UNIVERSITY OF MARYLAND
OFFICE OF THE SENIOR VICE PRESIDENT AND PROVOST

1119 Thomas V. Miller, Jr. Administration Building
College Park, Maryland 20742
301.405.5252 TEL 301.405.8195 FAX

June 14, 2024

MEMORANDUM

TO: Amitabh Varshney
Dean, College of Computer, Mathematical, and Natural Sciences

FROM: William Reed *Wm Reed*
Assistant Provost for Academic Planning

SUBJECT: Proposal to Establish a Master of Science in Quantum Computing (PCC Log No. 23048)

On April 19, 2024, the Board of Regents approved your proposal to establish a Master of Science in Quantum Computing. On April 22, 2024, the Maryland Higher Education Commission gave final approval. A copy of the approved proposal is attached.

The new program is effective Fall 2024. The Graduate Catalog entry for the program will be added by the Graduate School. Please ensure that the new program is fully described in all other relevant descriptive materials.

Please contact Linda Yokoi at lyokoi@umd.edu in the Office of the Registrar to establish a major code for the program. The new major code will be mapped to the following unit:

- 012030001300101 CMNS-College of Computer, Math & Natural Sciences

WLR/mdc

Enclosure

cc: Wendy Stickle, Chair, Senate PCC Committee
Barbara Gill, Office of Enrollment Management
Veronica Marin, University Senate
Huifang Pan, Division of Information Technology
Pam Phillips, Institutional Research, Planning & Assessment
Natalie Trapuzzano, University Archives
Linda Yokoi, Office of the Registrar
Jason Farman, Graduate School
John Fourkas, College of Computer, Mathematical, and Natural Sciences
Amy Chester, University of Maryland Science Academy

MHEC
ENGAGE • INFORM • SUPPORT

Wes Moore
Governor

Aruna Miller
Lt. Governor

Cassie Motz
Chair

Sanjay Rai, Ph.D.
Acting Secretary

April 22, 2024

Dr. Darryll Pines
President
University of Maryland College Park
1101 Thomas V. Miller, Jr. Administration Building
College Park, MD 20742

Dear President Pines:

The Maryland Higher Education Commission has reviewed a request from University of Maryland College Park to offer a Master of Science (M.S.) in Quantum Computing as both an on-campus education program and a distance education program.

I am pleased to inform you that the program proposal is approved for implementation in Fall 2024. This decision is based on an analysis of the program proposal in conjunction with the law and regulations governing academic program approval, in particular Code of Maryland Regulations (COMAR) 13B.02.03. As required by COMAR, the Commission circulated the proposal to the Maryland higher education community for comment and objection. No objections were received during the 30-day circulation period. The program meets COMAR's requirements and demonstrates potential for success, an essential factor in making this decision.

Additionally, the institution meets COMAR's requirements to provide distance education. An institution offering distance education must comply with the C-RAC guidelines in addition to other requirements outlined in COMAR, including 13B.02.03.22 and .29.

For the purposes of providing enrollment and degree data to the Commission, please use the following HEGIS and CIP codes:

Program Title	Award	Credits	HEGIS	CIP	Modality
Quantum Computing	M.S.	30	1703.05	27.0304	Dual

Should University of Maryland College Park desire to make a substantial modification to the program in the future, review by the Commission will be necessary. I wish you continued success.

Sincerely,

Sanjay Rai, PhD
Acting Secretary

EAAD:LS:BB:ae

C: Dr. Candace Caraco, Associate Vice Chancellor, Academic Affairs, USM
Michael Colson, Senior Coordinator for Academic Programs, UMCP
Dr. Jennifer King Rice, Senior Vice President and Provost, UMCP

File: 24095

UNIVERSITY SYSTEM of MARYLAND

701 E. PRATT STREET // BALTIMORE, MD 21202
WWW.USMD.EDU // 301.445.1901

OFFICE OF THE CHANCELLOR

June 13, 2024

Dr. Darryll J. Pines
President
University of Maryland, College Park
1101 Thomas V. Miller, Jr. Administration Building
College Park, MD 20742

Dear Darryll:

The Board of Regents met in public session on Friday, April 19, 2024, at Bowie State University. During the meeting, the Board approved the proposal from the University of Maryland, College Park to offer the Master of Science (M.S.) in Quantum Computing.

This Board action follows the recommendation for approval made at the Committee on Education Policy and Student Life and Safety meeting on April 12, 2024.

Sincerely yours,

Jay A. Perman
Chancellor

cc: Alison Wrynn
Candace Caraco
Zakiya Lee
Denise Wilkerson

PCC Proposal to Establish a Master of Science in Quantum Computing (Senate Document #23-24-19)

TO **Darryll J. Pines | President**

FROM **Christopher Jarzynski | Chair, University Senate**

I am pleased to forward the accompanying legislation for your consideration and approval. William Reed, on behalf of Wendy Stickle, Chair of the Programs, Curricula & Courses (PCC) Committee, presented the PCC Proposal to Establish a Master of Science in Quantum Computing (Senate Document #23-24-19), which the University Senate approved at its meeting on February 6, 2024. Please inform the Senate of your decision and any administrative action related to your conclusion.

Approved: [signature] **Date:** **02-14-2024**

Darryll J. Pines
President

Copies of this approval and the accompanying legislation will be forwarded to:

Jennifer King Rice, Senior Vice President and Provost
Veronica Marin, Executive Secretary and Director, University Senate
Jay Rosselló, Vice President of Legal Affairs and General Counsel
Dylan Baker, Associate Vice President for Finance and Personnel
John Bertot, Associate Provost for Faculty Affairs
Elizabeth Beise, Associate Provost for Academic Planning & Programs
Rhonda Smith, Director, Division of Academic Affairs
Konstantina Trivisa, Director, Institute for Physical Science and Technology
Amy Chester, Director, Science Academy

Establish a Master of Science in Quantum Computing (PCC 23048)

PRESENTED BY	**Wendy Stickle, Chair, Senate Programs, Curricula, and Courses Committee**
REVIEW DATES	**SEC – January 23, 2024 | SENATE – February 6, 2024**
VOTING METHOD	**In a single vote**
RELEVANT POLICY/DOCUMENT	
NECESSARY APPROVALS	**Senate, President, USM Board of Regents, and the Maryland Higher Education Commission**

ISSUE

The College of Computer, Mathematical, and Natural Sciences proposes to establish a Master of Science in Quantum Computing. This program exists currently as an iteration of the Master of Professional Studies (MPS) program. The 30-credit MPS program was established during the 2022-2023 academic year. Master of Professional Studies programs were first approved in 2005, when the University System of Maryland Board of Regents and Maryland Higher Education Commission approved an expedited review process for master's and graduate certificate programs that respond quickly to the changing market needs for working professionals. Once a new iteration of the MPS is approved through campus PCC review, it only needs approval by the USM Chancellor to become official.

A limitation of offering this program as an MPS iteration is that all Professional Studies programs must use the same generic Federal Classification of Instructional Programs (CIP) code, rather than a CIP code that accurately describes the program content. Those who search for academic programs by using the CIP codes related to Quantum Computing will not find this program. Moreover, some CIP codes are designated as "STEM" eligible by the US Department of Homeland Security, and international students with F1 visas who graduate from STEM designated programs may continue to work in the United States for two years longer than students in non-STEM designated programs. The generic CIP code for Professional Studies programs does not qualify as STEM-designated, even if the academic content of the Professional Studies program is STEM-related, as is the case with this program.

Consequently, the college proposes to transition the current program from a Master of Professional Studies program to a stand-alone Master of Science program in order for the program to be classified more accurately. The 30-credit curriculum will remain the same.

The Master of Science in Quantum Computing will provide students with the foundational, practical, and theoretical topics of quantum computing. Participants will discover current state-of-the-art quantum computing technology and areas of application, while also exploring its origins, evolution, and possible future states of this technology. The program consists of seven required 3-credit courses, and nine credits of electives. The program is a non-thesis program and will have both an in-person and distance education version. Course topics include quantum networks, quantum thermodynamics, quantum machine learning, quantum information theory, quantum Monte Carlo and simulations, and quantum computing hardware.

The proposal was approved by the Graduate School PCC committee on October 27, 2023, and the Senate Programs, Curricula, and Courses committee on December 1, 2023.

RECOMMENDATION(S)

The Senate Committee on Programs, Curricula, and Courses recommends that the Senate approve this new academic program.

COMMITTEE WORK

The committee considered this proposal at its meeting on December 1, 2023. Konstantina Trivisa, from the College of Computer, Mathematical, and Natural Sciences, presented the proposal and answered questions from the committee. The committee approved the proposal.

ALTERNATIVES

The Senate could decline to approve this new academic program.

RISKS

If the Senate declines to approve this new degree program, the university will lose an opportunity to apply a more accurate Federal CIP code to an existing program thereby making the program more marketable.

FINANCIAL IMPLICATIONS

There are no significant financial implications with this proposal as the program already exists as a self-supported Master of Professional Studies program.

913: QUANTUM COMPUTING

In Workflow

1. D-CHPH PCC Chair (jcrosby@umd.edu)
2. D-CHPH Chair (wth@umd.edu)
3. CMNS PCC Chair (jpresson@umd.edu; fourkas@umd.edu)
4. CMNS Dean (rinfanti@umd.edu)
5. Academic Affairs Curriculum Manager (mcolson@umd.edu)
6. Graduate School Curriculum Manager (jfarman@umd.edu)
7. Graduate PCC Chair (jfarman@umd.edu)
8. Dean of the Graduate School (jfarman@umd.edu; sroth1@umd.edu)
9. Senate PCC Chair (mcolson@umd.edu; wstickle@umd.edu)
10. University Senate Chair (mcolson@umd.edu)
11. President (mcolson@umd.edu)
12. Board of Regents (mcolson@umd.edu)
13. MHEC (mcolson@umd.edu)
14. Provost Office (mcolson@umd.edu)
15. Graduate Catalog Manager (bhernand@umd.edu; fantsao@umd.edu)

Approval Path

1. Mon, 15 May 2023 13:16:19 GMT
   Jessica Crosby (jcrosby): Approved for D-CHPH PCC Chair
2. Wed, 13 Sep 2023 21:26:12 GMT
   Wendell Hill (wth): Approved for D-CHPH Chair
3. Thu, 14 Sep 2023 22:29:31 GMT
   John Fourkas (fourkas): Approved for CMNS PCC Chair
4. Wed, 20 Sep 2023 13:18:10 GMT
   Robert Infantino (rinfanti): Approved for CMNS Dean
5. Mon, 16 Oct 2023 21:06:33 GMT
   Michael Colson (mcolson): Approved for Academic Affairs Curriculum Manager
6. Tue, 05 Dec 2023 18:12:59 GMT
   Jason Farman (jfarman): Approved for Graduate School Curriculum Manager
7. Tue, 05 Dec 2023 18:21:48 GMT
   Jason Farman (jfarman): Approved for Graduate PCC Chair
8. Tue, 05 Dec 2023 20:37:04 GMT
   Stephen Roth (sroth1): Approved for Dean of the Graduate School
9. Thu, 07 Dec 2023 18:17:02 GMT
   Wendy Stickle (wstickle): Approved for Senate PCC Chair
10. Fri, 14 Jun 2024 18:19:13 GMT
    Michael Colson (mcolson): Approved for University Senate Chair
11. Fri, 14 Jun 2024 18:19:22 GMT
    Michael Colson (mcolson): Approved for President
12. Fri, 14 Jun 2024 18:19:40 GMT
    Michael Colson (mcolson): Approved for Board of Regents
13. Fri, 14 Jun 2024 18:19:55 GMT
    Michael Colson (mcolson): Approved for MHEC
14. Fri, 14 Jun 2024 18:20:34 GMT
    Michael Colson (mcolson): Approved for Provost Office

New Program Proposal

Date Submitted: Thu, 27 Apr 2023 14:24:06 GMT

Viewing: 913 : Quantum Computing
Last edit: Fri, 14 Jun 2024 18:17:13 GMT

Changes proposed by: Konstantina Trivisa (trivisa)

Program Name

Quantum Computing

Program Status

Active

Effective Term

Spring 2024

Catalog Year

2023-2024

Program Level

Graduate Program

Program Type

Master's

Delivery Method

On Campus

Departments

Department
Institute for Physical Sciences & Technology

Colleges

College
Computer, Mathematical, and Natural Sciences

MHEC Inventory Program

Quantum Computing

CIP Code

27.0304 - 27.0304

HEGIS

170305

Degree(s) Awarded

Degree Awarded
Master of Science

Proposal Contact

Konstantina Trivisa, Amy Chester

Proposal Summary

This proposal is to convert the approved MPS in Quantum Computing to an MS in Quantum Computing. No curriculum changes proposed to the approved program.
CIP Code: 27.0304 Computational and Applied Mathematics

(PCC Log Number 23048)

Program and Catalog Information

Provide the catalog description of the proposed program. As part of the description, please indicate any areas of concentration or specializations that will be offered.

The Masters of Science in Quantum Computing provides participants with foundational, practical and theoretical topics of quantum computing. Participants will discover current state-of-the-art quantum computing technology and areas of application, while also exploring its origins, evolution, and possible future states of this technology.

Experiential learning is at the core of the program with courses that provide ample opportunity for the participant to apply concepts on current-day commercial quantum computing hardware.

Special topics include quantum networks, quantum thermodynamics, quantum machine learning, quantum information theory, quantum Monte Carlo and simulations, and quantum computing hardware.

Catalog Program Requirements. Please click on the help bubble for more specific information about formatting requirements.

The Master of Science in Quantum Computing requires 30 credits including 7 core courses and 3 electives.

Course	Title	Credits
Core courses		
MSQC601	Course MSQC601 Not Found (Mathematics and Methods of Quantum Computing)	3
MSQC602	Course MSQC602 Not Found (The Physics of Quantum Devices)	3
MSQC603	Principles of Machine Learning	3
MSQC604	Course MSQC604 Not Found (Quantum Computing Architectures and Algorithms)	3
MSQC605	Course MSQC605 Not Found (Advanced Topics in Quantum Computing)	3
MSQC606	Course MSQC606 Not Found (Practical Quantum Computing)	3
MSQC607	Course MSQC607 Not Found (Advanced Topics in Quantum Computing)	3
Elective courses		**9**
MSQC610	Course MSQC610 Not Found (Quantum Machine Learning- elective)	
MSQC611	Course MSQC611 Not Found (Quantum Networks- elective)	
MSQC612	Course MSQC612 Not Found (Quantum Computing Hardware- elective)	
MSQC613	Course MSQC613 Not Found (Quantum Monte Carlo and Applications- elective)	
MSQC614	Course MSQC614 Not Found (Quantum Information Theory- elective)	
MSQC615	Course MSQC615 Not Found (Quantum Thermodynamics- elective)	
Total Credits		**30**

Sample plan. Provide a term by term sample plan that shows how a hypothetical student would progress through the program to completion. It should be clear the length of time it will take for a typical student to graduate. For undergraduate programs, this should be the four-year plan.

Full time:

First Year					
Semester 1	**Credits**	**Semester 2**	**Credits**	**Semester 3**	**Credits**
MSQC601 (The Mathematics and Methods of Quantum Computing)	3	MSQC604 (Quantum Computing Architectures and Algorithms)	3	MSQC612 or MSQC613 (Quantum Computing Hardware or Quantum Monte Carlo and Applications)	3
MSQC602 (Physics of Quantum Devices)	3	MSQC606 (Practical Quantum Computing)	3		
MSML/MSQC603 (Principles of Machine Learning)	3	MSQC608 or MSQC610 (Quantum Information Theory or Quantum Machine Learning)	3		
	9		**9**		**3**

Second Year	
Semester 1	**Credits**
MSQC605 (Advanced Quantum Computing and Applications)	3
MSQC607 (Advanced Topics in Quantum Computing)	3
MSQC609 or MSQC611 (Quantum Thermodynamics or Quantum Networks)	3
	9

Total Credits 30

Sample Plan of Study (Part time)

Semester 1 (fall)

MSQC601 The Mathematics and Methods of Quantum Computing (core)
MSQC602 Physics of Quantum Devices (core)

Semester 2 (spring)

MSQC604 Quantum Computing Architectures and Algorithms (core)
[choose any one of the following]
MSQC608 Quantum Information Theory (elective)
MSQC610 Quantum Machine Learning (elective)

Semester 3 (summer)

[choose any one of the following]
MSQC612 Quantum Computing Hardware (elective)
MSQC613 Quantum Monte Carlo and Applications (elective)

Semester 4 (fall)

MSQC603 Principles of Machine Learning (core)
MSQC605 Advanced Quantum Computing and Applications (core)

Semester 5 (spring)
MSQC606 Practical Quantum Computing (core)

Semester 6 (fall)

MSQC607 Advanced Topics in Quantum Computing (core)
[choose any one of the following]
MSQC609 Quantum Thermodynamics (elective)
MSQC611 Quantum Networks (elective)

List the intended student learning outcomes. In an attachment, provide the plan for assessing these outcomes.

Learning Outcomes
Explain principles of quantum physics as they apply to quantum computing.
Develop quantum computing programs and implement them on quantum computing platforms.
Distinguish the elements of a quantum computing algorithm and differentiate it from a classical algorithm.
Describe current quantum computing hardware, and examine the effects of its current state of maturity on the design of quantum computing algorithms.
Discuss and implement quantum computing paradigms to solve problems in quantum networks and quantum machine learning.
Compare quantum thermodynamics and quantum information theory and how they relate to classical information theory.

New Program Information

Mission and Purpose

Describe the program and explain how it fits the institutional mission statement and planning priorities.

The Master of Science in Quantum Computing aims to provide training and advanced knowledge in the area of quantum computing with a focus on practical education for working professionals. This program will contribute to the development of the emerging labor market of quantum computing scientists and engineers in the state of Maryland, and the nation. Other countries, such as China, have invested greatly recently in these scientific and technological sectors. The potential benefits of early discoveries and implementation of technological solutions that use quantum computing promise to generate important societal and economical benefits in the long term. For these reasons, the Master of Science in Quantum Computing is aligned with the mission of the University of Maryland to provide excellent teaching, research and education in service of the needs of the citizens of Maryland, and the nation.

Program Characteristics

What are the educational objectives of the program?

The main educational objective of the Master of Science in Quantum Computing is to prepare the individual to be ready to apply the principles and techniques of quantum computing to the solution of a variety of problems in optimization, secure communications, encryption, materials discovery and any such problems that require considerable computing resources.
Moreover, the participant should be able to differentiate the many technologies currently used to implement quantum computers and compare their intrinsic strengths and limitations.
Finally, the individual will gain the ability to make appropriate business decisions now to be set up for success when quantum technologies reach maturity in the future.

Describe any selective admissions policy or special criteria for students interested in this program.

A four-year baccalaureate degree from a regionally accredited U.S. institution, or an equivalent degree from a non-U.S. institution

A 3.0 GPA (on a 4.0 scale) in all prior undergraduate and graduate coursework
Official copy of transcript for all post-secondary work

Curriculum vitae/resume

Personal statement including such elements as relevant experience and interests in engineering, mathematics, and natural sciences

Prior programming experience (Python preferred)

Quantitative abilities including coursework in Linear Algebra and Advanced Calculus

Summarize the factors that were considered in developing the proposed curriculum (such as recommendations of advisory or other groups, articulated workforce needs, standards set by disciplinary associations or specialized-accrediting groups, etc.).

In recent years, the federal government and private sector have substantially increased funding for research and development of quantum technologies, including quantum computing.
This new area of economic activity requires a highly trained and skilled labor force to take advantage of this technological era and contribute to the solution of problems at the local, regional, and national levels.
Conversations with experts at the National Institute for Standards and Technology (NIST), as well as the Universities Space Research Association (USRA), have confirmed that there are skills gaps in the current workforce and more trained experts in these areas are required.
The University of Maryland has seen an exponential growth in investments and the creation of multiple centers, institutes and departments bringing in research talent and economic resources in quantum physics and quantum computing.This program will take advantage of this ecosystem of quantum expertise on campus, and complement UMDs development by adding an educational component.
Therefore, the proposed program is aligned with the university mission to promote interdisciplinary and cross sector partnerships to advance science and technology for the benefit of the state and the nation.

Select the academic calendar type for this program (calendar types with dates can be found on the Academic Calendar). Please click on the help bubble for more specific information.

Traditional Semester

For Master's degree programs, describe the thesis requirement and/or the non-thesis requirement.

Non-thesis requirement: complete all courses, 30 credits, with a 3.0 cumulative GPA or better.

Identify specific actions and strategies that will be utilized to recruit and retain a diverse student body.

The primary recruitment activities will be via the CMNS Science Academy. The Science Academy uses a diverse, targeted approach when recruiting students. This digital strategy focuses on UMD alumni, current UMD graduating seniors, and working professionals in the DMV area, including senior scientist personnel in NIST, NASA, and NIH. The admissions review process reviews for not only academic readiness but also diversity in experiences, industries, backgrounds, and career aspirations to recruit a diverse student body.

To attract a diverse student population, we will engage in the following activities:
• Representing the program in educational fairs, conferences and events, e.g. the National Leadership Conference of the National Society of Black Engineers, GEM Grad Labs.
• Advertising the program to the National Society of Black Engineers (NSBE), the Society of Women Engineers (SWE), and the Association for Women in Computing (AWC).
• Direct mailing and email campaigns to domestic and international colleges
• Outreach to UMD Campus organizations and clubs
• Holding online (virtual) open houses, information sessions and career panels
• Outreach to US Military to attract veterans
• Social media and online advertising
• Establishing graduate scholarships to provide financial aid to underrepresented minority applicants

Once enrolled, the Science Academy staff, and faculty are committed to creating and fostering a supportive environment for all students to thrive. We regularly share resources and opportunities for counseling, support, and funding. All students are expected to complete and honor the TerrapinSTRONG orientation and initiatives. Students are encouraged to take part in Grad School programs that address diversity and inclusion in higher education, build communities of support and success, and create meaningful dialogue among graduate students. Such programs include"Cultivating Community Conversations" and the "Annual Office of Graduate Diversity and Inclusions Spring Speaker Services." Faculty that are involved in the Science Academy represent many departments, have a diversity of appointments (both tenure track, professional track, and adjunct) exposing students to many future career paths. The Science Academy and faculty provide student advising, academic support, and career guidance to students to retain all students and support timely graduation.

Our student retention efforts will consist of:
• Holding "Women in Engineering, Computing and STEM" seminars to addresses the obstacles faced by women in today's technical workplace and guide our women students to maneuver through the internship and job application process
• Requiring students to attend mandatory advising sessions with the program adviser to ensure that the students' study plans are in line with their interests and career goals, and that the students make satisfactory progress toward meeting the degree requirements

• Implementing an early warning system that detects students struggling with core courses and alerts the academic advisor, who meets with the students and designs a study plan to get them back on track

Relationship to Other Units or Institutions

If a required or recommended course is o#ered by another department, discuss how the additional students will not unduly burden that department's faculty and resources. Discuss any other potential impacts on another department, such as academic content that may significantly overlap with existing programs. Use space below for any comments. Otherwise, attach supporting correspondence.

One course is shared across existing programs in the Science Academy, DATA/MSML 603: Principles of Machine Learning. Other courses will be new courses and should not burden department's faculty or resources. New courses will be developed and delivered by a combination of tenure-track or professional-track faculty teaching on overload and adjuncts.

Accreditation and Licensure. Will the program need to be accredited? If so, indicate the accrediting agency. Also, indicate if students will expect to be licensed or certified in order to engage in or be successful in the program's target occupation.

No accreditation or licensure is required for the program.

Describe any cooperative arrangements with other institutions or organizations that will be important for the success of this program.

MSQC604 Quantum Computing Architectures and Algorithms and MSCQ605 Advanced Quantum Computing and Applications will be developed in collaboration with the Universities Space Research Association (USRA).

USRA will contribute industry perspective on in-demand skills and competencies, create real world problem sets/simulations/projects, identify prospective participants from government labs and private industry, and market the program.

Faculty and Organization

Who will provide academic direction and oversight for the program? In an attachment, please indicate the faculty involved in the program. Include their titles, credentials, and courses they may teach for the program. Please click on the help bubble for a template to use for adding faculty information.

Konstantina Trivisa Ph. D., Director of Institute for Physical Science and Technology, Professor of Mathematics Pratyush Tiwary Ph. D., Associate Professor IPST and Chemistry and BioChemistry
Alfredo Nava-Tudela Ph.D., Director of Scientific Computing, IPST
Charles Clark Ph.D., JQI Fellow and IPST
Maria Cameron Ph.D., Associate Professor of Mathematics
Nicole Yunger Halpern Ph.D., Adjunct Assistant Professor QuICS and IPST
Avik Dutt Ph.D., Assistant Professor Mechanical Engineering and IPST
Franz Klein Ph.D., Office of Academic Computing Services
Aaron Lott Ph.D., Universities Space Research Association (USRA)
Alejandra Mercado Ph.D., Associate Director ECE

Indicate who will provide the administrative coordination for the program

The Science Academy in the College of Computer, Mathematics and Natural Science will provide administrative coordination for the program, in collaboration with the Office of Extended Studies. The Office of Extended Studies provides program development support (budget development and projections, market research, preparation of PCC document), program management (UMD policies and procedures compliance, program website, data requests), student and program services (admission support, scheduling, registration, billing and payment, graduation, appeals), and financial management (faculty contracts, payment processing, course charge processor, net revenue distribution).

Resource Needs and Sources

Each new program is required to have a library assessment prepared by the University Libraries in order to determine any new library resources that may be required. This assessment must be done by the University Libraries. Add as an attachment.

The University of Maryland at College Park subscribes to substantial journal holdings and index databases, as well as additional support services and resources, to support teaching and learning in the Master of Science in Quantum Computing, per the University of Maryland Libraries assessment. These materials are supplemented by a strong monograph collection. Additionally, the Libraries Scan & Deliver and Interlibrary Loan services make materials that otherwise would not be available online, accessible to remote users. As a result, the University of Maryland Libraries are able to meet the curricular and research needs of the proposed Master of Science in Quantum Computing. This assessment stems from the assessment that the University of Maryland Libraries provided for the Professional Masters in Quantum Computing, which applies exactly to the curriculum of this new Masters of Science in Quantum Computing.

Discuss the adequacy of physical facilities, infrastructure and instructional equipment.

No additional physical facilities, infrastructure and instructional equipment is required for this program. Existing facilities (e.g., classrooms) and resources (e.g., instructional equipment) will be used. It is anticipated that most of the instruction will be in the evenings, to accommodate the working professional's schedule.

Discuss the instructional resources (faculty, staff, and teaching assistants) that will be needed to cover new courses or needed additional sections of existing courses to be taught. Indicate the source of resources for covering these costs.

The Master of Science in Quantum Computing will not use any state resources since all funding will come from tuition.
The instructors and course designers will include faculty members from the Institute of Physical Science and Technology, which consists of applied mathematicians, physicists, and engineers with the required expertise. We will also count with adjunct faculty from NIST and USRA, and other units within the College of Computer, Mathematical and Natural Sciences, as well as units within the J. Clark School of Engineering.

Discuss the administrative and advising resources that will be needed for the program. Indicate the source of resources for covering these costs.

The CMNS Science Academy will provide the academic and advising oversight to incoming and admitted students. Revenue generated from the program will be used to support administrative and advising resources including a Program Manager. No state resources will be used to support the program

Use the Maryland Higher Education Commission (MHEC) commission financial tables to describe the program's financial plan for the next five years. See help bubble for financial table template. Use space below for any additional comments on program funding. Please click on the help bubble for financial table templates.

Based on the attached proposed budget the program projects to bring in revenue during the first year and to cover all start up costs. This program will not use any state funds and will be revenue generating. All expenses will be paid for by the tuition revenue for this program. See attached document.

Implications for the State (Additional Information Required by MHEC and the Board of Regents)

Explain how there is a compelling regional or statewide need for the program. Argument for need may be based on the need for the advancement of knowledge and/or societal needs, including the need for "expanding educational opportunities and choices for minority and educationally disadvantaged students at institutions of higher education." Also, explain how need is consistent with the Maryland State Plan for Postsecondary Education. Please click on the help bubble for more specific information.

The National Institute of Standards and Technology has made substantial investments on campus to pursue research in quantum physics and technology over the past decades taking into account the vast faculty expertise in quantum physics and engineering. Campus has seen the creation of the Joint Quantum Institute (JQI), the Joint Center for Quantum Information and Computer Science (QuICS), and the Quantum Technology Center (QTC). This, combined with the need to create a skilled professional workforce in quantum computing, makes UMD a natural choice to create an educational offering for this workforce development. In particular NASA Goddard Space Flight Center personnel have expressed interest in courses like the ones proposed in this MS degree.

Present data and analysis projecting market demand and the availability of openings in a job market to be served by the new program. Possible sources of information include industry or disciplinary studies on job market, the USBLS Occupational Outlook Handbook, or Maryland state Occupational and Industry Projections over the next five years. Also, provide information on the existing supply of graduates in similar programs in the state (use MHEC's Office of Research and Policy Analysis webpage for Annual Reports on Enrollment by Program) and discuss how future demand for graduates will exceed the existing supply. As part of this analysis, indicate the anticipated number of students your program will graduate per year at steady state.) Please click on the help bubble for specific resources for finding this information.

A market research study shows that there are very few (2) programs with comparable focus and scope to the proposed certificate. No similar programs exist in the state of Maryland. A labor market study shows that participants in this program will have access to well remunerated jobs. See both market analysis documents attached.

Identify similar programs in the state. Discuss any di#erences between the proposed program and existing programs. Explain how your program will not result in an unreasonable duplication of an existing program (you can base this argument on program di#erences or market demand for graduates). The MHEC website can be used to find academic programs operating in the state. Please click on the help bubble for specific information on finding similar programs within the state.

No similar programs exist in the state of Maryland. Ref. market analysis by OES.

Discuss the possible impact on Historically Black Institutions (HBIs) in the state. Will the program affect any existing programs at Maryland HBIs? Will the program impact the uniqueness or identity of a Maryland HBI?

No impact as there are no similar programs in the state of Maryland. See above.

Supporting Documents

Attachments

Faculty List Template- Quantum.docx
PGP_Benchmark_Quantum_Computing_MPS 2023.xlsx
Collection_Assessment_MPS_QuantumComputing_2022.docx
MS in Quantum Computing Budget.xlsx
Quantum Learning Outcomes and Assessment.pdf
Quantum- Curriculum- MS in Quantum Computing.pdf

Administrative Documents

PCC_Presidential_Approval_23-24-19.pdf
MHEC Approval 24095 University of Maryland College Park MS Quantum Computing.pdf
BOR Approval UMCP - Master of Science in Quantum Computing.pdf

Key: 913

Faculty Information- Quantum Computing

The following faculty members are projected to teach in the program. All faculty are full-time unless otherwise indicated.

Name	**Highest Degree Earned, Program, and Institution**	**UMD Title (indicate if part-time)**	**Courses**
Babak Azimi-Sadjadi	Ph.D., ECE, UMD	Visiting Lecturer	DATA/MSML/BIOI/MSQC 603: Principles of Machine Learning
Maria Cameron	Ph.D., Mathematics, University of California - Berkeley	Associate Professor	Curriculum Advisor
Charles Clark	Ph.D., Physics, University of Chicago	Adjunct Professor	MSQC 602: Physics of quantum devices
Avik Dutt	Ph.D., Electrical and Computer Engineering, Cornell University	Assistant Professor	Curriculum Advisor
Nicole Yunger Halpern	Ph.D., Physics, California Institute of Technology	Adjunct Asst. Professor	Curriculum Advisor
Franz Klein	Ph.D., Physics, University of Bonn (Germany)	Engineer	MSQC 606: Practical Quantum Computing
Aaron Lott	Ph.D., AMSC, UMD	Adjunct Assoc. Professor	MSQC 604: Quantum Computing Architectures and Algorithms MSQC605: Advanced Quantum Computing and Applications
Alejandra Mercado	Ph.D., ECE, UMD	Associate Director	DATA/MSML/BIOI/MSQC 603: Principles of Machine Learning
Alfredo Nava-Tudela	Ph.D., AMSC, UMD	Director	MSQC 601: The Mathematics and Methods of Quantum Computing
Pratyush Tiwary	Ph.D., Materials Science, California Institute of Technology	Associate Professor	Curriculum Advisor
Konstantina Trivisa	Ph.D., Applied Mathematics, Brown University	Professor	MSQC 601: The Mathematics and Methods of Quantum Computing

OES In-House Market Research: Other Institution Comparison										
Quantum Computing -Masters										
Institution	Website	Delivery Method	Degree Name & Type (MPS, MA, MS, MPH, etc.)	# of Credits	Program Duration	Tuition (course or credit)		Target Population	Prior Education/ Pre-Requisites	Notes
						Resident	Non-Resident			
Big Ten Institutions										
Indiana University Bloomington	https://qis.iu.edu/academics/index.html	F2F	Quantum Informational Science (QIS), MS	30 credits	In as little as one year, (two full semesters and one summer session	$10,630/year	$30,704/year	Our MS degree program is designed to bridge students from a wide variety of BS degree-level backgrounds with the knowledge and skills needed to join this new field. Although many of the advances in QIS came from people with PhD-level backgrounds in math/chemistry/physics and similar areas, in the near future, companies foresee that the QIS field will require people who can combine an understanding of QIS concepts with significant knowledge from a variety of fields. Our MS degree program can be used to prepare you for jobs in the developing QIS industry or for other degree programs.	Must have a bachelor's degree, minimum GPA of 3.0 on a 4.0 scale for undergraduate coursework. Demonstrate proficiency in the English language. Do offer a non-credit "bootcamp" before the start of the program to help bring entrants into the program with a common point of understanding	Specialized courses provide you with opportunities to apply quantum concepts and/or to learn about the science and technology where quantum processes are hosted. Specializations include: Quantum Information and Simulation: including mathematical and computational models of quantum computation and simulation, and complexity theory. Quantum Materials and Sensing: including topological electron systems, strange metals, superconductors, theoretical physics and chemistry, photonics, nano-engineering, and quantum measurement. Quantum Applications and Operations: including optimization problems, quantum algorithms, logistics, operations research, and machine learning.
Northwestern University	https://www.mccormick.northwestern.edu/electrical-computer/academics/graduate/masters/electrical-engineering/quantum-computing-and-photonics.html	F2F	Electrical and Computer Engineering -Quantum Computing and Photonics Specialization	12 Unit (Courses)	not noted	$19,978/term		This track will prepare you for a career in the full range of fields in quantum information sciences to meet the challenges of this cutting-edge technology. In this multi-disciplinary field, you will acquire foundational skills in four key areas including quantum computation, quantum communication, quantum sensing, and fundamental quantum science. Additionally, you will also learn how to apply both theoretical and practical knowledge to design quantum algorithms, circuitry, cryptography, optical systems, communication protocols, and more.	For its master of science in electrical engineering program, the Department of Electrical and Computer Engineering looks for students who have a solid undergraduate background in electrical engineering and a desire to progress further into the field. A typical applicant is expected to have a Bachelor of Science in Electrical Engineering, Computer Engineering, or a related discipline from a recognized institution. Highly qualified candidates with other academic backgrounds may also be considered.	Have 3 degree options: Thesis Degree, Project Degree, and Course Degree
Penn State University Park	https://bulletins.psu.edu/graduate/programs/majors/engineering-science-mechanics/#text	F2F	Engineering Science and Mechanics, MS (research opportunities in Quantum Computation and Informational Sciences)	32 credits	Intense 1 year program	$1,086/credit	$1,803/credit	The Master of Science in Computer Science and Engineering programs requires the completion of 30 credits. Students interested in an M.S. in CSE should have already successfully completed Operating Systems Design and Construction, Introduction to Computer Architecture, Programming Language Concepts, Data Structures and Algorithms, and Logical Design of Digital Systems or Introduction to the Theory of Computation	Applicants who hold a baccalaureate degree in engineering, the sciences, mathematics, engineering science, and materials who present at least a 3.00 grade-point average will be considered for admission	There is a non-thesis track for the same program: The one-year intensive master's degree program is meant to prepare students for work in industry. As such, there is no thesis required, although a final paper is required during the last semester of the program.
University of Wisconsin–Madison	https://www.physics.wisc.edu/graduate/mspqc-prospective-students/	F2F	Physics: Quantum Computing, MS (MSPQC)	30 credits	Accelerated 1 year program (Fall, Spring, Summer)	$1600 per credit		The program provides students with a thorough grounding in the new discipline of quantum information and quantum computing. This begins with a study of the relevant parts of quantum theory, and proceeds to quantum gates, measurements, algorithms, quantum error correction and decoherence. Quantum communication theory and the secure transmission of information are also covered. The supporting areas of statistical mechanics, solid-state physics, and atomic physics will form part of the classroom training. Just as important, the program gives students a mastery of the advanced lab skills involved in quantum computation. Finally, all students have the opportunity to get involved in original research.	Admissions Materials: Three letters of recommendation; Official transcripts; Resume/CV; Statement of Purpose: Address relevant experiences and future research/industry interests and goals. Communicate motivations for pursuing the MSPQC, and convey how interests/experiences align with the strengths of the UW– Madison program. NOTE: GRE scores are NOT required and will not be considered.	Degree began in 2019, claims to be the first.
State of Maryland System Institutions: Overseen by MHEC (http://mhec.maryland.gov/publications/Pages/research/index.aspx)										
Capitol Technology University	https://www.captechu.edu/degrees-and-programs/doctoral-degrees/quantum-computing-phd	Online	Quantum Computing, PhD	60 credits	not noted	$933 per credit		The PhD in Quantum Computing is a unique doctoral program designed to meet the immediate industry need for innovative researchers and practitioners. Professionals will graduate with the skills necessary to become key leaders in the advancement, expansion, and support of the this rapidly growing industry.	All students interested in applying for a doctoral degree need a master's degree in a relevant field, a resume showing a minimum of 5 years of directly related work experience plus 2 completed recommendation forms.	The PhD program offers 2 degree completion requirement options. 1. Thesis Option: The student will produce, present, and defend a doctoral dissertation after receiving the required approvals from the student's Committee and the PhD Review Boards. 2. Publication Option: the student will produce, present and defend their original doctoral research and produce three published as articles in high-impact journals identified by the university and the student's Committee. Students must receive the required approvals from the student's Committee and the PhD Review Board prior to publication.
Morgan State University	https://www.morgan.edu/advanced-computing-ms/ms_advancedcomputing	F2F/Online	Advanced Computing, MS	30	Can be completed in 12 months and 16 months for the thesis option	$464/credit	$912/credit	This new program is designed for students who have recently completed a bachelor's degree program in Computer Science or a related field and wish to enhance their career, explore research opportunities in Computer Science, and apply their acquired skills in multi-disciplinary teams or for specific focus. The program also meets the needs of students who are already in the workforce and wish to update or improve their knowledge of current computer science.	Only students with an undergraduate cumulative grade point average of 3.0 will be considered for admission. Students with an undergraduate cumulative GPA of between 2.5 and 2.99 may be considered for conditional admission. Post-bachelor's undergraduate credits will not be used to enhance G.P.A. requirements for admission to graduate study.For admission to graduate study an applicant must: Have earned a bachelor's degree from a regionally accredited college or university. The undergraduate record must be of such quality as to promise successful achievement at the graduate level.	
Colleges & Universities in the Washington DC - Baltimore MD area										
No Washington DC-Baltimore MD area Quantum Computing Masters Programs										
Other Major Institutions Offering Similar Programs										
Duke University	https://ece.duke.edu/masters/study/quantum-computing	F2F	Master of Science in Electrical and Computer Engineering with a Quantum Computing Concentration (MS)	30 credits	3 semesters	$31,310 fulltime per semester, after 3 semesters charged $3,478 per credit		Duke ECE is home to international leaders in information physics research, embodied in pathbreaking programs in metamaterials, quantum devices, and optical systems. Master's students will learn from faculty team with deep interdisciplinary research strengths and a track record of entrepreneurship and innovation.	Three letters of recommendation, Statement of Purpose, GRE optional	The ECE Quantum Computing MS has two tracks: 1. **The Software Track** prepares students to program and control quantum information devices and builds off the well-established Software Development Concentration 2. **The Hardware Track** focuses on the design, fabrication and testing of quantum devices
University of California, Los Angeles, UCLA	https://qst.ucla.edu/	F2F	Masters of Quantum Science and Technology (MQST)	36 units (9 courses)	1 year (Fall, Winter, Spring)	$51,174 program cost		The UCLA Master of Quantum Science And Technology is a professional degree program designed to prepare students for careers in research and development of quantum technologies. The degree addresses the needs of both students and industry, tailored to those who wish to pursue technical positions that require a unique combination of specialized knowledge and skills. The program consists of a rigorous interdisciplinary course curriculum, a year-long program of laboratory skills development, and an industry-relevant capstone internship.	Bachelor's degree, 3 letters of recommendation, Statement of Purpose, and a Personal Statement	The UCLA Master of Quantum Science and Technology is a one-year, full-time program that begins in Fall and concludes at the end of the following Summer quarter. The program consists of nine courses (36 units), an internship, and a capstone presentation on the internship. The core courses are designed specifically for the MQST program. The MQST curriculum emphasizes breadth and laboratory work and will equip students to apply their skills in diverse settings.

Five-Year Enrollment Trends		
Year	Capitol Technology University	Morgan State University
	Quantum Computing, PhD	Advanced Computing, MS
2016	N/A	N/A
2017	N/A	N/A
2018	N/A	N/A
2019	N/A	N/A
2020	2	2
2021	7	10
Projected		

Five-Year Degree Recaps		
Year	Capitol Technology University	Morgan State University
	Quantum Computing, PhD	Advanced Computing, MS
2017	N/A	N/A
2018	N/A	N/A
2019	N/A	N/A
2020	N/A	N/A
2021	0	0
2022	0	2

http://mhec.maryland.gov/publications/Pages/research/index.aspx

Enrollment Trends: Go to "Enrollment Reports" then "Trends in Fall Enrollment by Program"

Degree Recaps: Go to "Student Outcomes" then "Trends in Degrees and Certificates by Program"

OES In-House Market Research: Projected Employment Information				
Quantum Computing				
Occupation	**# of Jobs in the Field**	**Where Professionals are Employed**	**Professional Salary Information**	**Projected Job Growth**
Information from U.S. Bureau of Labor Statistics' Occupational Outlook Handbook (https://www.bls.gov/ooh/)				
Physicists and Astronomers	25,200	Astronomers held about 2,200 jobs in 2021. The largest employers of astronomers were as follows: Research and development in the physical, engineering, and life sciences-41% Colleges, university, and professional schools; state, local, and private-24% Federal government, excluding postal service-22% hysicists held about 23,000 jobs in 2021. The largest employers of physicists were as follows: Scientific research and development services-44% Federal government, excluding postal service-15% Colleges, universities, and professional schools; state, local, and private-12% Ambulatory healthcare services-2%	$147,450/year $70.89/hour	Job Outlook, 2021-31: 8% (Faster than average)
Computer and Information Reseach Scientists	33,500	Federal government, excluding postal service-31% Computer systems design and related services-20% Research and development in the physical, engineering, and life sciences -16% Software publishers-6% Colleges, universities, and professional schools; state, local, and private-5%	$131,490/year $63.22/hour	Job Outlook, 2021-31: 21% (much faster than average)
Information from State of Maryland's Occupational and Industry Projections				
Physicists and Astronomers	2,010	Maryland is the highest employment level in Physicists and the third highest concentration of jobs.	$134,648/year	8% (as fast as average)
Computer and Information Reseach Scientists	2,220	Maryland is the third highest emloyement level and is the state with the highest concentration of jobs.	$123,324/year	4.9% (slower than average)

UNIVERSITY OF MARYLAND
UNIVERSITY LIBRARIES

McKeldin Library
7649 Library Lane
College Park, MD 20742
Phone: (301) 405-0800

DATE: September 16, 2022

TO: Alfredo Nava-Tudela , Director of Scientific Computing, ant@umd.edu,
Institute for Physical Science and Technology

FROM: On behalf of the University of Maryland (UMD) Libraries:
Sarah Weiss, STEM and Open Science Librarian, srweiss@umd.edu
Maggie Saponaro, Director of Collection Development Strategies, msaponar@umd.edu
Daniel Mack, Associate Dean, Collection Strategies & Services, dmack@umd.edu

RE: Library Collection Assessment to support a new program – Masters of Professional Studies in Quantum Computing

We are providing this assessment in response to a proposal by the Institute for Physical Science and Technology in the College of Computer, Mathematical, and Natural Sciences (CMNS) to create Masters of Professional Studie in Quantum Computing. The Institute for Physical Science and Technology asked that we at the University of Maryland Libraries assess our collection resources to determine how well the Libraries support the curriculum of this proposed program.

Serial Publications

The University of Maryland Libraries currently subscribe to a large number of scholarly journals—almost all in online format—that focus on quantum computing.

The Libraries subscribe to most of the top ranked journals, based on Journal Impact Factor (JIF), that are listed in the Quantum Science and Technology category in the 2021 Science Edition of *Journal Citation Reports.*[1]

The Libraries subscribes to top journals in this category, which are available online:

- *Progress in Quantum Electronics* (#2)
- *IEEE Journal of Selected Topics in Quantum Electronics* (#9)
- *Classical and Quantum Gravity* (#10)
- *Optical and Quantum Electronics (#11)*
- *IEEE Journal of Quantum Electronics* (#12)

[1]Note: *Journal Citation Reports* is a tool for evaluating scholarly journals. It computes these evaluations from the relative number of citations compiled in the *Science Citation Index* and *Social Sciences Citation Index* database tools.

- *International Journal of Quantum Chemistry* (#13)
- *Quantum Information Processing* (#14)
- *Quantum Electronics (#15)*

Some of the journals are open access and available online:

- *npj Quantum Information* (#1)
- PRX Quantum (#3)
- *EPJ Quantum Technology* (#4)
- *npj Quantum Materials* (#5)
- *Quantum* (#7)
- *Quantum Topology (last 2 years are OA)* (#16)

Articles in journals that we do not own will likely be available through Interlibrary Loan/Document Delivery.

Databases

The Libraries' *Database Finder* (https://lib.guides.umd.edu/az.php) offers online access to databases that provide indexing and access to scholarly journal articles and other information sources. Many of these databases cover subject areas that would be relevant to this proposed program. Databases that would be useful in the field of quantum computing include *ACM Digital Library, ArXiv, IEEEXplore, and NTIS (National Technical Reports Library).* Also, three general/multidisciplinary databases, *Academic Search Ultimate (EBSCO)*, *Web of Science (Clarivate Analytics)* and *ScienceDirect (Elsevier)* are good sources of articles relevant to this topic.

In many—and likely in most—cases, these indexes offer full text copies of the relevant journal articles. In those instances in which the journal articles are available only in print format, the Libraries can make copies available to students through the Libraries' Interlibrary Loan (ILL) service (https://www.lib.umd.edu/find/request-digital/ILL/how-article). (Note: See ILL section below.)

Monographs

The Libraries regularly acquire scholarly monographs in quantum computing and allied subject disciplines. Monographs not already part of the collection can usually be added upon request. Most monographs in this subject area are available as e-books. Relevant eBook collections for this program include*: Morgan & Claypool Synthesis Digital Library, IEEE/Wiley eBooks, IET Digital Library*, and *SIAM* *eBooks*. Even in instances when the books are only available in print, students will be able to request specific chapters for online delivery through the Interlibrary Loan program.[2]

A search of the University of Maryland Libraries' WorldCat UMD catalog was conducted, using a variety of relevant subject terms. For example, using the search string <kw:("quantum computing") OR kw:("quantum information theory")> resulted in the citations of almost 700 books that we own here at UMD. A further search revealed that the Libraries' membership in the Big Ten Academic Alliance (BTAA) dramatically increases these holdings and citations as the same search string returns upwards of 2,000 results. As with our own materials, students can request that chapters be copied from these BTAA books if the books are not available electronically.

Interlibrary Loan Services

Interlibrary Loan services (https://www.lib.umd.edu/find/request/ILL) provide online delivery of bibliographic materials that otherwise would not be available online. As a result, remote users who take online courses may find these services to be helpful. Interlibrary Loan services are available free of charge.
The article/chapter request service scans and delivers journal articles and book chapters within three business days of the request--provided that the items are available in print on the UM Libraries' shelves or in microform. In the event that the requested article or chapter is not available on campus, the request will be automatically forwarded to the Interlibrary Loan service (ILL). Interlibrary Loan is a service that enables borrowers to obtain online articles and book chapters from materials not held in the University System of Maryland.

Additional Materials and Resources

In addition to serials, monographs and databases available through the University Libraries, students in the proposed program will have access to a wide range of media, datasets, software, and technology. Media in a variety of formats that can be utilized both on-site and via ELMS course media is available at McKeldin Library. GIS Datasets are available through the GIS Data Repository (https://www.lib.umd.edu/research/services/gis) while statistical consulting and additional research support is available through the Research and Learning department (https://www.lib.umd.edu/research) and technology support and services are available through the Terrapin Learning Commons Tech Desk (https://www.lib.umd.edu/visit/libraries/mckeldin/techdesk) and the STEM Library (https://www.lib.umd.edu/visit/libraries/stem).

The subject specialist librarian for the discipline, *Sarah Weiss*, also serves as an important resource to programs such as the one proposed. Through departmental partnerships, subject specialists actively

[2] Note: Please note that one limitation of these services that might create some challenges for online students is that the Libraries are not allowed to make online copies of entire books. The only way that a student can get access to a print copy of an entire book is to physically come to the Libraries and check out that book.

develop innovative services and materials that support the University's evolving academic programs and changing research interests. Subject specialists provide one-on-one research assistance online, in-person, or via the phone. They also provide information literacy instruction and can provide answers to questions regarding publishing, copyright and preserving digital works.

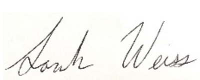
Other Research Collections

Because of the University's unique physical location near Washington D.C., Baltimore and Annapolis, University of Maryland students and faculty have access to some of the finest libraries, archives and research centers in the country vitally important for researchers in quantum computing. These include the National Institute of Technology, the National Library of Medicine, the Library of Congress, the National Archives to name just few.

Conclusion

With our substantial journals holdings and index databases, as well as additional support services and resources, the University of Maryland Libraries have resources to support teaching and learning in Masters of Professional Studies in Quantum Computing. These materials are supplemented by a strong monograph collection. Additionally, the Libraries Scan & Deliver and Interlibrary Loan services make materials that otherwise would not be available online, accessible to remote users. As a result, our assessment is that the University of Maryland Libraries are able to meet the curricular and research needs of the proposed Masters of Professional Studies in Quantum Computing.

Respectfully submitted:



Maggie Saponaro

Daniel C. Mack

Sarah Weiss | Maggie Saponaro | Daniel Mack

MS in Quantum Computing					
Five-Year Program Budget					
Tuition Revenue	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
A. Total enrolled students	9	19	20	21	23
First year enrollment	9	10	10	11	12
Second year enrollment		9	10	10	11
B. Total # of 3-credit Courses (by enrollment year)	8	10	10	10	10
# of courses offered for students in year one of the program	8	8	8	8	8
# of courses offered for students in year two of the program		2	2	2	2
C. Per Course Rate	$4,000	$4,120	$4,244	$4,371	$4,502
Total Tuition Revenue	$288,000	$403,760	$424,360	$472,058	$531,240
Direct Expenses	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
A. Instructor Salaries and Fringe	$157,556	$173,936	$179,154	$184,529	$190,065
1. Subtotal: Instructor salaries	$121,290	$133,900	$137,917	$142,055	$146,316
Average 3-credit course salary	$13,000	$13,390	$13,792	$14,205	$14,632
Program specific courses (100% FTE)	9	9	9	9	9
Shared courses (33% FTE)	1	1	1	1	1
2. Fringe Benefits: 29.9%	$36,266	$40,036	$41,237	$42,474	$43,749
Total Direct Expenses	$157,556	$173,936	$179,154	$184,529	$190,065
Total Annual Tuition Revenue	$288,000	$403,760	$424,360	$472,058	$531,240
Total Annual Direct Expenses	$157,556	$173,936	$179,154	$184,529	$190,065
Total Annual OES Administrative Fee	$28,800	$40,376	$42,436	$47,206	$53,124
Annual Distributable Revenue	$101,644	$189,448	$202,770	$240,323	$288,051

Indirect Expenses					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Administrative Salaries and Fringe	$53,692	$55,303	$56,962	$58,671	$60,431
1. Administrative Salaries	$39,596	$40,784	$42,007	$43,268	$44,566
Director (20% FTE)	$25,846	$26,621	$27,420	$28,243	$29,090
Faculty Director Stipend	$15,000	$15,450	$15,914	$16,391	$16,883
Program Manager (33% FTE)	$13,750	$14,163	$14,587	$15,025	$15,476
2. Fringe Benefits: 35.6%	$14,096	$14,519	$14,955	$15,403	15,865
Hourly Wages	$38,736	$51,648	$52,552	$53,474	$54,414
1. Hourly Wages	$36,000	$48,000	$48,840	$49,697	$50,571
Graders for program specific courses ($6K per course)	30,000	42,000	42,840	43,697	44,571
Graders for shared courses ($2K per course)	6,000	6,000	6,000	6,000	6,000
2. Hourly Wages Benefits: 7.6%	$2,736	$3,648	$3,712	$3,777	$3,843
Marketing	$2,500	$2,575	$2,652	$2,732	$2,814
1. Marketing	2,500	2,575	2,652	2,732	2,814
Equipment	$1,500	$1,545	$1,591	$1,639	$1,688
1. Equipment	1,500	1,545	1,591	1,639	1,688
Travel & Recruitment	$1,500	$1,545	$1,591	$1,639	$1,688
1. Travel & Recruitment	$1,500	$1,545	$1,591	$1,639	$1,688
Total Indirect Expenses	$97,928	$112,616	$115,349	$118,155	$121,035

Net Revenue	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
OES Distribution to CMNS	$101,644	$189,448	$202,770	$240,323	$288,051
Indirect Expenses	$97,928	$112,616	$115,349	$118,155	$121,035
Balance	**$3,716**	**$76,832**	**$87,421**	**$122,169**	**$167,016**

Learning Outcomes and Assessment

Learning Outcomes

Explain principles of quantum physics as they apply to quantum computing.
Develop quantum computing programs and implement them on quantum computing platforms.
Distinguish the elements of a quantum computing algorithm and differentiate it from a classical algorithm.
Describe current quantum computing hardware, and examine the effects of its current state of maturity on the design of quantum computing algorithms.
Discuss and implement quantum computing paradigms to solve problems in quantum networks and quantum machine learning.
Compare quantum thermodynamics and quantum information theory and how they relate to classical information theory.

Assessment for Learning Outcomes

Assessment for learning outcomes will be done via graded quizzes, exams, and assignments. Assignments will include a variety of professional focused work products where students will be applying learning to real life examples, such as quantum encryption and quantum key distribution, quantum chemistry, discrete combinatorial optimization, and quantum telecommunications. These applied learning and experiential opportunities will consist of case studies, simulations and oral presentations. To create this body of work students will need to demonstrate proficiency writing code in cloud quantum computing environments such as Amazon Braket, IBM Quantum, Azure Quantum, or similar cloud options.

MSQC601: The Mathematics and Methods of Quantum Computing

Learning objectives

The aim of quantum mechanics is to describe the movement of the atomic particles that matter is composed of. It is a mechanical theory that replaces classical mechanics in the domain of the microscopic world. Its origin dates back to the works of Heisenberg and Schrödinger. This theory has borne many technological advancements of which its latest ramification has been the development of quantum computers. This course will provide the student with the necessary mathematical tools and background knowledge to understand, model, and conceptualize quantum computing building blocks and systems.

Course outline - (under revision, see working copy of course)

Elements of real and complex analysis
Linear Algebra Review
Probability Review
Numerical Optimization
Elements of Differential Equations
Introductory Functional Analysis
Basic Notions of Quantum Mechanics
Elements of Theory and Practice of Computation
Quantum Gates and Circuits for Elementary Calculations

Prerequisites

Advanced calculus, linear algebra.

Grading

Quizzes (20%)
Homework (40%)
Midterm exam (20%)
Final exam (20%)

MSQC602: Physics of Quantum Devices

Learning objectives

An introduction to quantum physics with emphasis on topics at the frontiers of research, and developing understanding through exercises.
The Physics of the very small course aims to build a bridge between natural principles such as light and atoms and a variety of modern applications.
This course will provide the student with the necessary physical intuition and background information on quantum physics so that to be able to understand and appreciate a variety of applications in quantum computing such as quantum currency, encryption, random number generation. A **quantum money** scheme is a quantum cryptographic protocol to create and validate banknotes which are impossible to forge. Encryption is a means **of securing digital data using one or more mathematical techniques**, along with a password or "key" used to decrypt the information. **Random number generation** is a process by which, often by means of a **random**

number generator (**RNG**), a sequence of numbers or symbols that cannot be reasonably predicted better than by random chance is generated. This means that the particular outcome sequence will contain some patterns detectable in hindsight but unpredictable to foresight.

Course outline
The Schrödinger equation
Probabilities and probability amplitudes
Qubits
Waves: $c = \lambda v$
Interference and polarization of light
Quantization of light: $E = hv$
Projective measurement: optical polarization
Superposition principle: optical polarization
State preparation/analysis with polarizers and beamsplitters
Quantum random number generation
Quantum money
Quantum cryptography
Parametric down conversion/correlated photons
Recent photon Einstein-Podolsky-Rosen experiments
Optical and material qubits (spins)
Quantum gate operations

Prerequisites
Advanced calculus, algebra, linear algebra, elements of differential equations, complex numbers.

Grading
Quizzes (20%)
Homework (40%)
Midterm exam (20%)
Final exam (20%)

<u>MSQC603/MSML603: Principles of Machine Learning</u>

Learning objectives
Machine learning aims to make computer systems learn from experience. Learning systems are not manually programmed to solve a problem, but instead they are based on examples of how they should behave, or from trial-and-error experience trying to solve the problem. This requires learning algorithms to specify how the system should change its behavior as a result of experience. Machine learning is an interdisciplinary field, with historical roots in computer science, statistics, pattern recognition, and even neuroscience and physics. This course will focus on the classic machine learning methods that have been valuable and successful in practical applications. This course will cover various methods, with the aim of explaining the circumstances under which each is most appropriate. We will also discuss more advanced deep neural networks.

Course outline
Decision Tree
Linear regression
Logistic regression
SVM
Boosting
Clustering
Dimensionality reduction
Autoencoders (standard, denoising, contractive, etc etc)
Variational Autoencoders
Convolutional Neural Networks
Adversarial Generative Networks
Generative models and Discriminative models
Generative models with different data representations
Dynamical systems: RNNs
Attention and Memory Models
Applications with supervised and unsupervised learning

Prerequisites
Linear Algebra, Analysis, Probability, some notions of Signal Processing, and Numerical Optimization.

Grading
Homework (25%)
--Presentation including demonstration of running results with code
--Presentation about paper reviewing

Final project (15%)
--Project proposal in your own area with deep learning (middle term presentation)
--Final presentation to show your results

Final exam (60%)

MSQC604: Quantum Computing Architectures and Algorithms

Learning objectives
Quantum computing aims to utilize quantum properties of matter to efficiently solve problems that classical computing systems would take too long to solve. This course reviews modern noisy-intermediate scale quantum (NISQ) quantum computing architectures and algorithms for these platforms. We focus on mapping of optimization and machine learning problems onto NISQ architectures and also discuss how to leverage state-of-the-art classical simulation methods for these quantum-inspired algorithms. We review several NISQ architectures and associated software interfaces, we analyze performance for optimization and statistical sampling. We survey current literature to review and implement methods for mapping optimization and machine learning problems onto NISQ architectures and modern simulators and use them to solve and study example problems.

Course outline
Introduction to quantum computing (QC)
- Introduction to key mathematical concepts and notations for quantum computation
- Mathematical description of qubit mechanics
- Mathematical description of qubit controls and quantum gates
- Quantum logic gates

Overview of basic concepts and vocabulary of QC
- FTQ - Fault tolerant QC
- NISQ - Noisy intermediate scale QC
- Architecture types (superconducting, ion-trap, photon, neutral atom, annealing)
- Quantum computing extensions of key linear algebra operations
- Quantum computing extensions to key probability concepts

Algorithms & Analysis
- Mapping problems onto Ising model/Boltzmann Machines
- Overview of quantum algorithms landscape
- Optimization & Sampling methods
- Quantum Annealing
- QAOA (Quantum Approximate Optimization Algorithm)
- Trainability of quantum neural networks and barren plateaus

Software tools for QML & Optimization
- Tensorflow/PyTorch
- Cirq, Qiskit, Forrest, Ocean
- Tensorflow Quantum

Quantum Machine Learning
- Boltzmann machines
- Born machines
- Support Vector Machines
- Boosting
- Energy-based models
- Variational Autoencoders
- GANs

Prerequisites
MSQC601 The Mathematics and Methods of Quantum Computing,
MSQC602 The Physics of the Very Small and its Technological Ramifications

Grading
Quizzes (20%)
Homework (40%)
Midterm exam (20%)
Final exam (20%)

MSQC605: Advanced Quantum Computing and Applications

Learning objectives

When Richard Feynman first introduced the concept of quantum computers it was posed for the purpose of simulating nature. Today quantum simulation remains one of the likely first applications to benefit from quantum computers. This course introduces key concepts required for quantum simulation, and builds tools for performing quantum simulation using state-of-the-art architectures. We introduce classical schemes, like tensor networks, and machine learning approaches, that can be used for these simulations on CPU/GPU architecture. We survey current literature to review and implement methods of quantum simulation and use them to solve and study example problems.

Course Outline

Introduction to quantum simulation (QC)

- Introduction to quantum chemistry & materials

Quantum simulation algorithms

- Quantum Fourier Transform
- Quantum Phase Estimation
- Variational Quantum Eigensolver
- Hamiltonian simulation
- Quantum Monte Carlo

Methods for Quantum Simulation

- Tensor networks
- Matrix Product States
- Density matrix renormalization group
- Machine learning approaches for simulation

Prerequisites

MSQC604 Quantum Computing Architectures and Algorithms

Grading

Quizzes (20%)
Homework (40%)
Midterm exam (20%)
Final exam (20%)

MSQC606: Practical Quantum Computing

Learning objectives

Quantum computation is a rapidly growing field at the intersection of physics and computer science, electrical engineering and applied math. While instrumentation of quantum computers is in its infancy, quantum algorithms are being developed to provide efficient solutions to various computational problems.

This course covers basic quantum computing, including quantum circuits, significant quantum algorithms, and hybrid quantum-classical algorithms, with focus on applying the concepts to programming existing and near-future quantum computers. Example codes, homework assignments, and class projects will employ Python modules to handle the data exchange with quantum computers.

Course Outline
Single-qubit systems: properties, representations, basic operations
Tutorial (optional): basics of Python programming language using Jupyter notebooks. [Franz, make this part of the course, don't mark it as optional - Alfredo comment]
Multi-qubit systems: superposition, entanglement, controlled operations.
Applications: teleportation, quantum repeater (entanglement swapping).
Basic quantum algorithms:
- Grover's algorithm; Quantum Amplitude Amplification
- Quantum Fourier Transform
- Quantum Phase Estimation
- Shor's algorithm: factoring and period finding
- Hamiltonian simulation
State of instrumentation:
- Superconductors, photonic networks, quantum dots, neutral atoms traps, ion traps; (optional: visit of IonQ headquarters)
- Quantum error correction and mitigation methods
Near-term algorithms:
- Quantum annealing
- Quantum approximate optimization algorithm
- Variational quantum eigensolver
- SLE solver: HHL and derived algorithms
- Quantum Machine Learning: qSVM, qPCA, qGAN

Prerequisites
MSQC601 The Mathematics and Methods of Quantum Computing
MSQC602 The Physics of the Very Small and its Technological Ramifications

Grading
Homework (50%)
- Programming exercises: application of introduced concepts and methods
Final project (20%)
- Worked-out project using a near-term quantum algorithm
Midterm exam (15%)
Final exam (15%)

<u>MSQC607: Advanced Topics in Quantum Computing</u>

Learning objectives

This course will showcase a variety of topics from which students can select one, or come up with one of their own, and proceed to study it in depth. The students will make presentations of their findings to class by citing literature and code implementations where appropriate, and culminate with the writing of a scholarly paper on the topic chosen.

Course Outline

Prerequisites
All previous core courses

Grading
Quizzes (20%)
Homework (40%)
Midterm exam (20%)
Final exam (20%)

MSQC610: Quantum Machine Learning

Learning objectives
In this course we explore what quantum computing can contribute to data mining and machine learning. We focus on exploring what kind of speedups are possible using quantum computing as well as the storage capacity of quantum associative memories, for example.

Course Outline
Prerequisites
Grading
Quizzes (20%)
Homework (40%)
Midterm exam (20%)
Final exam (20%)

MSQC611: Quantum Networks

Learning objectives
The need to communicate in a network the quantum states of qubits will necessitate the existence of a “quantum Internet.” Quantum signals are weak and very fragile and in general cannot be copied or amplified. The area of quantum networking explores how to combine well established networking techniques with quantum repeaters to transmit quantum information over long distances. In this course we explore quantum repeaters and their applications to telecommunications.

Course Outline
Prerequisites
Grading
Quizzes (20%)
Homework (40%)
Midterm exam (20%)
Final exam (20%)

MSQC612: Quantum Computing Hardware

Learning objectives
There are a variety of technologies that implement qubits. In this course we explore these technologies.

Course Outline
Prerequisites
Grading
Quizzes (20%)
Homework (40%)
Midterm exam (20%)
Final exam (20%)

MSQC613: Quantum Monte Carlo and Applications (course still under revision)

Learning objectives
In this course we study the quantum Monte Carlo method and explore applications in diverse areas ranging from correlated systems, chemistry, quantum mechanic systems simulations.

Course Outline
Prerequisites
Grading
Quizzes (20%)
Homework (40%)
Midterm exam (20%)
Final exam (20%)

MSQC614: Quantum Information Theory

Learning objectives
Quantum information theory synthesizes three major themes: quantum physics, computer science, and information theory. At the core of information theory lies the work of Claude E. Shannon, which we review in this course, and we present and study three problems related to his work and subsequent extension to quantum computing. These are, compressing quantum

information, transmitting classical and quantum information through noisy quantum channels, and quantifying, characterizing, transforming, and using quantum entanglement.

Course Outline
Prerequisites
Grading
Quizzes (20%)
Homework (40%)
Midterm exam (20%)
Final exam (20%)

MSQC615: Quantum Thermodynamics

Learning objectives
Quantum thermodynamics is an emerging field that offers fundamental insights into energy, information, and their relationship. Thermodynamics originally described “classical” systems—everyday objects formed from many particles. The theory has recently extended to the quantum domain of single electrons and few atoms, which behave in ways impossible for everyday objects. For example, quantum particles correlate strongly through “entanglement,” which gives one particle a surprisingly large amount of information about others. We will explore how scientists are leveraging such quantum phenomena in technologies such as quantum computers.

Course Outline
Prerequisites
Grading
Quizzes (20%)
Homework (40%)
Midterm exam (20%)
Final exam (20%)

UNIVERSITY OF MARYLAND
OFFICE OF THE PRESIDENT

1101 Thomas V. Miller, Jr. Administration Building
College Park, Maryland 20742
301.405.5803 TEL
301.314.9560 FAX

February 29, 2024

Dr. Sanjay Rai
Acting Secretary
Maryland Higher Education Commission
6 N. Liberty Street
Baltimore, MD 21201

Dear Secretary Rai:

I am writing to request approval for a new Master of Science program in Quantum Computing. The program will be offered both on-campus and through distance education. The proposal for the new program is attached. I am also submitting this proposal to the University System of Maryland for approval.

The proposal was endorsed by the appropriate faculty and administrative committees. I also endorse this proposal and am pleased to submit it for your approval.

Sincerely,

Darryll J. Pines
President
Glenn L. Martin Professor of Aerospace Engineering

DJP/mdc

cc: Candace Caraco, Associate Vice Chancellor
Jennifer King Rice, Senior Vice President and Provost
Amitabh Varshney, Dean, College of Computer, Mathematical, and Natural Sciences

Office Use Only: PP#

Cover Sheet for In-State Institutions
New Program or Substantial Modification to Existing Program

Institution Submitting Proposal	University of Maryland, College Park

Each action below requires a separate proposal and cover sheet.

- ◉ New Academic Program
- ○ New Area of Concentration
- ○ New Degree Level Approval
- ○ New Stand-Alone Certificate
- ○ Off Campus Program
- ○ Substantial Change to a Degree Program
- ○ Substantial Change to an Area of Concentration
- ○ Substantial Change to a Certificate Program
- ○ Cooperative Degree Program
- ○ Offer Program at Regional Higher Education Center

Payment Submitted: ◉ Yes ○ No | Payment Type: ◉ R*STARS # JE322729 ○ Check # JE322729 | Payment Amount: 850 | Date Submitted: 2/26/2024

Department Proposing Program	College of Computer, Mathematical and Natural Sciences
Degree Level and Degree Type	Master's; Master of Science
Title of Proposed Program	Quantum Computing
Total Number of Credits	30
Suggested Codes	HEGIS: 070102 / CIP: 27.0304
Program Modality	○ On-campus ○ Distance Education (fully online) ◉ Both
Program Resources	◉ Using Existing Resources ○ Requiring New Resources
Projected Implementation Date (must be 60 days from proposal submission as per COMAR 13B.02.03.03)	◉ Fall ○ Spring ○ Summer Year: 2024
Provide Link to Most Recent Academic Catalog	URL: https://academiccatalog.umd.edu/
Preferred Contact for this Proposal	Name: Michael Colson
	Title: Senior Coordinator for Academic Programs
	Phone: (301) 405-5626
	Email: mcolson@umd.edu
President/Chief Executive	Type Name: Darryll J. Pines
	Signature: [signature] Date: 02/29/2024
	Date of Approval/Endorsement by Governing Board:

Revised 1/2021

A. Centrality to the University's Mission and Planning Priorities

Description. The University of Maryland, College Park currently offers an iteration of its Master of Professional Studies (MPS) in Quantum Computing. The goal of this proposal is to move the existing curriculum out from under the MPS umbrella and create a standalone Master of Science (MS) degree program in Quantum Computing. The program curriculum is not changing. The program consists of 30-credit course work and will be offered both in-person and through a fully online modality.

The transition to an MS will allow the program to be properly designated with a STEM CIP code. CIP codes that classify programs as STEM programs have become increasingly important as the development of STEM programs has become more incentivized. The current MPS program does not appear in the results for STEM program searches based on CIP codes or in STEM program reports for the institution, and therefore the state, despite the program's STEM content. Current students will benefit from having their program associated with a STEM CIP code. In particular, current international students studying here on F-1 visas will be able to qualify for an extended optional practical training (OPT) after they graduate and will thereby be more marketable to prospective employers.

The program will continue to provide students with the foundational, practical, and theoretical topics of quantum computing. Participants will discover current state-of-the-art quantum computing technology and areas of application, while also exploring its origins, evolution, and possible future states of this technology.

Relation to Strategic Goals. As written in our mission statement, "UMD embraces its flagship status and land-grant mission to share its research, educational, cultural, and technological strengths to bolster economic development, sustainability, and quality of life in Maryland and beyond." The Master of Science in Quantum Computing aims to provide training and advanced knowledge in quantum computing with a focus on practical education for working professionals. This program will contribute to the development of the emerging labor market of quantum computing scientists and engineers in the state of Maryland, and the nation. Other countries, such as China, have invested greatly recently in these scientific and technological sectors. The potential benefits of early discoveries and implementation of technological solutions that use quantum computing promise to generate important societal and economic benefits in the long term.

UMD has made quantum research and training a priority. UMD has more than 30 years of involvement in quantum research, more than 200 quantum researchers, and has produced more than 100 Ph.D.'s in physics with a quantum science focus. UMD ranks in the top 10 nationally in quantum physics programs.[1] As UMD president Darryll J. Pines, who singled out Quantum Computing as one of UMD's "new frontiers," has said, "Quantum can be for us what

[1] https://www.usnews.com/best-graduate-schools/top-science-schools/quantum-physics-rankings

silicon was for Silicon Valley. This is that big play for the state of Maryland and this entire region."[2]

In our recently approved strategic plan, *Fearlessly Forward: In Pursuit of Excellence and Impact for the Public Good*, UMD promises to "partner to advance the public good." One of the goals of this commitment is to "Catalyze innovation and entrepreneurship for inclusive economic development." One of the specific objectives of this commitment is to "Improve the vitality of the state of Maryland by growing and supporting the next generation of diverse innovators, creators, entrepreneurs, artists, and small businesses." Establishing this master's program with a STEM CIP code will attract to Washington, D.C.'s Maryland suburbs more students who will advance their careers, enhance their organizations, and launch their own businesses, thereby bringing economic growth to the area.

Funding. Just as with the current MPS program, the MS program will be self-supporting with tuition revenue. Since the program already exists as a professional studies program, it does not require new resources. UMD already has the instructional, physical, and administrative resources to offer the program.

Institutional Commitment. UMD is committed to leveraging its strengths in technological and mathematical fields to provide highly skilled professionals for the state's workforce needs. In the unlikely event that the program is no longer financially viable, program faculty and staff would continue to support and teach the necessary courses to allow enrolled students to complete their degree within a reasonable and customary period of time.

B. Critical and Compelling Regional or Statewide Need as Identified in the State Plan

Need. The need for this program can be summed up in COMAR 13B.02.03.08B(3): *Occupational and professional needs relative to upgrading vocational/technical skills or meeting job market requirements.* The Washington, D.C. area is already one of the top areas in the country for organizations with quantum research activities. With many professionals already here or thinking of moving to this area, they will see this program as a way to upgrade their technical skills and career prospects. A program like this that produces a highly-technical set of graduates is an essential piece for a region and state that is trying to develop its economic strength in highly technical industries.

The National Institute of Standards and Technology has made substantial investments on UMD's campus to pursue research in quantum physics and technology over the past decades taking into account the vast faculty expertise in quantum physics and engineering. Campus has seen the creation of the Joint Quantum Institute (JQI), the Joint Center for Quantum Information and Computer Science (QuICS), and the Quantum Technology Center (QTC). This,

[2] https://quantum.umd.edu/

combined with the need to create a skilled professional workforce in quantum computing, makes UMD a natural choice to create an educational offering for this workforce development.

State Plan. The proposed program aligns broadly with the 2022 *Maryland State Plan for Postsecondary Education*, specifically Priority 5, "Maintain the commitment to high-quality postsecondary education in Maryland," in particular, the Action Item to "Identify innovative fields of study." The main educational objective of the program is to prepare the individual to be ready to apply the principles and techniques of quantum computing to the solution of a variety of problems in optimization, secure communications, encryption, materials discovery and any such problems that require considerable computing resources. Students will be able to differentiate the many technologies currently used to implement quantum computers and compare their intrinsic strengths and limitations. Finally, students will gain the ability to make appropriate business decisions for success when quantum technologies reach maturity in the future. This program's ability to apply state-of-the-art scientific research in the physical sciences with technological and business development will be attractive for those in private industry, as well as for potential entrepreneurs.

C. Quantifiable and Reliable Evidence and Documentation of Market Supply and Demand in the Region and State

National and state projections show a dramatic increase in the number of computer and information research positions. The United States Bureau of Labor Statistics indicates a 23% increase in the next 10 years with more than 8,300 jobs being added. Maryland state occupational projections show a 16.78% increase from 2020-2030 with more than 470 positions being added. Computer and information research is just one related occupation. The National Center for Education Statistics indicates via its CIP SOC Crosswalk that Computational and Applied Mathematics programs (CIP: 27.0304) are directly linked to a variety of occupations: Natural Science Managers, Actuaries, Mathematicians, Statisticians, Data Scientists, and Postsecondary Teachers. This program is a highly technical program that will significantly enhance a professional's skills and abilities. The MS in Quantum Computing will qualify graduates for more highly specialized positions and provide highly technical areas to explore for emergent and experienced entrepreneurs.

D. Reasonableness of Program Duplication

Capitol Technology University is the only university that offers a master's level program in quantum computing. Its offering targets experienced professionals in the quantum computing field to train them in research techniques as they pertain to quantum computing. Its program is structured for experienced professionals in the quantum computing field who are looking to develop research skills in it. Contrasting with this focus, UMD's program targets recent undergraduate students or professionals with STEM backgrounds looking to enter the quantum computing field, for which we assume no prior experience in quantum computing. Otherwise, there are no master's programs in the Maryland state institutions that specifically focus on quantum computing. The State of Maryland is seeing tremendous expansion in organizations engaging in quantum computing activities and research and our offering will expand opportunities for state and regional professionals. For students living in the Washington, D.C. area in particular who want an in-person graduate program, only the University of Maryland, College Park location is within the national capital beltway and serviced by the Washington Metropolitan Area Transit Authority's bus and rail systems.

E. Relevance to Historically Black Institutions (HBIs)

As indicated above, only Capitol Technology University has a master's degree program in quantum computing, which serves a different audience and has a different focus compared to UMD's offering. Master's levels programs in computing exist at Morgan State (Advanced Computing) and Bowie State (Computer Science). The program offered by Morgan State is more general in nature and only offers one course specific to quantum computing (quantum cryptography). In the case of Bowie State, the courses offered in their master's program have no quantum computing specific content. UMD's program goes into greater depth in quantum computing, with core courses in the mathematics and physics of quantum computing and several electives specifically related to quantum computing. These range from the study of the hardware of quantum devices, to areas of application such as quantum networks, quantum cryptography, quantum machine learning, and in-depth study of current state of the art quantum computing hardware implementations and how these implementations guide quantum algorithm design. The UMD program would complement Morgan State's and Bowie State's offerings and provide an opportunity to strengthen the offerings in the state rather than competing.

F. Relevance to the identity of Historically Black Institutions (HBIs)

We do not anticipate any negative impacts on the special identities of the HBIs in the state of Maryland. As mentioned above, UMD has been engaged in quantum research for more than 30 years. We also believe that this is a growing field of significant importance to economic development in the Baltimore and Washington areas, and therefore a critical growth area for the state economy as a whole. The state should encourage the development of more highly specialized technical programs in different geographic areas to encourage inclusive economic development. Furthermore, our location within the national capital beltway that is serviced by the Washington Metropolitan Area Transit Authority has traditionally made UMD a favorable campus for professionals working in and around Washington, D.C.

G. Adequacy of Curriculum Design, Program Modality, and Related Learning Outcomes

Curricular Development. In recent years, the federal government and private sector have substantially increased funding for research and development of quantum technologies, including quantum computing. This new area of economic activity requires a highly trained and skilled labor force to take advantage of this technological era and contribute to the solution of problems at the local, regional, and national levels. Conversations with experts at the National Institute for Standards and Technology (NIST), as well as the Universities Space Research Association (USRA), have confirmed that there are skills gaps in the current workforce and more trained experts in these areas are required. UMD has seen an exponential growth in investments and the creation of multiple centers, institutes and departments bringing in research talent and economic resources in quantum physics and quantum computing. This program will take advantage of this ecosystem of quantum expertise on campus and complement UMDs development by adding an educational component.

Faculty Oversight. Appendix A includes a list of faculty that will be teaching in the program. Our faculty members come from a variety of technical backgrounds, including engineering, mathematics, computer science, physical sciences, and mathematics.

Educational Objectives and Learning Outcomes. The learning outcomes for the program are as follows:

1. Explain principles of quantum physics as they apply to quantum computing.
2. Develop quantum computing programs and implement them on quantum computing platforms.
3. Distinguish the elements of a quantum computing algorithm and differentiate it from a classical algorithm.
4. Describe current quantum computing hardware and examine the effects of its current state of maturity on the design of quantum computing algorithms.
5. Discuss and implement quantum computing paradigms to solve problems in quantum networks and quantum machine learning.
6. Compare quantum thermodynamics and quantum information theory and how they relate to classical information theory.

Institutional assessment and documentation of learning outcomes. Assessment for learning outcomes will be done via graded quizzes, exams, and assignments. Assignments will include a variety of professional focused work products where students will be applying learning to real life examples, such as quantum encryption and quantum key distribution, quantum chemistry, discrete combinatorial optimization, and quantum telecommunications. These applied learning and experiential opportunities will consist of case studies, simulations and oral presentations. To create this body of work students will need to demonstrate proficiency writing code in cloud quantum computing environments such as Amazon Braket, IBM Quantum, Azure Quantum, or similar cloud options.

Course requirements. The program requires seven three-credit courses for a total of 21 credits and three three-credit electives from a short list.

Course Number	Course Title	Credits
MSQC601	Mathematics and Methods of Quantum Computing	3

MSQC602	The Physics of Quantum Devices	3
MSQC603	Principles of Machine Learning	3
MSQC604	Quantum Computing Architectures and Algorithms	3
MSQC605	Advanced Topics in Quantum Computing	3
MSQC606	Practical Quantum Computing	3
MSQC607	Advanced Topics in Quantum Computing	3
Electives (Choose three)		9
MSQC610	Quantum Machine Learning	
MSQC611	Quantum Networks	
MSQC612	Quantum Computing Hardware	
MSQC613	Quantum Monte Carlo and Applications	
MSQC614	Quantum Information Theory	
MSQC615	Quantum Thermodynamics	

A list of courses and descriptions is included in Appendix B

General Education. Not applicable for our graduate programs.

Accreditation or Certification Requirements. No accreditation or licensure is required for the program.

Other Institutions or Organizations. The offering unit is not planning to contract with another institution or non-collegiate organization for this program.

Student Support. The Science Academy in the College of Computer, Mathematics and Natural Science will provide administrative coordination for the program, in collaboration with the Office of Extended Studies. Students will be supported through the Science Academy for academic guidance and advising. They will also have access to the Graduate School Counseling and the Counseling Center resources. The Science Academy Program Manager will be the first point of contact for students, while the Office of Extended Studies, which provides administrative services for a host of professional programs, provides student and program services, such as admission support, scheduling, registration, billing and payment, graduation, and appeals. Students will see admission criteria, financial aid resources, costs, and complaint procedures on both the Science Academy website and the Extended Studies program page. For technical aspects of both the in-person and online versions of the program, specific technological competence and equipment will be included in the admission criteria. Learning management information will also be included in these materials.

Marketing and Admissions Information. Students will see admission criteria, financial aid resources, and costs on both the Science Academy website and the Extended Studies program page.

H. Adequacy of Articulation

Not applicable for this graduate program.

I. Adequacy of Faculty Resources

Program faculty. Appendix A contains a list of faculty members who will teach in the program. Faculty will primarily be from engineering, mathematics, computer science, physical sciences, and mathematics backgrounds.

Faculty training. Faculty teaching in the program will use the university's learning management system along with its extensive electronic resources. They will have access to instructional development opportunities available across the College Park campus, including those offered as part of the Teaching and Learning Transformation Center, many of which are delivered in a virtual environment. Instructors will work with the learning design specialists on campus to incorporate best practices when teaching in the online environment.

J. Adequacy of Library Resources

The University of Maryland Libraries assessment concluded that the Libraries are able to meet, with current resources, the curricular and research needs of the program.

K. Adequacy of Physical Facilities, Infrastructure, and Instructional Resources

All physical facilities, infrastructure, and instructional equipment are already in place. No new facilities are required as this program already exists as an MPS program. For the online components of the coursework, UMD maintains an Enterprise Learning Management System (ELMS). ELMS is a Web-based platform for sharing course content, tracking assignments and grades, and enabling virtual collaboration and interaction. All students and faculty have access to UMD's electronic mailing system.

L. Adequacy of Financial Resources

Tables 1 and 2 contain the details of resources and expenditures.

Table 1 Resources:
The program will be self-supported through tuition revenue. There are no start up costs because the program is already in operation as a Master of Professional Studies.

1. Line 1 shows no reallocated funds since the program is supported by tuition from existing students.
2. Graduate students will be paying tuition by the credit. We anticipate that 9 full-time students will be taking 8 courses per year and 9 part-time students (term-based) will take 8 courses per year.

3. The tuition rate will be $4000 per three-credit course with an assumed annual increase of 3%.
4. No external sources of funding are assumed.
5. No other sources of funding are assumed.

Table 2 Expenditures:

1. Faculty salaries are based on cost per course.
2. We assume an annual increase of 3% in salaries with a corresponding 33% benefits rate.
3. Administrative positions include an academic director (1 FTE) who will provide administrative support.
4. Included is an annual 3% increase and a corresponding benefits rate of 33% for the academic director and program manager positions.
5. Other expenditures include an administrative fee for UMD's Office of Extended Studies and a modest budget for marketing, equipment, and travel and recruitment.

M. Adequacy of Program Evaluation

Formal program review is carried out according to the University of Maryland's policy for Periodic Review of Academic Units, which includes a review of the academic programs offered by, and the research and administration of, the academic unit (http://www.president.umd.edu/policies/2014-i-600a.html). Program Review is also monitored following the guidelines of the campus-wide cycle of Learning Outcomes Assessment (https://irpa.umd.edu/Assessment/loa_overview.html). Faculty within the department are reviewed according to the University's Policy on Periodic Evaluation of Faculty Performance (http://www.president.umd.edu/policies/2014-ii-120a.html). Since 2005, the University has used an online course feedback survey instrument for students that standardizes course feedback across campus. The course survey has standard, university-wide questions and allows for supplemental, specialized questions from the academic unit offering the course.

N. Consistency with Minority Student Achievement goals

The primary recruitment activities will be via the Science Academy, the offering unit for this program. The Science Academy uses a diverse, targeted approach when recruiting students. This digital strategy focuses on UMD alumni, current UMD graduating seniors, and working professionals in the Washington, D.C. metropolitan area. The admissions review process reviews for not only academic readiness, but also diversity in experiences, industries, backgrounds, and career aspirations to recruit a diverse student body.

To attract a diverse student population, we will engage in the following activities:

• Representing the program in educational fairs, conferences and events, e.g. the National Leadership Conference of the National Society of Black Engineers, GEM Grad Labs.
• Advertising the program to the National Society of Black Engineers (NSBE), the Society of Women Engineers (SWE), and the Association for Women in Computing (AWC).
• Direct mailing and email campaigns to domestic and international colleges
• Outreach to UMD Campus organizations and clubs
• Holding online (virtual) open houses, information sessions and career panels
• Outreach to US Military to attract veterans
• Social media and online advertising
• Exploring establishing graduate scholarships to provide financial aid to underrepresented minority applicants

Once enrolled, the Science Academy staff, and faculty are committed to creating and fostering a supportive environment for all students to thrive. The staff regularly shares resources and opportunities for counseling, support, and funding. All students are expected to complete and honor the TerrapinSTRONG orientation and initiatives. TerrapinSTRONG is an onboarding course for all new faculty, staff, and students that "introduces and infuses its vision of inclusion and our institutional values across the university to create a more cohesive identity and a stronger commitment to community, connection and inclusion" (see https://terrapinstrong.umd.edu/). Students in the program are encouraged to take part in Graduate School programs that address diversity and inclusion in higher education, build communities of support and success, and create meaningful dialogue among graduate students. Such programs include "Cultivating Community Conversations" and the "Annual Office of Graduate Diversity and Inclusion’s Spring Speaker Services." Faculty that are involved in the Science Academy represent many departments, have a diversity of appointments (both tenure track, professional track, and adjunct) exposing students to many future career paths. The Science Academy and faculty provide student advising, academic support, and career guidance to students to retain all students and support timely graduation.

Our student retention efforts will consist of:
• Holding “Women in Engineering, Computing and STEM” seminars to address the obstacles faced by women in today's technical workplace and guide our women students to maneuver through the internship and job application process.
• Requiring students to attend mandatory advising sessions with the program adviser to ensure that the students’ study plans are in line with their interests and career goals, and that the students make satisfactory progress toward meeting the degree requirements.
• Implementing an early warning system that detects students struggling with core courses and alerts the academic advisor, who meets with the students and designs a study plan to get them back on track.

O. Relationship to Low Productivity Programs Identified by the Commission

N/A

P. Adequacy of Distance Education Programs

The distance-education version of the program will be entirely online. This will allow the program to reach a wider audience, including those in the Washington, D.C. area whose professional commitments may not allow for regular travel to College Park. The online curriculum will be the same as the in-person curriculum. Learning outcomes, academic rigor and program curricula will be exactly the same for the online program as it is for the on-campus program. The program will go through periodic evaluations, at least every three years, by the Science Academy leadership and academic department chairs. Students will have access to the same services that online students and will be advised by both the Science Academy and the Office of Extended Studies.

Table 1: Resources

Resources Categories	Year 1	Year 2	Year 3	Year 4	Year 5
1. Reallocated Funds	$0	$0	$0	$0	$0
2. Semester-Based Revenue (by year)	$288,000	$293,760	$299,635	$305,628	$311,740
a. Semester-based Annual Students	9	9	9	9	9
b. Semester-based Annual Courses	8	8	8	8	8
3. Term-Based Revenue (by year)	$288,000	$293,760	$299,635	$305,628	$311,740
c. Term-based Annual Students	9	9	9	9	9
d. Term-based Annual Courses	8	8	8	8	8
4. Tuition Per Course Rate (assumes 2% increase)	$4,000	$4,080	$4,162	$4,245	$4,330
5. Grants, Contracts, & Other External Sources	$0	$0	$0	$0	$0
6. Other Sources	$0	$0	$0	$0	$0
Total Tuition Revenue	**$576,000**	**$587,520**	**$599,270**	**$611,256**	**$623,481**

Table 2: Expenditures

Expenditure Categories	Year 1	Year 2	Year 3	Year 4	Year 5
1. Faculty (b+c below)	$172,900	$178,087	$183,430	$188,932	$194,600
a. #FTE	1.0	1.0	1.0	1.0	1.0
b. Total Salary	$130,000	$133,900	$137,917	$142,055	$146,316
c. Total Benefits	$42,900	$44,187	$45,513	$46,878	$48,284
2. Admin. Staff (b+c below)	$52,663	$54,243	$55,870	$57,546	$59,272
a. #FTE	1.0	1.0	1.0	1.0	1.0
b. Total Salary	$39,596	$40,784	$42,007	$43,268	$44,566
c. Total Benefits	$13,067	$13,459	$13,862	$14,278	$14,707
3. Total Support Staff (b+c below)	$0	$0	$0	$0	$0
a. #FTE	0.0	0.0	0.0	0.0	0.0
b. Total Salary	$0	$0	$0	$0	$0
c. Total Benefits	$0	$0	$0	$0	$0
4. Graduate Assistants (b+c)	$0	$0	$0	$0	$0
a. #FTE	0.0	0.0	0.0	0.0	0.0
b. Stipend	$0	$0	$0	$0	$0
c. Tuition Remission	$0	$0.00	$0	$0.00	$0
5. Equipment	$3,000	$3,000	$3,000	$3,000	$3,000
6. Library	$1,500	$5,000	$5,000	$5,000	$5,000
7. Hourly Workers	$50,000	$51,500	$53,045	$54,636	$56,275
8. Other Expenses: Operational Expenses	$25,000	$25,750	$26,523	$27,318	$28,138
TOTAL (Add 1 - 8)	**$305,063**	**$317,580**	**$326,867**	**$336,433**	**$346,286**

Appendix A: Faculty Information- Bioinformatics and Computational Biology

The following faculty members are projected to teach in the program. All faculty are full-time unless otherwise indicated.

Name	Highest Degree Earned, Program, and Institution	University of Maryland, College Park Title (indicate if part-time)	Courses
Babak Azimi-Sadjadi	Ph.D., Electrical and Computer Engineering, UMD	Visiting Lecturer	DATA/MSML/BIOI/MSQC 603: Principles of Machine Learning
Maria Cameron	Ph.D., Mathematics, University of California - Berkeley	Associate Professor	Curriculum Advisor
Charles Clark	Ph.D., Physics, University of Chicago	Adjunct Professor	MSQC 602: Physics of quantum devices
Avik Dutt	Ph.D., Electrical and Computer Engineering, Cornell University	Assistant Professor	Curriculum Advisor
Nicole Yunger Halpern	Ph.D., Physics, California Institute of Technology	Adjunct Asst. Professor	Curriculum Advisor
Franz Klein	Ph.D., Physics, University of Bonn (Germany)	Engineer	MSQC 606: Practical Quantum Computing
Aaron Lott	Ph.D., Applied Mathematics and Scientific Computation, UMD	Adjunct Assoc. Professor	MSQC 604: Quantum Computing Architectures and Algorithms MSQC605: Advanced Quantum Computing and Applications
Alejandra Mercado	Ph.D., Electrical and Computer Engineering, UMD	Associate Director	DATA/MSML/BIOI/MSQC 603: Principles of Machine Learning
Alfredo Nava-Tudela	Ph.D., Applied Mathematics and Scientific Computation, UMD	Director	MSQC 601: The Mathematics and Methods of Quantum Computing
Pratyush Tiwary	Ph.D., Materials Science, California Institute of Technology	Associate Professor	Curriculum Advisor

Konstantina Trivisa	Ph.D., Applied Mathematics, Brown University	Professor	MSQC 601: The Mathematics and Methods of Quantum Computing

Appendix B: Course Descriptions

Core Courses

MSQC601 The Mathematics and Methods of Quantum Computing (3 Credits)
This course will provide the student with the necessary mathematical tools and background knowledge to understand, model, and conceptualize quantum computing and its building blocks and systems. We shall review concepts of computation and how they translate to the microscopic world.

MSQC602 Physics of Quantum Devices (3 Credits)
An introduction to quantum physics with emphasis on topics at the frontiers of research. This course aims to build a bridge between natural principles such as light and atoms and a variety of modern applications. This course will provide the student with the necessary physical intuition and background information on quantum physics so that to be able to understand and appreciate a variety of applications in quantum computing such as quantum currency, encryption, random number generation.

MSQC603 Principles of Machine Learning (3 Credits)
A broad introduction to machine learning and statistical pattern recognition. Topics include the following. Supervised learning: Bayes decision theory; discriminant functions; maximum likelihood estimation; nearest neighbor rule; linear discriminant analysis; support vector machines; neural networks; deep learning networks. Unsupervised learning: clustering; dimensionality reduction; principal component analysis; auto-encoders. The course will also discuss recent applications of machine learning, such as computer vision, data mining, autonomous navigation, and speech recognition.

MSQC604 Quantum Computing Architectures and Algorithms (3 credits)
Quantum computing aims to utilize quantum properties of matter to efficiently solve problems that classical computing systems would take too long to solve. This course reviews modern noisy-intermediate scale quantum (NISQ) quantum computing architectures and algorithms for these platforms. We focus on mapping of optimization and machine learning problems onto NISQ architectures and also discuss how to leverage state-of-the-art classical simulation methods for these quantum-inspired algorithms. We review several NISQ architectures and associated software interfaces, we analyze performance for optimization and statistical sampling. We survey current literature to review and implement methods for mapping optimization and machine learning problems onto NISQ architectures and modern simulators and use them to solve and study example problems.

MSQC605 Advanced Quantum Computing and Applications (3 credits)
When Richard Feynman first introduced the concept of quantum computers it was posed for the purpose of simulating nature. Today quantum simulation remains one of the likely first

applications to benefit from quantum computers. This course introduces key concepts required for quantum simulation, and builds tools for performing quantum simulation using state-of-the-art architectures. We introduce classical schemes, like tensor networks, and machine learning approaches, that can be used for these simulations on CPU/GPU architecture. We survey current literature to review and implement methods of quantum simulation and use them to solve and study example problems.

MSQC606 Practical Quantum Computing (3 credits)
Quantum computation is a rapidly growing field at the intersection of physics and computer science, electrical engineering and applied math. While instrumentation of quantum computers is in its infancy, quantum algorithms are being developed to provide efficient solutions to various computational problems. This course covers basic quantum computing, including quantum circuits, significant quantum algorithms, and hybrid quantum-classical algorithms, with focus on applying the concepts to programming existing and near-future quantum computers. Example codes, homework assignments, and class projects will employ Python modules to handle the data exchange with quantum computers.

MSQC607 Advanced Topics in Quantum Computing (3 credits)
This course will showcase a variety of topics from which students can select one, or come up with one of their own, and proceed to study it in depth. The students will make presentations of their findings to class by citing literature and code implementations where appropriate, and culminate with the writing of a scholarly paper on the topic chosen.

Elective Courses

MSCQ610 Quantum Machine Learning (3 credits)
In this course we explore what quantum computing can contribute to data mining and machine learning. We focus on exploring what kind of speedups are possible using quantum computing as well as the storage capacity of quantum associative memories, for example.

MSQC611 Quantum Networks (3 credits)
The need to communicate in a network the quantum states of qubits will necessitate the existence of a “quantum Internet.” Quantum signals are weak and very fragile and in general cannot be copied or amplified. The area of quantum networking explores how to combine well established networking techniques with quantum repeaters to transmit quantum information over long distances. In this course we explore quantum repeaters and their applications to telecommunications.

MSQC612 Quantum Computing Hardware (3 credits)
There are a variety of technologies that implement qubits. In this course we explore these technologies.

MSQC613 Quantum Monte Carlo and Applications (3 credits)

In this course we study the quantum Monte Carlo method and explore applications in diverse areas ranging from correlated systems, chemistry, quantum mechanic systems simulations.

MSQC614 Quantum Information Theory (3 credits)
Quantum information theory synthesizes three major themes: quantum physics, computer science, and information theory. At the core of information theory lies the work of Claude E. Shannon, which we review in this course, and we present and study three problems related to his work and subsequent extension to quantum computing. These are, compressing quantum information, transmitting classical and quantum information through noisy quantum channels, and quantifying, characterizing, transforming, and using quantum entanglement.

MSQC615 Quantum Thermodynamics (3 credits)
Quantum thermodynamics is an emerging field that offers fundamental insights into energy, information, and their relationship. Thermodynamics originally described “classical” systems—everyday objects formed from many particles. The theory has recently extended to the quantum domain of single electrons and few atoms, which behave in ways impossible for everyday objects. For example, quantum particles correlate strongly through “entanglement,” which gives one particle a surprisingly large amount of information about others. We will explore how scientists are leveraging such quantum phenomena in technologies such as quantum computers.