



M.S. QUANTUM COMPUTING

2 Years (4 Semesters)

Dept. Of Computer Science

SVU College of CM & CS, SRI VENKATESWARA UNIVERSITY: TIRUPATI

An Industry Collaborative Programme

WITH EXAFLUENCE INC., USA

Structure and Curriculum



Department of Computer Science
SVU COLLEGE OF COMMERCE MANAGEMENT & COMPUTER SCIENCE
SRI VENKATESWARA UNIVERSITY, TIRUPATI

M.S. Quantum Computing

An Industry Collaborative Programme in Hybrid Mode (online and offline)

EXAFLUENCE INC having its register office at 3759, US Route 1South, Suite 203, New Jersey, South Brunswick, United States of America- 08852 with overseas development centres in Bangalore, Chennai, Dubai, Canada and UK and ODC at #201, Ecco Greens- DTP, Upadhyaya Nagar, Tirupati 517507 Bangalore, Chennai in India and in Dubai entered a memorandum of understanding on 12th day of August 2022, with SRI VENKATESWARA UNIVERSITY, TIRUPATI, Andhra Pradesh, one of the oldest and renewed state-owned University in Andhra Pradesh.

Sri Venkateswara University was established in 1954, in Tirupati to cater the educational needs and aspirations of people of the Rayalaseema Region of Andhra Pradesh. After completing 68 years of excellence in teaching, research, extension and outreach activities, the University is committed to cater the needs of higher education offering a full range of post-graduate programs in Arts, Sciences, Law, Management, Education, Physical Education, Engineering and Pharmacy disciplines. From a humble beginning of one College with six departments, the University has now grown into the second largest University in Andhra Pradesh having five constituent Colleges Viz. College of Arts, College of Sciences, College of Commerce, Management & Computer Science, College of Pharmacy, and College of Engineering accommodating 52 departments offering 88 programs.

Exafluence head quartered in New Jersey USA with overseas development centres in Bangalore, Chennai, Tirupati in India, Dubai, Canada and UK, Exafluence has presence across global the intent is to enroll students in worldwide and bring in international students to SV University. Exafluence is promoted by alumni of SV University Mr. RaviKiran Dharmavaram and COO TN Sreenivas, and it's associated with MongoDB, AWS, Microsoft, Google etc., and with rich experience in data science, the students can get benefited with latest technologies and work in Real Time environment and connect with technical leaders spread across global.

1. Duration Of the Program:

- The professional postgraduate programme leading to the degree of Master of Science in Quantum Computing will extend 2 academic years/over a period of 4 semesters.
- Each academic year being divided into two consecutive (one odd + one even) semesters
- Each semester will normally have duration of 90 working days.
- Minimum duration of the full-time M.S. Quantum Computing Professional Programme is two consecutive academic years i.e. four semesters and maximum period is four academic years, i.e. eight semesters

2. Minimum Qualifications for Admission:

Candidates for admission into the first semester of the M.S. QUANTUM COMPUTING Professional programme must have a

- B.Sc. with Mathematics as main subject along with any two of the following subjects: Physics, Chemistry, Statistics, Electronics, Computer Science
- B.Tech. CSE/ IT/ Electronics
- BCA

of academic input of any university recognized by the Universities Grants Commission.

3. Admission Procedure

- 3.1 The first academic year admission into M.S. Quantum Computing is through an online entrance examination which consisted of 50 multiple choices objective type questions for 50 Marks. There is no negative marking for the wrong answers.
- 3.2 The selection process for the qualified students in the entrance examination
- 3.3 The short-listed candidates are called for counselling by Directorate of Admissions (DOA), SV University, for certificate verification, and first year course fee payment (through online portal <https://pay.svupayonline.edu.in/>.)
- 3.4 Admission of Foreign / NRI Students for M.S. QUANTUM COMPUTING Professional Programme:
 - o Students should have earned their qualifying degree from a University / Institute recognized by the Association of Indian Universities / similar Indian

body.

- o Students nominated by Foreign Governments may be accepted to M.S. QUANTUM COMPUTING Professional programme, without any further test / interview, if their request for admission is routed through MHRD / any agency of the Government of India.

- 3.5 The candidate at the time of admission should produce a Transfer certificate (T.C.), Degree certificate, Marks statement or equivalent credit statements, Migration certificate and any other certificate as stipulated by the University.
- 3.6 Candidates should abide by the conditions, rules and regulations stipulated by the University / Exafluency Inc. and Laws of the University applicable from time to time.
- 3.7 For further information the candidate may contact the ACADEMIC INCHARGE - Exafluency Education Campus Centre, Next to Distance Education Centre Bldg.SV University, Tirupati – 517502.email ID: admissions@svudatascience.in

Note: This MS programme is a self- Supporting course and is not applicable for benefits under government scholarships.

Note: Admission will be given as per rules in vogue from time to time.

4. Structure of the Programme:

The M.S. QUANTUM COMPUTING Professional programme has a curriculum, with syllabus consisting of:

- Core courses, which give a broad base in the main field of study in the academic programme concerned.
 - Elective courses chosen by the student in consultation with the faculty adviser
- Elective course is a course which can be chosen from a pool of papers. It may be:
- o Supportive to the discipline of study
 - o Providing an expanded scope
 - o Enabling an exposure to some other discipline/domain
 - o Nurturing student's proficiency/skill.

An elective may be “Generic Elective” focusing on those courses which add generic proficiency to the students. These electives shall be “Discipline centric”.

- Second type elective may be open elective and shall be offered for other disciplines.
- The Foundation Courses may be of two kinds: Compulsory Foundation and Elective foundation. “Compulsory Foundation” courses are the courses based upon the content that leads to Knowledge enhancement. They are mandatory for all disciplines. Elective Foundation courses are value-based and are aimed at man-making education.
- Skill enhancement Course and Multidisciplinary Course/Project are introduced as per Action Plan of National Education Policy-NEP-2020.
 - o Laboratory, project work and software design courses where special emphasis is laid on the application of knowledge to real-life problems.
 - o The program will also include involve lectures /tutorials/ lab work, Technical Seminars, Group discussions and practical Industry exposure training, as prescribed by the Board of Studies in the curriculum & syllabus and approved by the Academic Council.
- Audit Course
 - o The main aim of Audit Course is too aware the Contemporary Societal issues. This course is under self-study.
 - o In addition, the students may have to choose audit courses, in consultation with the faculty adviser.
- MOOCS and e-Learning:

Discipline centric elective course through MOOCs (Massive Open Online Course) platform. Students can register for the course offered by authorized Institutions/Agencies online with the approval of the course coordinator. The certificate issued by the Institutions/Agencies after successful completion of the course will be considered for the award of the Grade to that course in open electives only.

5. The Credit System:

- Each course has a certain number of credits assigned to it, depending upon whether it is a lecture or tutorial, or practical work and the number of periods assigned per week. The practical courses shall include laboratory work and project work.
- The credits are assigned according to the following pattern:
 - o 1 credit for each lecture period/week,
 - o 1 credit for each tutorial period/week,
 - o 1 credit for each practical session of 2 periods/week &
 - o 2 credits for each project session of 3 periods / week.

6. Minimum Instruction Days:

- The normal duration of M.S. QUANTUM COMPUTING Course is 4 semesters.
- Semesters I, II, III, IV shall consist of a minimum of 90 instruction days (based on six instruction days per week) excluding the days allotted for internal assessment, semester end examinations and preparation holidays.
- 4th semester shall consist of a minimum of 15 weeks for undertaking major project work either in the College or any of the recognized Public Service Sectors/ Government Sectors, National Laboratories and Industrial Houses or any other organizations approved by the Department course coordinator & Exafluence Inc., USA.

7. Medium of Instruction and Examination:

The medium of instruction will be English, and the examination will be in English only.

8. Credits Required for Award of M.S. QUANTUM COMPUTING Degree:

A student earns credits by passing courses every semester. A student, who has registered the M.S. QUANTUM COMPUTING Professional programme, must acquire 90 credits to become eligible for the award of the degree.

- It is mandatory for a student to complete successfully all the core courses pertaining to his/her specialization of study.
- A student may choose Generic Electives from the list of elective courses offered from his/her specialization of study.
- Further, a student may select from a list of Elective courses from other

Departments as Open Electives to “suit the required” number of credits, such that the total credits is at least 90.

- There should be a register maintained by the course coordinator & Head of the Department indicating for each student, the course (s) registered by the student within the department, so that “Generic Electives” opted by the student are indicated.
- In the case of Open Elective, the course coordinator & Head of the Department should prepare a statement/register indicating the courses chosen/ opted by the students of the department in other departments.
- The Course coordinator (or) Head of the Department should send the list of registered papers (opted by the student) to the principal with a copy to the controller of examinations immediately within a week commencement of each semester.
- A copy of the courses registered by the students in each semester approved by Dept. Course coordinator shall be sent to the Academic Branch as well as Examination Branch.
- The list of students registered for MOOCs shall be furnished by dept. course coordinator giving details of the programme with a copy to the Principal and Controller of Examinations.
- A model of Registers to be maintained by the course coordinator & Head of the Department. It is mandatory on the part of the course coordinator & Head of the Department to maintain Register for each Course separately.

9. Evaluation of Academic Performance:

The performance of the students in each semester shall be evaluated paper wise.

The distribution of marks between sessional work (internal assessment) and University Examination is as follows:

Paper Category	Sessional Marks	University Examination Marks
Theory	30	70

Practical	30 Designing of the Program (10) + Program Execution (10) + Viva-Voce (10)	70 Record (20) + Designing of the Program (20) + Program Execution (20) + Viva Voce (10)
Minor Project Work	30 Presentation (15) + Viva Voce (15)	70 Documentation (10) + Presentation (20) + Execution (20) + Viva Voce (20)
Major Project Work	100 Project Documentation (50) + Presentation (30) + Viva Voce (30)	200 National / International Conference Publication Proceedings (External): 50 Marks (Paper based on project should be submitted to conference and published in the form of proceedings) or National / International Journal Publication (External): 50 Marks (Paper based on project should be submitted to the journal and should be published) 1. Project Documentation: 50 Marks 2. Presentation: 50 Marks 3. Viva Voce: 50 Marks

10. University Examinations:

- 11.1 For each theory subject, there shall be a comprehensive University Examination of three hours' duration. Setting of Question papers shall be done by external examiners from the panels recommended by the Board of Studies.
- 11.2 The semester end university examination in each course and paper is of three hours duration with a maximum of 70 marks. The Question paper consists of two parts; A & B. Part A consists of 10 short answer questions and 5 to be answered (5 X 4 = 20 Marks). Part B consists of 10 questions with choice from each unit (5 X 10 = 50 Marks).

- 11.3 (a) For each practical subject, the University Examination shall be conducted by one Internal examiner and one external examiner/two examiners.
(b) Viva -Voce examination in practical subject shall be conducted by Examiners (One Internal and One External Examiner/Two Examiners)
- 11.4 Viva-Voce Examination in Minor Project Work shall be conducted by One Internal Examiner and One External Examiner / Two Examiners
- 11.5 Viva-voce examination in Major Project Work shall be conducted by a committee consisting of Two External Examiners and One Internal Examiner / Three Examiners
- 11.6 (a) The Examiners for Practical examinations and Viva-voce examinations (Stated in 11.3) shall be appointed from among the panels submitted by the Chairperson/Chairman of the Board of Studies.
(b) The Examiners for Project report evaluation for Minor/Major Project Works and Viva Voce examination for Minor/Major Project Works (Stated in 11.4, 11.5) shall be appointed from among the panels submitted by the Chairperson/Chairman of the Board of Studies.
- 11.7 All students enrolled in MOOCS and seeking academic credit or certificate must pay the prescribed examination fee as notified by the prescribed MOOC's Platform
- 11.8 Regulation on Supplementary Examination for MOOCs

Students who fail or are absent in a MOOC (Massive Open Online Course) approved for credit transfer by the University shall be permitted to appear for the University-conducted supplementary examination in the respective course, subject to fulfillment of eligibility criteria and payment of the prescribed examination fee. The supplementary examination shall be conducted in accordance with the University's examination schedule and evaluation procedures.

11. Attendance Requirements:

- 12.1 Regular course of study, in a semester, means a minimum average attendance of 75% in all the papers computed by totalling the number of periods of lectures, tutorials, and practical's and project as the case may be, held in every paper as the denominator and the total number of periods attended by the student in all papers, as the numerator.
- 12.2 However, a student has to put in a minimum attendance of 50% in each subject, in addition to the condition laid down in clause 12.1.
- 12.3 No consideration whatsoever in attendance will be shown to any student for late admission due to any reason.



- 12.4 Condonation of shortage of attendance may be recommended on medical grounds only provided a student puts in at least 62.5% attendance, in all the papers put together as calculated in clause 12.1 above, along with a minimum of 50% attendance in each subject as stated in clause 12.2.
- 12.5 A student, who could not satisfy these requirements of attendance as given in clauses above, in any semester, shall have to repeat that semester in the subsequent academic years with the written permission of the university.
- 12.6 A student shall not be permitted to study any semester for more than 2 times during the course of study.
- 12.7 A certificate of satisfactory attendance must be submitted by the student from the organization where he/she undertakes Project Work. For the above purpose, the candidate is not expected to avail more than 12 working days of leave of absence.
- 12.8 Further, a student is required to complete the course of study satisfying the attendance requirements in all the 4 semesters, within a period of first 8 semesters from the time of admission, failing which he/she shall forfeit his /her seat.
- 12.9 A student, who has not satisfied the minimum attendance requirements in any semester, may repeat that semester after obtaining written permission from the university, canceling the previous record of attendance and sessional marks of that semester. However, this facility may be availed by any student not more than twice during the entire course of study and the entire course of study shall be within the first eight semesters as stipulated in clause 12.8.

13. Academic Requirements:

- 13.1 A candidate shall be declared to have passed whole examination of a semester if he/she secures a minimum aggregate of 50% along with minimum marks of 40% in the University Examination in each theory and practical paper, including project work. Aggregate for this purpose shall mean the total marks obtained in the University Examination and sessional put together in all the papers of that semester.
- 13.2 A candidate who secures a minimum aggregate of 50% in any semester as specified in clause 13.1 but fails to secure the paper minimum of 40% in the University Examination in any paper, shall be declared to have failed in that paper. The candidate may appear for the University Examination in such papers as and when conducted and pass by securing the subject minimum of 40% in each of such papers.

- 13.3 A candidate, who could not secure the minimum aggregate of 50% in any semester, as given in clause 13.1, shall be declared to have exempted in such theory papers in which he/she secured a minimum of 50% of the marks in the University Examination.
- 13.4 A candidate who could not secure the minimum aggregate of 50% in any semester, as given in clause 13.1, shall be declared to have exempted in such practical papers in which he/she secured a minimum of 40% in the University Examination and a minimum of 50% of the marks in the University Examination and sessional put together in each of such papers.
- 13.5 A candidate must appear for all the other papers in which he/she has not satisfied the stipulations of clauses 13.3 and 13.4 and pass compartmentally by satisfying the stipulations stated in clauses 13.3 and 13.4. Rechecking of the aggregate shall not arise when a candidate opts for compartmental passing.
- 13.6 Candidates who would not like to avail themselves of the facility of compartmental pass given in clauses 11.4, 11.5 and 11.6 may reappear for the whole examination of that semester, after cancelling the previous result. In such a case, clauses 13.1 to 13.5 shall apply in that order.
- 13.7 Candidates shall register for improvement in one or more theory papers of a semester indicating the same in the application form. However, improvement facility is not extended to practical and project work papers.

NOTE: The question of checking the aggregate shall arise only when the candidate registers for the whole examinations for the first time or when he/she registers for the whole examinations at a subsequent attempt after having cancelled the previous result.

14. Condition of Promotion:

A candidate shall be promoted to the next semester, if he/she satisfies the minimum attendance requirements of that semester of M.S. QUANTUM COMPUTING as stipulated in clause 13.

15. Award of Degree:

The degree of M.S. QUANTUM COMPUTING shall be conferred on a candidate who has satisfied the following conditions:

- 15.1 The candidate, after admission to the M.S. QUANTUM COMPUTING Professional programme of the University, must have studied each of the 4 semesters at least once
- 15.2 The candidate must have satisfied minimum attendance requirements as stipulated in clause 12, and minimum academic requirements as prescribed in clause 13, in each of the 4 semesters of the M.S. QUANTUM COMPUTING Professional programme.
- 15.3 The Programme of Study for the M.S. QUANTUM COMPUTING shall cover normally a period of 2 academic years, comprising of 4 semesters and No student shall be permitted to complete the course of study of M.S. QUANTUM COMPUTING earlier than 4 semesters or to take not more than 8 consecutive semesters, failing which he / she shall forfeits his / her seat (or) He/she will not be getting degree .
- 15.4 A student who has earned a minimum of 90 credits by passing in all the core courses and the minimum number of electives prescribed shall be declared to have passed the course work and shall be eligible for the award of degree.
- 15.5 A student who has earned extra credit shall be issued a separate certificate to that effect, mentioning the subject and grade.

16.Award Grades and Grade Points:

- 16.1 After a candidate has satisfied all requirements for the award of the degree as specified in clause 15, he/she shall be placed in one of the following three classifications, irrespective of whether the candidate passed compartmentally or otherwise, even after the regular period of study of four semesters.

Grade Point: It is a numerical weight allotted to each letter grade on a 10-point scale.

Letter Grade: It is an index of the performance of students in a said course. Grades are denoted by letters O, A+, A, B+, B, C, P and F.

Semester Grade Point Average (SGPA): It is a measure of performance of work done in a semester. It is ratio of total credit points secured by a student in various courses registered in a semester and the total course credits taken during that semester. It shall be expressed up to two decimal places

$$SGPA (S_i) = \sum(C_i \times G_i) / \sum C_i$$

where C_i is the number of credits of the i^{th} course and G_i is the grade point scored by the student in the i^{th} course.

The CGPA is also calculated in the same manner taking into account all the courses undergone by a student over all the semesters of a programme, i.e.

Cumulative Grade Point Average (CGPA): It is a measure of overall cumulative performance of a student over all semesters. The CGPA is the ratio of total credit points secured by a student in various courses in all semesters and the sum of the total credits of all courses in all the semesters. It is expressed up to two decimal places

$$CGPA = \frac{\sum(C_i \times S_i)}{\sum C_i}$$

Where S_i is the SGPA of the i th semester and C_i is the total number of credits in that semester.

The SGPA and CGPA shall be rounded off to 2 decimal points and reported in the transcripts

Letter Grades and Grade Points

A 10-point grading system with the following letter grades is to be followed:

S.no	Grade	Grade Points
1.	O (Outstanding)	10
2.	A+(Excellent)	9
3.	A (Very Good)	8
4.	B+ (Good)	7
5.	B (Above Average)	6
6.	C (Average)	5
7.	P (Pass)	4
8.	F (Fail)	0
9.	Ab. (Absent)	0

A student obtaining Grade F shall be considered failed and will be required to reappear in the examination.

For non-credit courses 'Satisfactory' or "Unsatisfactory' shall be indicated instead of the letter grade and this will not be counted for the computation of SGPA/CGPA

For this purpose, aggregate shall mean the aggregate of the marks in the University Examinations and sessional put together at all 4 semester of M.S. QUANTUM COMPUTING.

- 16.2 A Candidate, before and even after becoming eligible for the award of the Degree, may reappear for the University Examination, as and when conducted, in any of the theory subjects, which he/she has already passed, for the purpose of improving the aggregate. However, this facility cannot be availed by a candidate who has taken the Provisional Pass Certificate. Candidates shall not be permitted to appear for University examination in Practical papers including project work for the purpose of improvement.

17. Award of Rank:

The rank shall be awarded based on the following:

- 17.1 Ranks shall be awarded for the top ten students appearing for the regular M.S. QUANTUM COMPUTING examination.
- 17.2 Only such candidates, who satisfy the minimum academic requirements as stipulated in clause 13, by the end of their 4th semester, and become eligible for the award of the degree, are eligible for the award of rank. Candidates, who lose one or more semesters for any reason whatever, are not eligible for the award of rank.
- 17.3 For the purpose of awarding rank, aggregate of marks in University Examination and Sessional put together at all the semesters of M.S. QUANTUM COMPUTING, secured at the first attempt only, shall be taken into account.
- 17.4 Award of Prizes, scholarships and other honors shall be according to the rank secured by a candidate, consistent with the desire of the Donor.

18. Transitory Regulations:

- 18.1 Candidates who studied the M.S. QUANTUM COMPUTING Course under the Regulations (Semester Pattern) and syllabus from 2023-2024 but who could not satisfy the minimum attendance requirements in any semester may join the appropriate semester in the Regulations (For the full time, regular course) – 2025-27 for the remaining part of the course and be governed by the Regulations of that batch from then on.

18.2 University Examinations shall be conducted 2 more times, after the last regular examination, in all those papers prescribed under the Regulations & syllabus from 2024-2025

18.3 Candidates, who satisfied the minimum attendance requirements in any semester under the Regulations & syllabus from 2024-2025 but who are yet to pass some papers of that semester even after Two chances shall appear for the equivalent papers under Regulations from time to time, specified by the Chairman / Chairperson of the Board of Studies.

20. Fee & Remuneration

20.1 The fee payable in each year is collected in one instalment as detailed below:

Exafluence Inc. Programme	Tuition Fee Rs. Incl GST
II Years	3,32,400/-
I year	166200/-
II year	166200/-

Note: The fee is subject to changes to be made by the University from time to time.

21. Remuneration / Honorarium and Allowances

- Honorarium for Principal $3000 * 10 \text{ months} = \text{Rs } 30000/-$
- Honorarium to Coordinator $3000 * 10 \text{ months} = \text{Rs } 30000/-$
- Honorarium for AAO $1000 * 10 \text{ months} = \text{Rs } 10000/-$
- Honorarium for Junior Assistant, Department of CS $850 * 10 \text{ months} = \text{Rs } 8500/-$

Note: Remuneration, TA & DA related to examinations and evaluation will be as per rules in vogue time to time

22. Amendments of Regulation:

The University may, from time to time, revise, amend, or change the Regulations, Scheme of Examinations and Syllabi, whenever necessary.

24. Internship & Industrial Training:

- 24.1 The Industry will take students as “Interns” or “Trainees” for a maximum period of 4 months and a minimum period of 2 Months.
- 24.2 The Industry will select students who are ready for Industry Internship and then shortlist students for the purpose. The Programme Coordinator will make alternative arrangements for such students who are successful reaching the final semester but fail to meet the expectations of the industry.
- 24.3 The Industry may or may not pay any stipend to the students during the Internship period. If the industry is comfortable, it may plan for some incentives and other benefits when and where available.
- 24.4 The selected students will be under the direct control of the industry during the period of internship. A consultant/officer/executive will take care of the candidate and statutory requirements by a Flexi contract.
- 24.5 The Industry will render knowledge transfer on key practical areas to the students during the period of internship.
- 24.6 Each student will have a Project Guide in the Partner industry institution and or in the organization, where the student carries out his/her project work / internship.
- 24.7 The Industry will certify the project/work reports of the students which have to be submitted to the University as part of their course completion.
- 24.8 The “Interns” shall abide by all the terms and regulations of the Internship Programme as stipulated by the industry

25. Important Instructions:

- 25.1 No refund of the fee will be made once remitted. There are no fee concessions for any category of students. The fee once paid by the candidate will neither be refunded nor adjusted. Please check the eligibility before obtaining the admission.
- 25.2 All the fee paid receipts must be preserved till the candidate completes the course and obtains the degree certificate
- 25.3 All matters relating to examinations / results / marks / certificates etc will be dealt with only by the Controller of Examinations, Sri Venkateswara University, Tirupati.
- 25.4 For all legal matters the Jurisdiction is restricted to Tirupati city only.
- 25.5 Candidates are required to abide by the rules and regulations that are in force and those that will come into effect from time to time as formulated for M.S. Quantum computing by the Industry Collaborative Programme by Exafluence Inc and /or by the University.
- 25.6 Admission at any time may be cancelled by the coordinator/ Head/ Principal/ DOA - Industry Collaborative Programme if the candidates is found ineligible for admission into the said course or he/she is found to be guilty of indiscipline.

Website information:

www.svuniversity.edu.in & www.exfedu.in/ will give all the information about the M.S. Quantum Computing Professional programme

Visiting Faculty:

Faculty visits from industry as per their specializations will be organized strictly. The Programme schedule of the visiting faculty from industry with personal details, Years of experience, teaching experience, Telephone, E-mail along with their photos should be submitted to the department course Coordinator, S.V. University at regular intervals

Industry connectivity:



Exafluence Inc. should appoint a “placement and internship officer/coordinator” who should work along with SV University for achieving 100% internships and placements only for M.S Quantum Computing students.

Communication:

Any communication to the University by the Exafluence Inc. should be through the department course coordinator only.

MS Quantum Computing

SEMESTER- I

Code	Title of the Paper	Teaching Hours per Week			No. of Credits	Sessional Marks	Semester End Exam	Exam Duration	Max Marks
		L	T	P					
MSQC 101	Linear Algebra and Mathematics for Quantum Computing	3	1	0	3	25	50	3 Hrs.	75
MSQC 102	Quantum Information Processing	4	0	0	4	30	70	3 Hrs.	100
MSQC 103	Quantum Circuits, Simulation, and Hardware-Aware Computational Models	4	0	0	4	30	70	3 Hrs.	100
MSQC 104	Python and Classical Computing for Quantum Engineers	4	0	0	4	30	70	3 Hrs.	100


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MSQC 105	Foundations of Quantum Algorithms and Research Mini Project	2	0	2	3	25	50	3 Hrs.	75
MSQC 106	Quantum Circuit Implementation and Simulation Lab with IBM Qiskit	3	1	0	3	25	50	3 Hrs.	75
MSQC 107	Hands-on: Python and Classical Computing for Quantum Engineers	0	0	4	2	15	35	3 Hrs.	50
MSQC 108	Hands-on: Quantum Circuit Implementation and Simulation Lab with IBM Qiskit	0	0	4	2	15	35	3 Hrs.	50
QRS 109	Weekly Quantum Research Paper Reading and Seminar - Research Literacy	0	0	2	0	-	-	-	-
Total					25				625

Quantum Research Seminar (QRS)

QRS 109	Weekly Quantum Research Paper Reading and Seminar - Research Literacy
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SEMESTER- II

Code	Title of the Paper	Teaching Hours per Week			No. of Credits	Sessional Marks	Semester End Exam	Exam Duration	Max Marks
		L	T	P					
MSQC 201	Quantum Algorithm Engineering and Optimization	4	0	0	4	30	70	3 Hrs.	100
MSQC 202	Quantum Machine Learning	4	0	0	4	30	70	3 Hrs.	100
MSQC 203	Quantum Algorithm Engineering and Simulation Lab with Google Cirq	3	1	0	3	25	50	3 Hrs.	75
MSQC 204	Hybrid Quantum-Classical Systems and Cloud Platforms	3	1	0	3	25	50	3 Hrs.	75
MSQC 205	Computational Quantum Science, Simulation, and HPC Acceleration	3	1	0	3	25	50	3 Hrs.	75
MSQC 206	Elective I	3	1	0	3	25	50	3 Hrs.	75
MSQC 207	Elective II	3	1	0	3	25	50	3 Hrs.	75


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MSQC 208	Hands-on: Quantum Algorithm Engineering and Simulation Lab with Google Cirq	0	0	4	2	15	35	3 Hrs.	50
QRS 209	Research Methodology, Proposal Development, and Quantum Seminar (Non-Credit Academic Activity)	0	0	2	0	-	-	-	-
Total					25				625

ELECTIVE DETAILS

Code	Elective – I (Choose any one)	Code	Elective – II (Choose any one)
MSQC 206A	Quantum Cryptography and Post-Quantum Security	MSQC 207A	Quantum Computing in Finance and Optimization
MSQC 206B	Quantum Communication Software Protocols	MSQC 207B	Quantum Computing for Drug Discovery and Life Sciences

Quantum Research Seminar (QRS)

QRS 209	Research Methodology, Proposal Development, and Quantum Seminar
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SEMESTER III

Code	Title of the Paper	Teaching Hours per Week			No. of Credits	Sessional Marks	Semester End Exam	Exam Duration	Max Marks
		L	T	P					
MSQC 301	Quantum Systems Engineering and Software Architecture	3	1	0	3	25	50	3 Hrs.	75
MSQC 302	Quantum Error Correction and Fault Tolerant Computing	4	0	0	4	30	70	3 Hrs.	100
MSQC 303	Quantum Resource Estimation and Cloud Execution Lab with Microsoft Q# and Azure Quantum	3	1	0	3	25	50	3 Hrs.	75
MSQC 304	Quantum Open-Source Engineering, APIs, and Reproducible Systems	3	1	0	3	25	50	3 Hrs.	75


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MSQC 305	Quantum Applications Engineering, Benchmarking and Responsible Deployment	3	1	0	3	25	50	3 Hrs.	75
MSQC 306	Elective III	3	1	0	3	25	50	3 Hrs.	75
MSQC 307	Elective IV	3	1	0	3	25	50	3 Hrs.	75
MSQC 308	Hands-on: Quantum Resource Estimation and Cloud Execution Lab with Microsoft Q# and Azure Quantum	0	0	4	2	15	35	3 Hrs.	50
QRS 309	Research Project Phase I (Non-Credit based research activity)	0	0	2	0	-	-	-	-
Total					24	600			


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ELECTIVE DETAILS

Code	Elective – III (Choose anyone)	Code	Elective – IV (Choose anyone)
MSQC 306A	Quantum Natural Language Processing	MSQC 307A	Quantum Computing Solution Architecture and Cloud Deployment
MSQC 306B	Quantum Reinforcement Learning	MSQC 307B	Advanced Quantum Cybersecurity and Secure Software Systems

Quantum Research Seminar (QRS)

QRS 309	Research Project Phase I (Non-Credit based research activity)
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SEMESTER – IV

Code	Title of the Paper	Category of Courses	As per NEP 2020	Teaching Hours per Week			No. of Credits	Sessional Marks	Semester End Exam	Exam Duration	Max Marks
			Course Level	L	T	P					
MSQC 401	Research Project Phase II / Thesis and Final Defense	Credit-bearing Research Component	500-599	0	0	30	16	100	200	3 Hrs.	350
Total							16				350

Total credits:

Semester	SEMESTER- I	SEMESTER- II	SEMESTER- III	SEMESTER – IV	Total
Credits	2	25	24	16	90

Total Marks:

Semester	SEMESTER- I	SEMESTER- II	SEMESTER- III	SEMESTER – IV	Total
Marks	625	625	600	350	2200


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SEMESTER 1

Subject 1: Linear Algebra and Mathematics for Quantum Computing

Unit 1: Vectors, Matrices, and Linear Transformations

Vector spaces and subspaces, basis and coordinate representation, matrix addition and multiplication, transpose and inverse operations, systems of linear equations, Gaussian elimination, rank and null space, linear transformations, orthogonality, Gram-Schmidt orthogonalization, inner products, norms, geometric interpretation for quantum states.

Unit 2: Complex Numbers, Inner Products, and Hilbert Spaces

Complex numbers in Cartesian and polar forms, complex conjugate, modulus and phase, complex vector spaces, inner products and norms, Hilbert space definition, orthonormal bases, Dirac bra-ket notation, projection onto subspaces, completeness, distance interpretation in quantum state spaces.

Unit 3: Eigenvalues, Eigenvectors, and Spectral Methods

Eigenvalue and eigenvector computation, characteristic polynomial, diagonalization, Hermitian matrices, unitary matrices, normal matrices, spectral decomposition, projection operators, matrix exponentials, functions of matrices, use of spectral methods in quantum gates and measurement.

Unit 4: Tensor Products, Operators, and Density Matrices

Kronecker products, tensor products of vectors and matrices, multi-qubit state construction, unitary evolution, outer products, pure and mixed states, density matrix representation, partial trace, expectation values, reduced density matrices, and Bloch sphere representation.

Unit 5: Probability, Entropy, and Information Foundations

Classical probability distributions, expectation and variance, quantum probability and Born rule, Shannon entropy, von Neumann entropy, fidelity, trace distance, distinguishability of quantum states, no-cloning theorem, quantum correlations, and basic channel concepts.

References:

1. Mathematics of Quantum Computing: An Introduction by Wolfgang Scherer
2. Introduction to Quantum Algorithms via Linear Algebra by Richard J. Lipton and Kenneth W. Regan, 2nd Edition
3. Quantum Computation and Quantum Information by Michael A. Nielsen and Isaac L. Chuang, 10th Anniversary Edition
4. Quantum Information Theory by Mark M. Wilde, 2nd Edition

Subject 2: Quantum Information Processing

Unit 1: Quantum Computing Motivation and Information Perspective

Classical information versus quantum information, limitations of classical computing for selected problems, motivation for quantum computing, historical milestones, CSE relevance, NISQ-era context, responsible interpretation of quantum advantage claims, overview of quantum computing research and career pathways.

Unit 2: Quantum Information Representation

Bits versus qubits, computational basis states, state vectors, superposition, phase, interference, bra-ket notation, Hilbert space interpretation, pure and mixed states, density matrices, Bloch sphere representation, and essential physics principles required for quantum computation.

Unit 3: Quantum State Evolution and Information Transformation

Unitary evolution, quantum operators, Pauli gates, Hadamard and phase gates, rotation gates, tensor products, controlled operations, reversible transformations, universal gate-set awareness, information transformation through quantum circuits.

Unit 4: Quantum Correlations, Entanglement, and Measurement

Composite quantum systems, entanglement, Bell states, EPR pairs, quantum correlations, no-cloning theorem, measurement postulates, Born rule, projective measurement, state collapse, expectation values, reduced density matrices, and quantum-to-classical information extraction.

Unit 5: Quantum Information Processing Models and Applications

Quantum circuit model, quantum registers, gate-based computing, measurement-based computing overview, adiabatic computing and quantum annealing overview, NISQ computing paradigm, hardware constraints and noise awareness, applications in cybersecurity, optimization, machine learning, scientific simulation, finance, drug discovery, logistics, and CSE-oriented career pathways.

References:

1. Quantum Computation and Quantum Information by Michael A. Nielsen and Isaac L. Chuang, 10th Anniversary Edition
2. Quantum Information Processing, Quantum Computing, and Quantum Error Correction: An Engineering Approach by Ivan B. Djordjevic, 2nd Edition
3. Quantum Computing: A Gentle Introduction by Eleanor G. Rieffel and Wolfgang H. Polak
4. An Introduction to Quantum Computing by Phillip Kaye, Raymond Laflamme and Michele Mosca

Subject 3: Quantum Circuits, Simulation, and Hardware-Aware Computational Models

Unit 1: Single-Qubit Gates and State Transformations

Identity, Pauli X/Y/Z, Hadamard, S, T, phase gates, rotation gates Rx/Ry/Rz, general single-qubit unitaries, matrix representation, Bloch sphere interpretation, gate composition, and universal single-qubit transformations.

Unit 2: Multi-Qubit Gates and Entangling Circuits

Tensor product systems, CNOT, CZ, SWAP, Toffoli, controlled operations, Bell state preparation, entanglement generation, multi-controlled gates, multi-qubit measurement, and circuit construction patterns.

Unit 3: Circuit Design, Depth, and Optimization Basics

Circuit notation, quantum and classical registers, measurement placement, circuit depth, width, gate count, barriers, ancilla qubits, uncomputation, gate cancellation, parameterized circuits, modular subcircuits, and shallow circuit design for NISQ devices.

Unit 4: Universal Gate Sets, Compilation, and Device Mapping

Reversible computation, universal gate sets, Clifford and non-Clifford gates, Solovay-Kitaev theorem overview, native gate sets, basis gate decomposition, transpilation, qubit mapping, routing, device topology constraints, and compiler-stage awareness for quantum systems and software engineers.

Unit 5: Simulation Models, Noise Awareness, and Hardware Platforms

Gate-based model, measurement-based model overview, adiabatic computing and annealing overview, statevector simulation, density matrix simulation, shot-based sampling, basic noise models, NISQ constraints, simulator-versus-hardware interpretation, hardware-literacy-oriented coverage of superconducting, trapped-ion, neutral-atom, and photonic quantum computing platforms, and hardware performance metrics such as coherence time, gate fidelity, readout fidelity, error rate, connectivity, crosstalk, and calibration awareness.

References:

1. Quantum Computing: An Applied Approach by Jack D. Hidary, 2nd Edition
2. Quantum Computing for Computer Scientists by Noson S. Yanofsky and Mirco A. Mannucci
3. Quantum Computer Systems: Research for Noisy Intermediate-Scale Quantum Computers by Yongshan Ding and Frederic T. Chong

4. Quantum Computation and Quantum Information by Michael A. Nielsen and Isaac L. Chuang, 10th Anniversary Edition

Subject 4: Python and Classical Computing for Quantum Engineers

Unit 1: Python Programming Essentials

Python syntax, functions, modules, classes, object-oriented design for quantum projects, exception handling, file I/O, JSON handling, package management using pip and virtual environments, readable code, and modular project organization.

Unit 2: Scientific Computing with NumPy and SciPy

NumPy arrays, matrix multiplication, complex number operations, tensor products, eigenvalue computation, sparse matrices, SciPy linear algebra, numerical stability, matrix exponentials, FFT basics, and numerical experiments for quantum states.

Unit 3: Visualization and Experiment Analysis

Matplotlib visualization, probability histograms, Bloch sphere visualization, circuit diagrams, density matrix heatmaps, optimization curves, measurement result plots, experiment logging, and clear scientific reporting of simulation outputs.

Unit 4: Classical Optimization for Quantum Workflows

Gradient descent, Adam optimizer, L-BFGS-B, COBYLA, Nelder-Mead, Powell, SPSA, Bayesian optimization overview, convergence criteria, early stopping, optimizer selection and benchmarking for variational quantum workflows.

Unit 5: Classical-Quantum Interfacing Basics

REST API concepts, SDK authentication patterns, asynchronous job submission, retry logic, data serialization, classical preprocessing and quantum execution flow, result retrieval, and building a small Python-based quantum workflow.

References:

1. Quantum Computing: An Applied Approach by Jack D. Hidary, 2nd Edition
2. Numerical Python: Scientific Computing and Data Science Applications with Numpy, SciPy and Matplotlib by Robert Johansson, 3rd Edition
3. Effective Computation in Physics: Field Guide to Research with Python by Anthony Scopatz and Kathryn D. Huff

Subject 5: Foundations of Quantum Algorithms and Research Mini Project

Unit 1: Computation Models and Complexity Foundations

Classical algorithms review, Boolean circuits, Turing machine awareness, P, NP, BPP, BQP, oracle model, query complexity, speedup categories, dequantization caution, and responsible claims about quantum advantage.

Unit 2: Elementary Quantum Algorithmic Ideas

Phase kickback, interference-based computation, oracle construction basics, Deutsch algorithm, Deutsch-Jozsa overview, Bernstein-Vazirani overview, Simon problem intuition, and introductory circuit-level reasoning.

Unit 3: Quantum Program Representation, Portability, and Reproducibility

OpenQASM overview, circuit serialization, intermediate representations, backend abstraction, SDK portability, versioning concerns, simulator-to-hardware workflow, reproducible notebook structure, and documentation practices for introductory research-oriented projects.

Unit 4: Quantum Software Stack and Backend Abstraction

Application layer, algorithm layer, circuit layer, compiler/transpiler layer, simulator layer, cloud service layer, hardware interface layer, provider abstraction, and SDK-agnostic quantum software design across these layers.

Unit 5: Research Mini Project and Concept Integration

introductory end-to-end project involving problem framing, literature awareness, circuit design, Qiskit implementation, simulator execution, measurement analysis, basic benchmarking, reproducibility notes, technical report writing, and oral explanation of concept-oriented design decisions.

References:

1. Quantum Computing: An Applied Approach by Jack D. Hidary, 2nd Edition
2. Introduction to Quantum Algorithms via Linear Algebra by Richard J. Lipton and Kenneth W. Regan, 2nd Edition
3. Programming Quantum Computers: Essential Algorithms and Code Samples by Eric R. Johnston, Nic Harrigan and Mercedes Gimeno-Segovia

4. Quantum Computation and Quantum Information by Michael A. Nielsen and Isaac L. Chuang, 10th Anniversary Edition
5. Quantum Computing: A Gentle Introduction by Eleanor G. Rieffel and Wolfgang H. Polak

Subject 6: Quantum Circuit Implementation and Simulation Lab with IBM Qiskit

Unit 1: Qiskit for Circuit Implementation and Simulation

IBM Quantum platform access, account setup, local development environment, Qiskit architecture, Qiskit Aer, Qiskit Runtime overview, Composer and Lab awareness, documentation usage, community resources, responsible use of cloud hardware, and concept-oriented use of Qiskit as an implementation environment.

Unit 2: Qiskit Circuit Construction Fundamentals

QuantumCircuit class creation, quantum and classical registers, single-qubit and multi-qubit gates, parameterized circuits, measurement operations, subcircuit composition, circuit visualization, statevector and density matrix objects, and clean Qiskit coding style.

Unit 3: Simulation, Measurement, and Result Analysis

Aer simulators, statevector simulation, unitary simulation, shot-based execution, count dictionaries, result objects, histogram plotting, fake backends, basic noise model usage, and comparison between ideal simulation and noisy simulation.

Unit 4: Transpilation, Runtime Primitives, and Backend Management

Transpilation pipeline, basis gates, optimization levels, backend properties, coupling maps, layout selection, Estimator and Sampler primitives, Qiskit Runtime sessions, noise-aware execution, queue awareness, and result metadata interpretation.

Unit 5: Qiskit Implementation, Benchmarking, and Lab Reporting

Single-qubit gate implementation, multi-qubit gate implementation, Bell state preparation, superposition and measurement circuits, entanglement circuits, Deutsch algorithm implementation, basic Deutsch-Jozsa implementation, Qiskit Aer simulator execution, circuit depth and gate-count reporting, visualization, reproducibility notes, and lab report writing.

References:

1. A Practical Guide to Quantum Computing: Hands-on Approach to Quantum Computing with Qiskit by Elías F. Combarro and Samuel González-Castillo, 1st Edition

2. Learn Quantum Computing with Python and IBM Quantum by Robert Lored, 2nd Edition
3. Qiskit Pocket Guide: Quantum Development with Qiskit by James L. Weaver and Frank J. Harkins

Subject 7: Weekly Quantum Research Paper Reading and Seminar - Research Literacy (Non-credit Academic Activity)

Unit 1: Research Literacy and Reading Discipline

Weekly structured reading habits, selecting introductory-level quantum computing papers, understanding abstracts, introductions, methods, results, limitations, research claims, reproducibility notes, and implications for CSE-oriented quantum computing.

Unit 2: Faculty-Led Paper Walkthrough

Guided discussion of recent or landmark papers from arXiv, IEEE Quantum, ACM, Nature, Physical Review, QCE, NeurIPS, ICML, and related venues, with focus on concepts, novelty, and limitations.

Unit 3: Student Presentation Practice

Short student seminars, paper summary slides, explanation of problem statements, method, results, and future work, peer questions, and faculty feedback.

Unit 4: Research Note Writing

One-page paper summaries, key contribution identification, method diagrams, limitation analysis, citation discipline, reproducibility notes, and professional academic writing.

Unit 5: Research Proposal and Semester Research Portfolio

Compilation of weekly summaries, seminar reflections, selected implementation ideas, open questions, reproducibility observations, and preliminary research-interest exploration for later proposal development.

SEMESTER 2

Subject 1: Quantum Algorithm Engineering and Optimization

Unit 1: Quantum Algorithm Design Principles

Problem suitability analysis, quantum algorithm engineering workflow, oracle design, phase kickback, interference, amplitude amplification, reversible circuit design, correctness guarantees, complexity analysis, qubit count, gate count, depth, and scalability trade-offs.

Unit 2: Search, Amplitude Amplification, and Counting

Grover's algorithm, diffusion operator, optimal iterations, multi-target search, amplitude amplification generalization, amplitude estimation, quantum counting, applications in search and Monte Carlo, and implementation planning across SDKs.

Unit 3: QFT, QPE, Shor, and HHL

Quantum Fourier Transform, inverse QFT, Quantum Phase Estimation, Shor period-finding structure, classical post-processing, HHL motivation and circuit structure, speedup conditions, precision limits, and resource requirements.

Unit 4: Variational Algorithms: VQE and QAOA

VQE formulation, ansatz design, Hamiltonian decomposition, expectation measurement, classical optimization loop, QAOA cost and mixer Hamiltonians, Max-Cut and scheduling examples, noise impact, and engineering choices for NISQ systems.

Unit 5: Benchmarking, Resource Estimation, and Quantum Advantage

Circuit profiling, gate count, depth, qubit utilization, runtime, scalability, fidelity-aware benchmarking, hardware-vs-simulator comparison, logical-versus-physical qubit estimates, resource estimation reports, quantum advantage analysis, algorithm selection rubric, and responsible reporting.

References:

1. Quantum Computing: An Applied Approach by Jack D. Hidary, 2nd Edition
2. Quantum Computation and Quantum Information by Michael A. Nielsen and Isaac L. Chuang, 10th Anniversary Edition
3. An Introduction to Quantum Computing by Phillip Kaye, Raymond Laflamme and Michele Mosca
4. Introduction to Quantum Algorithms via Linear Algebra by Richard J. Lipton and Kenneth W. Regan, 2nd Edition

5. Programming Quantum Computers: Essential Algorithms and Code Samples by Eric R. Johnston, Nic Harrigan and Mercedes Gimeno-Segovia

Subject 2: Quantum Machine Learning

Unit 1: Classical ML Review and QML Paradigm

Supervised, unsupervised, and neural network foundations; model evaluation; regularization; kernels; limitations of classical ML; near-term and fault-tolerant QML categories; and realistic assessment of QML advantages.

Unit 2: Quantum Data Encoding and Feature Mapping

Basis encoding, amplitude encoding, angle encoding, feature maps, quantum kernels, ZZ feature map, Pauli feature map, IQP circuits, data re-uploading, encoding cost, encoding selection, and advanced treatment of quantum data encoding methods.

Unit 3: Quantum Kernels and Quantum Classification

Quantum kernel estimation, QSVM, quantum distance estimation, swap test usage, quantum clustering overview, quantum dimensionality reduction overview, and benchmarking quantum classifiers against classical baselines.

Unit 4: Quantum Neural Networks and Variational Circuits

Parameterized quantum circuits, quantum neural networks, cost functions, parameter-shift rule, barren plateaus, expressibility, entanglement capacity, hardware-efficient ansatz design, and training with established classical optimizers.

Unit 5: Hybrid QML Toolchains and Evaluation

Qiskit Machine Learning, PennyLane, TensorFlow Quantum overview, PyTorch integration, dataset preparation, deployment of hybrid QML experiments, result interpretation, limitations of current hardware, and reproducible QML reporting.

References:

1. Machine Learning with Quantum Computers by Maria Schuld and Francesco Petruccione, 2nd Edition
2. Quantum Machine Learning: An Applied Approach by Santanu Ganguly, 1st Edition
3. Quantum Machine Learning with Python: Using Cirq from Google Research and IBM Qiskit by Santanu Pattanayak, 1st Edition
4. Hands-On Quantum Machine Learning with Python Volume 1 by Dr. Frank Zickert, 1st Edition

5. Quantum Machine Learning: Quantum Algorithms and Neural Networks edited by Pethuru Raj, Houbing Herbert Song, Dac-Nhuong Le and Narayan Vyas

Subject 3: Quantum Algorithm Engineering and Simulation Lab with Google Cirq

Unit 1: Cirq for Algorithm Engineering and Simulation

Google Quantum AI overview, Cirq design philosophy, installation, qubit types, operations, gates, devices, concept-oriented use of Cirq for algorithm engineering, comparative analysis of Cirq and Qiskit, documentation usage, and integration awareness with TensorFlow Quantum and OpenFermion.

Unit 2: Circuit Construction with Qubits, Moments, and Gates

LineQubit, GridQubit, NamedQubit, gates, operations, moments, circuit construction, insertion strategies, measurements, parameterized gates, controlled gates, custom gates, visualization, and Bell-state examples.

Unit 3: Cirq Simulators, Sampling, and Noise Modeling

Cirq Simulator, DensityMatrixSimulator, Clifford simulation overview, sampling results, noisy circuits, depolarizing and dephasing channels, amplitude damping, shallow NISQ circuit design, and basic error mitigation experiments.

Unit 4: Backend Integration and Hardware-Aware Programming

Device objects, topology constraints, routing awareness, Google Quantum Computing Service overview, job submission concepts, result retrieval, simulator-hardware comparison, and performance tuning for large circuit simulation.

Unit 5: Cirq Algorithm Implementation, Benchmarking, and Comparative Reporting

Cirq implementation of Grover search, QFT, QPE, VQE workflow, and QAOA workflow; comparative analysis of Qiskit and Cirq syntax; circuit depth, gate count, runtime, and result comparison; Cirq simulator and noise model experiments; SDK portability issues; reproducibility notes; and comparative technical lab report.

References:

1. Quantum Computing: An Applied Approach by Jack D. Hidary, 2nd Edition
2. Quantum Machine Learning with Python: Using Cirq from Google Research and IBM Qiskit by Santanu Pattanayak, 1st Edition

3. Programming Quantum Computers: Essential Algorithms and Code Samples by Eric Johnston, Nic Harrigan and Mercedes Gimeno-Segovia, 1st Edition
4. Quantum Computing: A Gentle Introduction by Eleanor G. Rieffel and Wolfgang H. Polak
5. An Introduction to Quantum Computing by Phillip Kaye, Raymond Laflamme and Michele Mosca

Subject 4: Hybrid Quantum-Classical Systems and Cloud Platforms

Unit 1: Hybrid System Architecture and Design Patterns

Classical co-processor role, quantum inner loop and classical outer loop, feedforward and feedback patterns, data flow, latency, batching, NISQ suitability, and decision framework for when quantum components are appropriate.

Unit 2: Quantum Cloud Platforms Overview

IBM Quantum, Google Quantum AI, Microsoft Azure Quantum, AWS Braket, IonQ, Rigetti, and Quantinuum access models; platform comparison by cost, queue, backend quality, provider ecosystem, security, and CSE development workflow.

Unit 3: Quantum APIs, SDK Integration, and Workflow Orchestration

REST concepts, Qiskit Runtime, Cirq-Google interfaces, Azure Quantum Python SDK, AWS Braket SDK, OpenQASM exchange, checkpointing, caching, parallel job submission, middleware, and multi-backend orchestration.

Unit 4: Optimization Loops in Hybrid Systems

Application of classical optimizers such as Adam optimizer, COBYLA, SPSA, L-BFGS-B, Nelder-Mead, and Bayesian optimization in hybrid loops; convergence monitoring, warm starts, adaptive workflows, and optimizer benchmarking for hybrid quantum-classical workflows.

Unit 5: Deployment, Scalability, and Resource Planning

Resource estimation, cost estimation, cloud job monitoring, Docker-based environments, reproducible workflows, logging, multi-cloud strategy, secure token management, and production-readiness assessment for hybrid quantum applications.

References:

1. Quantum Software Engineering by Manuel A. Serrano, Ricardo Pérez-Castillo and Mario Piattini
2. Quantum Computing: An Applied Approach by Jack D. Hidary, 2nd Edition

3. Quantum Computing for Programmers by Robert Hundt, 2nd Edition
4. Learn Quantum Computing with Python and IBM Quantum by Robert Lored, 2nd Edition

Subject 5: Computational Quantum Science, Simulation, and HPC Acceleration

Unit 1: Computational Quantum Science and Quantum Simulation Foundations

Computational quantum science motivation, quantum simulation workloads, Hamiltonian simulation overview, statevector memory scaling, tensor-network relevance, HPC architecture, CPU and GPU models, shared and distributed memory, parallel computing, clusters, job scheduling, and performance bottlenecks.

Unit 2: Hamiltonian Simulation, Quantum Chemistry, and Materials Applications

Hamiltonian construction, time evolution overview, quantum chemistry workflows, molecular simulation, materials discovery, energy applications, OpenFermion, Qiskit Nature, active-space awareness, classical preprocessing, and benchmarking against classical scientific-computing baselines.

Unit 3: GPU Programming and NVIDIA cuQuantum for Accelerated Simulation

GPU architecture, CUDA cores, memory hierarchy, CuPy, Numba, cuBLAS, cuSolver, cuQuantum SDK, cuStateVec, cuTensorNet, GPU-accelerated statevector and density-matrix simulation, circuit batching, Qiskit Aer and Cirq integration, profiling, and CPU-vs-GPU benchmarking.

Unit 4: Tensor Networks and GPU-Accelerated Contractions

Tensor network fundamentals, MPS, PEPS, MERA overview, tensor contraction order, cuTensorNet contraction, approximate simulation, exact simulation comparison, applications in quantum chemistry, QML, and optimization, and practical limitations.

Unit 5: Scaling Hybrid Scientific Workloads on HPC Infrastructure

VQE, QAOA, Hamiltonian simulation, and quantum chemistry acceleration from a performance perspective; parallel optimizer evaluations; multi-GPU and distributed simulation concepts; MPI awareness; workflow orchestration; performance measurement; reproducibility; and cost-resource planning.

References:

1. Quantum Computing: An Applied Approach by Jack D. Hidary, 2nd Edition
2. Quantum Computing for Programmers by Robert Hundt, 2nd Edition
3. Quantum Chemistry and Computing for the Curious by Keeper L. Sharkey and Alain Chancé, 1st Edition
4. Programming Massively Parallel Processors: A Hands-on Approach by David B. Kirk and Wen-mei W. Hwu, 4th Edition
5. Quantum Computing for Computer Scientists by Noson S. Yanofsky and Mirco A. Mannucci

Subject 6: Elective I

Option A: Quantum Cryptography and Post-Quantum Security

Unit 1: Classical Cryptography Foundations and Quantum Threats

Symmetric and asymmetric cryptography, RSA, ECC, Diffie-Hellman, hash functions, digital signatures, Shor impact on public-key systems, Grover impact on symmetric security, harvest-now-decrypt-later risk, and quantum-safe migration motivation.

Unit 2: Quantum Key Distribution Concepts and Simulation

QKD principles, BB84, E91, B92, eavesdropping detection, information-theoretic security, reconciliation, privacy amplification, Python/Qiskit simulation of QKD concepts, and practical limitations of QKD systems.

Unit 3: Post-Quantum Cryptography and Standards

NIST PQC process, ML-KEM/Kyber family, ML-DSA/Dilithium family, SPHINCS+, Classic McEliece overview, lattice-based assumptions, hash-based signatures, code-based schemes, security levels, and performance trade-offs.

Unit 4: Quantum-Safe Software Implementation

Open Quantum Safe, liboqs, hybrid certificates, TLS transition, cryptographic agility, key management, implementation testing, side-channel awareness, secure coding, and integration into enterprise applications.

Unit 5: Migration Strategy and Governance

Inventory of cryptographic assets, risk prioritization, regulatory considerations, quantum-safe VPN and secure communication software, phased migration plans, compliance documentation, and future quantum-safe internet architecture.

References:

1. Post-Quantum Cryptography by Daniel J. Bernstein, Johannes Buchmann and Erik Dahmen
2. Quantum Cryptography and Secret-Key Distillation by Gilles Van Assche
3. Quantum Cryptography: From Key Distribution to Conference Key Agreement by Federico Grasselli
4. Cryptography Apocalypse: Preparing for the Day When Quantum Computing Breaks Today's Crypto by Roger A. Grimes
5. Introduction to Modern Cryptography by Jonathan Katz and Yehuda Lindell, 3rd Edition

Option B: Quantum Communication Software Protocols

Unit 1: Quantum Communication and Network Models

Quantum channels, entanglement as a communication resource, quantum repeaters overview, quantum memory role, classical control plane, network topologies, quantum node architecture, and quantum internet roadmap.

Unit 2: Teleportation, Superdense Coding, and Entanglement Distribution

Quantum teleportation, Bell measurement, classical communication requirement, superdense coding, entanglement swapping, state transfer, protocol simulation using Qiskit or Cirq, and correctness testing.

Unit 3: QKD Protocol Software Stack

Sifting, reconciliation, privacy amplification, authentication, QBER estimation, channel monitoring, key management software, device-independent concepts, and integration of QKD outputs with classical security systems.

Unit 4: Quantum Network Simulation and Protocol Engineering

NetSquid, SimulaQron overview, channel modeling, repeater protocol simulation, entanglement distribution simulation, software-defined quantum networking concepts, protocol verification, and scalability testing.

Unit 5: Quantum Internet Application Software

Entanglement-as-a-service, blind quantum computing protocol overview, distributed quantum computing, secure multiparty computation concepts, API design for quantum network services, and future applications.

References:

1. The Quantum Internet: The Second Quantum Revolution by Peter P. Rohde
2. An Introduction to Quantum Communication Networks: Or, How Shall We Communicate in the Quantum Era? by Mohsen Razavi
3. Quantum Communication Networks by Riccardo Bassoli, Holger Boche, Christian Deppe, Roberto Ferrara, Frank H. P. Fitzek, Gisbert Janssen and Sajad Saeedinaeeni
4. Quantum Communications and Cryptography by Alexander V. Sergienko
5. Quantum Information Theory by Mark M. Wilde, 2nd Edition

Subject 7: Elective II

Option A: Quantum Computing in Finance and Optimization

Unit 1: Optimization Formulation for Finance and Business

QUBO formulation, Ising mapping, binary and integer encoding, penalty functions, classical baselines, quantum annealing overview, gate-based optimization, problem scaling, and feasibility assessment.

Unit 2: Portfolio Optimization and Risk Analysis

Modern portfolio theory, mean-variance optimization, portfolio QUBO, QAOA and VQE usage as established variational methods, risk measures, quantum amplitude estimation for risk, and benchmarking against classical solvers.

Unit 3: Quantum Monte Carlo and Financial Simulation

Classical Monte Carlo, quantum amplitude estimation for integration, option pricing, credit risk, stochastic process simulation overview, convergence interpretation, hardware requirements, and suitability for near-term and fault-tolerant quantum computing.

Unit 4: Combinatorial Optimization Applications

Max-Cut, graph coloring, routing, scheduling, knapsack, resource allocation, D-Wave overview, hybrid classical-quantum optimization pipelines, and benchmark design for business optimization.

Unit 5: Financial Quantum Software Tools and Use Cases

Qiskit Finance, PennyLane, AWS Braket, IBM Quantum case studies, fraud detection possibilities, compliance challenges, quantum readiness assessment, and responsible business communication.

References:

1. Quantum Algorithms for Optimizers by Giacomo Nannicini
2. The Quadratic Unconstrained Binary Optimization Problem: Theory, Algorithms, and Applications edited by Abraham P. Punnen
3. Quantum Computing: An Applied Approach by Jack D. Hidary, 2nd Edition
4. Quantum Computers: Theory and Algorithms by Belal Ehsan Baaquie and Leong-Chuan Kwek
5. Quantum Computing and Blockchain in Business by Arunkumar Krishnakumar

Option B: Quantum Computing for Drug Discovery and Life Sciences

Unit 1: Quantum Simulation Foundations for Molecular Problems

Molecular Hamiltonians, second quantization overview, fermionic mappings, Jordan-Wigner and Bravyi-Kitaev transformations, active space selection, small molecule simulation, and resource requirements.

Unit 2: Quantum Chemistry Algorithms in Life Sciences

Application-focused use of VQE and QPE, ground-state energy estimation, excited states overview, binding energy estimation, reaction pathways, OpenFermion and Qiskit Nature workflows, and limitations.

Unit 3: Protein Folding, Genomics, and Biomedical Data

Protein folding optimization, lattice models, QUBO formulation, sequence alignment overview, genomic pattern matching, quantum clustering for biological data, and comparison with classical AI and HPC methods.

Unit 4: Quantum Machine Learning in Biomedical Research

Application of QML and encoding methods to medical image analysis, disease classification, patient stratification, ADMET prediction, drug interaction prediction, and privacy-aware healthcare workflows.

Unit 5: Life Sciences Toolchains and Pipelines

Qiskit Nature, OpenFermion-PySCF, PennyLane, Azure Quantum, AWS Braket, integration with classical bioinformatics tools, hybrid HPC-quantum pipelines, industry collaborations, and future fault-tolerant drug discovery.

References:

1. Quantum Chemistry and Computing for the Curious by Keeper L. Sharkey and Alain Chancé, 1st Edition
2. Quantum Computing: An Applied Approach by Jack D. Hidary, 2nd Edition
3. Quantum Computing in Practice with Qiskit and IBM Quantum Experience by Hassi Norlén, 1st Edition
4. Quantum Computing for the Quantum Curious by Ciaran Hughes, Joshua Isaacson, Anastasia Perry, Ranbel F. Sun and Jessica Turner, 1st Edition
5. Quantum Computing for Computer Scientists by Noson S. Yanofsky and Mirco A. Mannucci

Research Methodology, Proposal Development, and Quantum Seminar (Non-Credit Academic Activity)

Unit 1: Research Theme Coverage and Problem Identification

Quantum algorithms, quantum software engineering, quantum machine learning, quantum error correction, post-quantum cryptography, quantum communication, quantum cloud platforms, quantum AI, quantum applications, computational quantum science, emerging research trends, and early problem identification.

Unit 2: Faculty-Led Paper Discussion and Research Methodology

Problem statement identification, technical background, research methodology awareness, methodology walkthrough, result interpretation, limitations, reproducibility considerations, and relevance to CSE-oriented quantum computing.

Unit 3: Student Seminar Presentation and Preliminary Literature Review

Paper summary preparation, seminar delivery, slide-based explanation, comparison with existing work, preliminary literature review writing, research-gap identification, and peer question handling.

Unit 4: Research Proposal and Reproducibility Planning

Structured paper notes, research gap identification, preliminary research proposal preparation, reproducibility planning, ethical and responsible claims about quantum advantage, and short review writing.

Unit 5: Research Proposal and Semester Research Portfolio

Compilation of weekly summaries, selected implementation notes, reflections on open problems, preliminary research proposal preparation, supervisor or topic alignment, and preparation for Research Project Phase I.

SEMESTER 3

Subject 1: Quantum Systems Engineering and Software Architecture

Unit 1: Quantum Systems Architecture and Hardware-Software Interaction

Quantum systems architecture, layered quantum software architecture, hardware-software interaction, non-determinism, latency, hardware variability, device constraints, coherence time, gate fidelity, readout fidelity, error rates, abstraction, modularity, cohesion, coupling, scalability, portability, and C4-style documentation for quantum systems.

Unit 2: Device Topology, System Decomposition, and Design Patterns

Device topology, coupling constraints, backend properties, connectivity, crosstalk, calibration awareness, quantum circuit as component, reusable algorithm modules, quantum-classical adapter pattern, prepare-

evolve-measure pattern, uncomputation pattern, backend abstraction, middleware design, and interface contracts.

Unit 3: Compiler, Transpiler, and Interoperability Architecture

Compiler pipeline, OpenQASM 3, QIR overview, basis conversion, qubit allocation, routing, optimization passes, noise-aware compilation, resource-estimation awareness, Qiskit transpiler, Cirq transformers, and SDK-agnostic application layers.

Unit 4: Full-Stack Quantum Application Design and Benchmarking

Frontend layer, backend services, quantum job API, database design for experiment results, circuit generation layer, result processing, visualization, Docker-based reproducibility, system benchmarking, simulator-versus-hardware comparison, logical-versus-physical qubit tracking, and end-to-end application case study.

Unit 5: Quantum DevOps, Reproducibility, and Lifecycle Management

Centralized treatment of Git workflows, CI/CD, GitHub Actions, automated simulation tests, dependency management, documentation standards, code review, open-source collaboration, reproducibility practices, monitoring, technical debt, release management, and production lifecycle governance.

References:

1. Quantum Software Engineering by Manuel A. Serrano, Ricardo Pérez-Castillo and Mario Piattini
2. Quantum Computer Systems: Research for Noisy Intermediate-Scale Quantum Computers by Yongshan Ding and Frederic T. Chong
3. Quantum Computing for Programmers by Robert Hundt, 2nd Edition
4. Software Architecture in Practice by Len Bass, Paul Clements and Rick Kazman, 4th Edition

Subject 2: Quantum Error Correction and Fault-Tolerant Computing

Unit 1: Quantum Noise and Error Models

Decoherence, T1 and T2, gate errors, readout errors, crosstalk, bit flip, phase flip, depolarizing noise, amplitude damping, Kraus operators, Pauli channels, calibration effects, hardware performance metrics, and how noise affects software execution.

Unit 2: Quantum Error Correction Code Foundations

Classical error correction review, no-cloning constraint, quantum error correction conditions, 3-qubit bit-flip and phase-flip codes, Shor code, Steane code, CSS construction, syndrome measurement, and logical qubit concept.

Unit 3: Stabilizer Codes and Surface Codes

Pauli group, stabilizer formalism, stabilizer generators, syndrome extraction, logical operators, toric code overview, surface code layout, decoding concepts, minimum weight perfect matching overview, and threshold intuition.

Unit 4: Fault-Tolerant Circuit Design

Threshold theorem overview, transversal gates, magic state distillation, logical gate implementation, logical circuit compilation, lattice surgery overview, logical-versus-physical qubit overhead, resource overhead estimation, and software patterns for fault-tolerant algorithms.

Unit 5: NISQ Error Mitigation for Quantum Software

Difference between correction and mitigation, zero-noise extrapolation, probabilistic error cancellation, measurement mitigation, dynamical decoupling, symmetry verification, randomized compiling, Qiskit Runtime resilience levels, logical and physical qubit implications, and trade-offs between cost and accuracy.

References:

1. Quantum Error Correction edited by Daniel A. Lidar and Todd A. Brun
2. Quantum Error Correction and Fault Tolerant Quantum Computing by Frank Gaitan
3. Quantum Computation and Quantum Information by Michael A. Nielsen and Isaac L. Chuang, 10th Anniversary Edition
4. Quantum Computing for Programmers by Robert Hundt, 2nd Edition
5. Quantum Computing: A Gentle Introduction by Eleanor G. Rieffel and Wolfgang H. Polak
- 6.

Subject 3: Quantum Resource Estimation and Cloud Execution Lab with Microsoft Q# and Azure Quantum

Unit 1: Azure Quantum, QDK, and Resource-Oriented Programming Environment

Azure Quantum workspace, QDK components, Q# language philosophy, provider ecosystem, local and cloud development, resource estimator, Python/Jupyter integration, documentation usage, and concept-oriented use of Q# for resource estimation and cloud execution.

Unit 2: Q# Language Fundamentals

Namespaces, entry points, operations and functions, Qubit, Result, Pauli, arrays, tuples, user-defined types, controlled and adjoint functors, loops, conditionals, repeat-until-success, assertions, and modular Q# structure.

Unit 3: Practical Q# Implementation of Algorithms, Resource Estimation, and Benchmarking

Q# implementation of superposition circuits, entanglement circuits, quantum teleportation, Deutsch-Jozsa algorithm, Grover search, QFT and QPE, VQE-style hybrid workflows, quantum random number generation, Q# resource estimation for selected algorithms, logical-versus-physical qubit interpretation, comparison with Qiskit and Cirq implementations, modular Q# coding, testing, debugging, and benchmarking.

Unit 4: Python Integration and Azure Quantum Execution

Calling Q# from Python, passing classical data, local simulators, job submission to Azure Quantum, provider selection, result retrieval, resource estimation reports, debugging tools, and notebook-based workflow.

Unit 5: Testing, Resource Estimation, and Deployment with QDK

Q# unit testing, modular libraries, assertions, deployment patterns, CI integration at a high level, resource estimation, hybrid application architecture, documentation, and production-grade QDK best practices.

References:

1. Learn Quantum Computing with Python and Q# by Sarah C. Kaiser and Cris Granade
2. Q# Pocket Guide: Instant Help for Q# Developers by Mariia Mykhailova
3. Introduction to Quantum Computing with Q# and QDK by Filip Wojcieszyn
4. Introducing Microsoft Quantum Computing for Developers: Using the Quantum Development Kit and Q# by Johnny Hooyberghs
5. Quantum Computing for Programmers by Robert Hundt, 2nd Edition

Subject 4: Quantum Open-Source Engineering, APIs, and Reproducible Systems

Unit 1: Anatomy of Quantum Software Frameworks and SDKs

SDK responsibilities, circuit representation, gate abstractions, operation models, backend provider interfaces, simulator integration, versioning, compatibility, deprecation policy, and comparative architecture of Qiskit, Cirq, Q#, and PennyLane.

Unit 2: Quantum Circuit API Design

Quantum circuit class design, fluent APIs, gate object design, parameters, composition, instruction validation, serialization using JSON/OpenQASM/Protobuf, error handling, backward compatibility, and developer-friendly API documentation.

Unit 3: Backend Connectors and Provider Integration

Backend abstraction layer, simulator interface, hardware provider interface, authentication, job submission protocol, polling, webhooks, asynchronous job management, result schema design, multi-provider registries, and hardware mocking for tests.

Unit 4: Testing and Developer Experience for Quantum Software Frameworks

Unit and integration testing, property-based testing, cross-platform tests, documentation with Sphinx or MkDocs, Jupyter examples, API usability, regression testing, performance tests, and test-driven development for quantum SDK components.

Unit 5: Publishing, Open-Source Contribution, and Reproducibility

Python packaging, pyproject.toml, semantic versioning, PyPI publishing, licensing, changelogs, release notes, pull request workflow, code review standards, reproduction of published results, contribution to Qiskit/Cirq/PennyLane, reproducible examples, and community maintenance.

References:

1. Quantum Computing for Programmers by Robert Hundt, 2nd Edition
2. Quantum Computing: An Applied Approach by Jack D. Hidary, 2nd Edition
3. API Design Patterns by J. J. Geewax
4. Publishing Python Packages by Dane Hillard

Subject 5: Quantum Applications Engineering, Benchmarking, and Responsible Deployment

Unit 1: Quantum Application Technology Landscape and Frameworks

Quantum application technology landscape, PennyLane, TensorFlow Quantum, Qiskit Machine Learning, hybrid AI architecture, maturity assessment, realistic value assessment, NISQ limitations, benchmarking standards, responsible claims, and industry research directions.

Unit 2: Quantum Machine Learning Application Evaluation

Hybrid neural networks, quantum layers in classical models, QCNNs overview, transfer learning, trainability, barren plateaus, expressibility, application suitability analysis, evidence-based evaluation, and benchmarking against classical machine learning and deep learning baselines.

Unit 3: Emerging Quantum-Enhanced Models and Generative Approaches

Classical GAN/VAE review, introductory awareness of QGANs, quantum circuit Born machines, quantum Boltzmann machines, and variational autoencoders, maturity and feasibility assessment, training challenges, selected use cases in data generation and chemistry, and implementation awareness using PennyLane and Qiskit, with emphasis on maturity, feasibility, and responsible evaluation.

Unit 4: Quantum-Assisted Search, Optimization, and Scientific Workflows

Application of Grover, QAOA, and QML methods to search, optimization, hyperparameter exploration, combinatorial problems, scientific workflow acceleration, and hybrid decision pipelines with clear classical baseline comparison.

Unit 5: Responsible Deployment, Benchmarking, and Governance

Bias, fairness, explainability, reliability, governance, reproducibility, responsible quantum advantage claims, deployment patterns, monitoring, limitations, benchmarking culture, and ethics of quantum application deployment.

References:

1. Quantum Machine Learning: An Applied Approach by Santanu Ganguly, 1st Edition
2. Machine Learning with Quantum Computers by Maria Schuld and Francesco Petruccione, 2nd Edition
3. Quantum Computing: An Applied Approach by Jack D. Hidary, 2nd Edition
4. Quantum Machine Learning with Python: Using Cirq from Google Research and IBM Qiskit by Santanu Pattanayak, 1st Edition

Subject 6: Elective III

Option A: Quantum Natural Language Processing

Unit 1: Classical NLP Foundations and Quantum Motivation

Tokenization, embeddings, RNNs, Transformers, LLM overview, compositional semantics, computational cost of NLP, motivation for QNLP, category-theoretic intuition, and research landscape.

Unit 2: Quantum Text Encoding and Semantics

Encoding words and sentences as quantum states, DisCoCat model, pregroup grammars, string diagrams, Hilbert space meaning, density-matrix representations, semantic similarity, and comparison with classical embeddings.

Unit 3: QNLP Models, Lambeq, and Circuit Classifiers

Lambeq toolkit, sentence-to-circuit conversion, tket integration, variational circuit classifiers, text classification, custom ansatz design, training workflows, and benchmarking against classical baselines.

Unit 4: Quantum Sentiment Analysis and Information Retrieval

Sentiment analysis, multi-class text classification, quantum sequence model ideas, quantum attention research directions, question answering concepts, information retrieval, and evaluation metrics.

Unit 5: QNLP Benchmarks and Research Frontiers

QNLP datasets, PennyLane workflows, NISQ feasibility, quantum transformers research, quantum self-attention concepts, open problems, limitations, and future directions for quantum language models.

References:

1. Picturing Quantum Processes by Bob Coecke and Aleks Kissinger
2. Categories for Quantum Theory: An Introduction by Chris Heunen and Jamie Vicary
3. Quantum in Pictures: A New Way to Understand the Quantum World by Bob Coecke and Stefano Gogioso
4. Natural Language Processing with Transformers by Lewis Tunstall, Leandro von Werra and Thomas Wolf, Revised Edition
5. Neural Network Methods for Natural Language Processing by Yoav Goldberg

Option B: Quantum Reinforcement Learning

Unit 1: Reinforcement Learning Foundations and QRL Paradigm

Agent, environment, state, action, reward, Markov decision processes, Q-learning, SARSA, DQN, PPO overview, sample efficiency challenges, quantum RL motivation, and research landscape.

Unit 2: Quantum State Representation and Policy Models

Application of quantum encoding methods to RL state representation, variational circuits as policy networks, hybrid preprocessing, parameter-shift gradients, and PennyLane-based policy implementation.

Unit 3: Quantum Policy Gradient and Variational RL

REINFORCE overview, quantum policy gradients, actor-critic structures, trainability issues, barren plateaus, CartPole and GridWorld benchmarks, action selection, and hybrid quantum-classical training loops.

Unit 4: QRL for Optimization and Multi-Agent Problems

Combinatorial optimization as RL, Max-Cut and scheduling, resource allocation, routing, multi-agent settings, quantum game-theoretic concepts, and use of entanglement as a research concept.

Unit 5: QRL Frameworks and Research Frontiers

PennyLane, TensorFlow Quantum, OpenAI Gymnasium / RL environment integration. integration, simulation environments, hardware feasibility, benchmark protocols, robotics concepts, logistics, energy grid applications, and open research problems.

References:

1. Quantum Machine Learning: Quantum Algorithms and Neural Networks edited by Pethuru Raj, Houbing Herbert Song, Dac-Nhuong Le and Narayan Vyas
2. Quantum Machine Learning: An Applied Approach by Santanu Ganguly, 1st Edition
3. Machine Learning with Quantum Computers by Maria Schuld and Francesco Petruccione, 2nd Edition
4. Reinforcement Learning: An Introduction by Richard S. Sutton and Andrew G. Barto, 2nd Edition
5. Quantum Machine Learning with Python: Using Cirq from Google Research and IBM Qiskit by Santanu Pattanayak, 1st Edition

Subject 7: Elective IV

Option A: Quantum Computing Solution Architecture and Cloud Deployment

Unit 1: Quantum Solution Architecture and Design Thinking

Role of quantum solution architect, problem framing, feasibility assessment, stakeholder communication, quantum-suitable problem identification, architectural deliverables, proof-of-concept planning, and enterprise readiness.

Unit 2: End-to-End Quantum Application Design

Problem-to-algorithm mapping, algorithm-to-circuit design, data flow, interface design, MVP definition, success criteria, documentation, experiment management, and stakeholder alignment.

Unit 3: Multi-Cloud Quantum Deployment

AWS Braket, Azure Quantum, IBM Quantum, Google Quantum AI overview, multi-cloud strategy, vendor lock-in avoidance, cost-latency-quality comparison, cloud security, and monitoring of production quantum jobs.

Unit 4: Enterprise Quantum Cloud Deployment Operations

Application of the centralized DevOps concepts from software architecture to deployment pipelines, containerized environments, automated simulation-based testing, infrastructure-as-code awareness, monitoring, logging, incident response, and cost optimization.

Unit 5: Business Case and Enterprise Governance

Quantum ROI, total cost of ownership, vendor evaluation, talent planning, migration roadmap, regulatory considerations, governance structures, and enterprise quantum adoption strategy.

References:

1. Quantum Software Engineering by Manuel A. Serrano, Ricardo Pérez-Castillo and Mario Piattini
2. Quantum Computing: An Applied Approach by Jack D. Hidary, 2nd Edition
3. Quantum Computing Solutions: Solving Real-World Problems Using Quantum Computing and Algorithms by Bhagvan Kommadi
4. Quantum Computing in Action by Johan Vos
5. Enterprise-Grade Hybrid and Multi-Cloud Strategies by Sathya AG and Hitesh Raje

Option B: Advanced Quantum Cybersecurity and Secure Software Systems

Unit 1: Quantum Threat Modeling for Software Systems

Threat modeling, quantum threat timeline, vulnerable cryptographic assets, identity systems, blockchain exposure, data confidentiality risk, harvest-now-decrypt-later attacks, and secure software architecture implications.

Unit 2: Post-Quantum Secure Application Engineering

Integrating PQC libraries, hybrid cryptography, secure API design, key lifecycle management, certificate migration, TLS experimentation, authentication, secure coding, and automated crypto inventory tools.

Unit 3: Quantum-Resistant Cloud and DevSecOps

DevSecOps for quantum-safe transition, CI checks for cryptographic dependencies, secrets management, secure deployment, compliance logging, cloud KMS considerations, and policy-driven cryptographic agility.

Unit 4: Quantum Randomness and Secure Protocol Components

Quantum random number generation concepts, entropy assessment, protocol-level randomness, secure key generation, simulations of quantum randomness, and integration into security systems.

Unit 5: Governance, Compliance, and Future Cybersecurity

NIST PQC adoption, national cybersecurity guidance, enterprise migration roadmap, risk reporting, regulatory readiness, secure software documentation, and future quantum cyber defense research.

References:

- Cryptography Apocalypse: Preparing for the Day When Quantum Computing Breaks Today's Crypto by Roger A. Grimes
- Post-Quantum Cryptography by Daniel J. Bernstein, Johannes Buchmann and Erik Dahmen
- Threat Modeling: Designing for Security by Adam Shostack
- Implementing DevSecOps Practices by Alisson Machado de Menezes

- Quantum Random Number Generation: Theory and Practice edited by Christian Kollmitzer, Stefan Schauer, Stefan Rass and Benjamin Rainer

Research Project Phase I (Non-credit based Research Activity)

Unit 1: Research Theme Selection and Reproduction Study

Selection of research themes across quantum algorithms, quantum systems engineering, quantum machine learning, error correction, security, communication, computational quantum science, and emerging research trends; reproduction of selected published results; and feasibility assessment for Research Project Phase I.

Unit 2: Faculty-Led Research Discussion and Problem Formulation

Faculty-guided discussion of problem statements, technical background, methodology, result interpretation, limitations, reproducibility constraints, system-level evaluation, and relevance to CSE-oriented quantum computing.

Unit 3: Student Mid-Term Research Presentation

Research presentation preparation, slide-based explanation, comparison with existing work, preliminary implementation status, peer question handling, and documented mid-term feedback.

Unit 4: Critical Review, Implementation, and Reproducibility Practice

Structured paper notes, research-gap identification, initial implementation, experiment logging, version control, reproducibility discussion, ethical and responsible claims about quantum advantage, and short review writing.

Unit 5: Research Project Phase I Portfolio and Mid-Term Review

Compilation of weekly summaries, selected implementation notes, reproduction results, reflections on open problems, preliminary system benchmarks, supervisor feedback, and preparation for Research Project Phase II in Semester 4.

MS Quantum Computing

SEMESTER 4

RESEARCH PROJECT PHASE II (FINAL SEMESTER CAPSTONE PROJECT)