, and or Research Area	State
Massachusetts	No specific program; Institutes/Schools & Research Areas; Many science/STEM fields with exposure to Quantum Computing at MIT	MA

Institute of Technology	Research Area: Quantum Information Science; https://physics.mit.edu/research-areas/quantum-information-science/	
	Research Area: Quantum Gravity and Field Theory; https://physics.mit.edu/research-areas/quantum-gravity-and-field-theory/	
	Quantum Engineering/Quantum Computing; https://cqe.mit.edu/	
	MIT xPro-noncredit Four (4) courses: https://learn-xpro.mit.edu/quantum-computing	
University of California, Berkeley	MS Multidisciplinary Quantum Information Science *(was not able to find program on UC Berkeley webpage, embedded into various programs)*	CA
	Berkeley Quantum Information and Computation Center; http://bqic.berkeley.edu/	
	Berkeley Quantum Industry Day; https://simons.berkeley.edu/events/quantum-industry-day-2022	
	Quantum Science; https://physics.berkeley.edu/quantum-science	
University of California, Santa Barbara	MS & PhD Materials Engineering, Quantum Mechanics *(closest possible program)*	CA
	https://news.ucsb.edu/2023/021185/uc-santa-barbara-quantum-scientists-conduct-nsf-funded-research-pursue-quantum-scale	
University of Chicago	Engineering: MS Computational Modeling of Materials *(closest possible program)*	IL
	Engineering: PhD Quantum Science & Engineering	
	Chicago Quantum Exchange (CQE)	
	Quantum Information Science and Engineering Network (QISE-NET) https://qisenet.uchicago.edu/	
University of Maryland, College Park	Quantum Physics; Quantum Information Degree with Computer Science and Linear Algebra	MA
	Quantum Computing; Post-Baccalaureate Level Certificate; https://academiccatalog.umd.edu/graduate/programs/quantum-computing-Z157/; 4 courses 12 credits; https://academiccatalog.umd.edu/graduate/programs/quantum-computing-Z157/quantum-computing-pbc/	
University of Massachusetts, Boston Campus	Appears to be part of Physics Department; Undergraduate Quantum Information Certificate; https://www.umb.edu/science-mathematics/academics/physics/quantum-information-certificate/ Four (4) Classes: 1) Fundamentals of Quantum Physics, 2) Quantum Computation, 3) Physics and Information, and 4) Quantum Science Applications	MA

University of Southern California	MS Quantum Information Science; Department of Computer and Electrical Engineering https://viterbigradadmission.usc.edu/programs/masters/msprograms/electrical-computer-engineering/ms-in-quantum-information-science/	CA
California Institute of Technology (CALTECH)	CALTECH offers a graduate minor option in all their graduate degrees: https://iqim.caltech.edu/quantum-science-and-engineering-minor/	CA
	Institute-Quantum Information and Matter: https://iqim.caltech.edu/people/	
	Physics, Mathematics, Astronomy, and Engineering and Applied Science programs: https://iqim.caltech.edu/people/graduate-students/	
University of Pittsburgh	BS Physics & Quantum Computing; Physics & Computer Science https://www.academics.pitt.edu/programs/physics-quantum-computing	PA
	Undergraduate Certificate, Quantum Computing & Quantum Information https://www.academics.pitt.edu/programs/quantum-computing-quantum-information	
University of Illinois, Urbana Champaign	No program, but courses and embedded information at the undergraduate and graduate level. See below Note-part of undergraduate Physics program	IL
	PHYS 370 Introduction to Quantum Information and Computing credit: 3 Hours. Introduction to quantum information and computing for sophomores, juniors and seniors from any major. Self-contained description of quantum states and qubits, operators, measurements, tensor products, density matrices, quantum gates and circuits, and quantum computing/simulation algorithms. One of the key points of departure from classical physics, quantum entanglement, is threaded throughout all these topics including a dedicated discussion of Bell's theorem. Students will apply these basic aspects of quantum mechanics to program online quantum computers (e.g., IBM cloud) to gain insight into canonical algorithms such as Deutsch-Jozsa, Shor, and/or Grover as well as standard protocols such as teleportation and entanglement swapping. Prerequisite: PHYS 214.	
	The Beckman Institute houses a variety of interdisciplinary opportunities related to quantum computing. https://beckman.illinois.edu/	

Boston University	BA in Physics and Computer Science with a required course in Quantum Computing: https://www.bu.edu/academics/cas/programs/physics/ba-in-physics-computer-science/ Course: https://www.bu.edu/academics/cas/courses/cas-py-536/	MA
	Graduate Engineering course titled: Quantum Engineering and Technology https://www.bu.edu/academics/eng/courses/eng-ec-585/	
Duke University	Duke Quantum Center https://quantum.duke.edu/	NC
	Master of Science or a Master of Engineering-areas of research include Quantum Computing, two (2) tracks software and hardware: https://ece.duke.edu/masters/study/quantum-computing	
Stanford University	Q FARM (Fundamentals, Architectures, and Machine Learning) https://qis.slac.stanford.edu/	CA
	Noncredit Online EdX; Quantum Mechanics for Scientists and Engineers; https://online.stanford.edu/courses/soe-yeeqmse01-quantum-mechanics-scientists-and-engineers	
	Stanford Law; Towards Responsible Quantum Technology; https://cyber.harvard.edu/publication/2023/towards-responsible-quantum-technology	
	There does not appear to be a program titled Quantum Computing but many of the programs in the Engineering College are related.	
Harvard University	PhD Quantum Science & Engineering; Computer Science, Applied Physics, Electrical Engineering, Physics https://quantum.harvard.edu/graduate-studies	MA
	Harvard Quantum Initiative https://quantum.harvard.edu/	
Carnegie Mellon University	PhD Physics appears to include a limited study in Quantum Computing https://www.cmu.edu/physics/graduate-program/index.html	PA
	Software Engineering Institute; Cybersecurity of Quantum computing: A New Frontier; https://insights.sei.cmu.edu/blog/cybersecurity-of-quantum-computing-a-new-frontier/	
University of Colorado, Boulder	Quantum Engineering undergraduate minor: Includes one class in quantum computing. https://www.colorado.edu/engineering/academics/guide-degrees-certificates/minors/quantum-engineering-minor	CO

	There does not appear to be a program titled Quantum Computing but it does appear to be embedded within Computer Science and many of the engineering programs	
	Quantum Physics, Quantum Computing, and Laser Systems	
University of New Mexico	Center for Quantum Information and Control; http://cquic.unm.edu/	NM
	I could not find an academic program but many courses; http://cquic.unm.edu/courses/index.html	
Capital Technology University; Maryland USA Campus	PhD in Quantum Computing; Offered Online; https://www.captechu.edu/degrees-and-programs/doctoral-degrees/quantum-computing-phd	MA
	Master of Research in Quantum Computing; Offered Online; https://www.captechu.edu/degrees-and-programs/masters-degrees/quantum-computing-mres	
University of Wisconsin, Madison	Physics Dept, MS in Physics-Quantum Computing https://guide.wisc.edu/graduate/physics/physics-ms/physics-quantum-computing-ms/	WI
	Quantum Computing; and Quantum Technologies appears to be embedded into MS & PhD programs in Electrical and Computer Engineering & Material Science and Engineering	
Purdue University	Physics BS courses related to Quantum Computing; https://catalog.purdue.edu/preview_program.php?catoid=16&poid=25212&_ga=2.50729569.951936221.1694106768-59750801.1694106768	IN
	Embedded in graduate computer science, computer engineering, physics, mechanical engineering, etc.	
Columbia University	No program, but courses and embedded information at the undergraduate and graduate level.	NY
Georgia Institute of Technology	No program, but courses and embedded information at the undergraduate and graduate level.	GA
Yale University	No program but embedded into various areas: Yale Quantum Institute; https://quantuminstitute.yale.edu/programs-events/csyqi-quantum-computing-colloquium-series	CT

Below is a list of potential students at the above institutions that may or may not have had exposure to Quantum Computing at some level (courses, part of related BS/MS program, center or institute, research opportunity, etc.). Below are completion numbers in combined fields in Physics, Mathematics, Engineering (computer, software, hardware, materials…) and the Computational Sciences at each higher education institution.

Institution	2019 Total Completions	2020 Total Completions	2021 Total Completions
Massachusetts Institute of Technology	1,191	1,087	1,118
University of California, Berkeley	1,092	1,161	1,199
University of California, Santa Barbara	278	272	263
University of Chicago	403	462	626
University of Maryland, College Park	994	993	943
University of Massachusetts, Boston Campus	89	90	93
University of Southern California	2,499	2,751	2,742
California Institute of Technology (CALTECH)	244	187	223
University of Pittsburgh	769	823	993
University of Illinois, Urbana Champaign	1,522	1,771	1,842
Boston University	1,105	1,215	1,089
Duke University	605	703	677
Stanford University	1,438	1,459	1,399
Harvard University	546	794	796
Carnegie Mellon University	2,346	2,533	2,428
University of Colorado, Boulder	691	824	763
University of New Mexico	255	252	209

Capital Technology University; Maryland USA Campus	93	77	97
University of Wisconsin, Madison	951	846	933
Purdue University	343	318	345
Columbia University	1,744	2,168	2,327
Georgia Institute of Technology	2,792	3,427	3,804
Yale University	378	306	265
Exposure to Quantum Computing	**22,368**	**24,519**	**25,174**

b) Findings:
   i) Given there is not a CIP Code match determining completion numbers, growth, enrollment potential is difficult.
   ii) This is an emerging and growing field.
   iii) As noted above, the University of Colorado in Boulder and the University of New Mexico are the only regional or semi regional higher education institutions that have entered this arena. This presents an opportunity for the University of Wyoming.

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3) Employment trends and projections given core competencies of the degree or certificate.

a) Below is information for Computer Science, Computer Engineering, Physics, and Mathematics
   i) BLS One-year historic employment growth for all of the above is strong, increasing.
   ii) BLS Three-year historic employment growth for all of the above is strong, increasing.
   iii) BLS Future job growth projections is **very** strong.

b) The employment market is not saturated. There are many opportunities for employment in this field.

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4) Graduate salary trends and other post-completion trends.

a) Below is BLS mean annual wage nation wide

Computer Science	$75,230.00
Computer Engineering	$92,460.00
Physics	$112,511.00
Mathematics	$78,818.00
Average	$89,754.75