Engineering Curriculum: 6 Advanced Courses
Courses Included:

1. **Engineering Mechanics & Materials**
2. **Construction Elements & Engineering Technology**
3. **Thermodynamics & Statistical Physics**
4. **Electronics & Hardware Production**
5. **Quantum Computing & CPU/GPU Production**
6. **Quantum Mechanics & Advanced Hardware Applications**

1. Engineering Mechanics & Materials
Weeks 1–6: Engineering Mechanics
Textbook: *Engineering Mechanics: Statics & Dynamics* by R.C. Hibbeler

- **Week 1**: Forces, equilibrium, free-body diagrams (Ch. 2–3).
- **Week 2**: Moments and rigid body equilibrium (Ch. 4–5).
- **Week 3**: Truss analysis (Ch. 6).
- **Week 4**: Friction applications (Ch. 8).
- **Week 5**: Stress/strain basics (Ch. 1 of *Mechanics of Materials*).
- **Week 6**: Beam bending (Ch. 6–7).
  Projects: Bridge truss analysis, beam design.

Weeks 7–12: Materials Science
Textbook: *Materials Science and Engineering* by Callister & Rethwisch

- **Week 7**: Stress-strain curves (Ch. 6–7).
- **Week 8**: Metals/alloys (Ch. 9–11).
- **Week 9**: Polymers/ceramics (Ch. 13–14).
- **Week 10**: Composites (Ch. 16).
- **Week 11**: Failure analysis (Ch. 8–9).
- **Week 12**: Material selection (Ch. 22).
  Projects: Composite panel design, failure case study.

2. Construction Elements & Engineering Technology
Weeks 1–6: Construction Elements
Textbook: *Construction Technology* by Chudley & Greeno

- **Week 1**: Building materials (Ch. 2–4).

- **Week 2**: Structural systems (Ch. 5–6).
- **Week 3**: Foundations/soil mechanics (Ch. 7).
- **Week 4**: MEP systems (Ch. 10).
- **Week 5**: Sustainability (Ch. 12).
- **Week 6**: Building codes (Ch. 1).
  Projects: MEP plan design, code-compliant building.

Weeks 7–12: Engineering Technology
Textbook: *BIM Handbook* by Eastman et al.

- **Week 7**: CAD/BIM basics (Ch. 2).
- **Week 8**: FEA simulations (ANSYS/SolidWorks).
- **Week 9**: Drones/3D printing (Ch. 6).
- **Week 10**: Project management (Ch. 5).
- **Week 11**: IoT in construction (research papers).
- **Week 12**: AI/AR trends (Ch. 9).
  Projects: BIM floor plan, drone site mapping.

3. Thermodynamics & Statistical Physics
Weeks 1–6: Thermodynamics
Textbook: *Fundamentals of Engineering Thermodynamics* by Moran et al.

- **Week 1**: Laws of thermodynamics (Ch. 1–2).
- **Week 2**: Phase diagrams (Ch. 3).
- **Week 3**: Energy analysis (Ch. 4).
- **Week 4**: Entropy (Ch. 6–7).
- **Week 5**: Power cycles (Ch. 8–10).
- **Week 6**: Combustion (Ch. 13).
  Projects: Rankine cycle optimization, carbon footprint analysis.

Weeks 7–12: Statistical Physics
Textbook: *Thermal Physics* by Kittel & Kroemer

- **Week 7**: Kinetic theory (Ch. 1).
- **Week 8**: Ensembles (Ch. 2).
- **Week 9**: Quantum statistics (Ch. 4).
- **Week 10**: Phase transitions (Ch. 10).
- **Week 11**: Transport phenomena (Reif Ch. 12).
- **Week 12**: Modern applications (Bose-Einstein condensates).
  Projects: Ising model simulation, quantum system analysis.

4. Electronics & Hardware Production
Weeks 1–6: Electronics
Textbook: *Microelectronic Circuits* by Sedra & Smith

- **Week 1**: Basic components (Ch. 1–2).
- **Week 2**: Diodes (Ch. 3–4).
- **Week 3**: Transistors (Ch. 5–6).
- **Week 4**: Op-amps (Ch. 2, 13).
- **Week 5**: Digital logic (Ch. 14).
- **Week 6**: Power supplies (Ch. 17).
  Projects: Audio filter design, voltage regulator.

Weeks 7–12: Hardware Production
Textbook: *PCB Designer's Reference* by Robertson

- **Week 7**: PCB design (KiCad/Eagle).
- **Week 8**: Fabrication processes (Gerber files).
- **Week 9**: SMT soldering (IPC standards).
- **Week 10**: Through-hole assembly.
- **Week 11**: Testing (ICT, thermal imaging).
- **Week 12**: DFM optimization.
  Projects: Custom PCB assembly, DFM report.

5. Quantum Computing & CPU/GPU Production
Weeks 1–6: Quantum Computing
Textbook: *Quantum Computation and Quantum Information* by Nielsen & Chuang

- **Week 1**: Qubits (Ch. 1).
- **Week 2**: Quantum gates (Ch. 4).
- **Week 3**: Algorithms (Ch. 5–6).
- **Week 4**: Cryptography (Ch. 5).
- **Week 5**: Hardware (superconducting qubits).
- **Week 6**: Error correction (Ch. 10).
  Projects: Grover's algorithm, error-correcting code.

Weeks 7–12: CPU/GPU Production
Textbook: *Modern Semiconductor Devices* by Chenming C. Hu

- **Week 7**: Semiconductor physics (Ch. 1–2).
- **Week 8**: CMOS fabrication (Ch. 3–4).
- **Week 9**: CPU architecture (Hennessy & Patterson).
- **Week 10**: GPU architecture (CUDA programming).

- **Week 11**: Packaging/testing (ATE tools).
- **Week 12**: AI accelerators.
  Projects: MIPS pipeline design, GPU thermal analysis.

6. Quantum Mechanics & Advanced Hardware Applications
Week 1: Mathematical Prerequisites
Textbook: *Mathematical Methods in the Physical Sciences* by **Mary L. Boas** (3rd ed.)

- **Topics**:
  - Linear algebra (vectors, matrices, eigenvalues).
  - Differential equations (separable, Fourier series).
  - Complex numbers and probability theory.
- **Chapters**:
  - Ch. 3 (Linear Algebra), Ch. 8 (Differential Equations), Ch. 2 (Complex Numbers), Ch. 14 (Probability).
- **Lab**: Solve quantum-inspired problems using Python (NumPy/SymPy).

Week 2: Classical Mechanics Primer
Textbook: *Classical Mechanics* by **Herbert Goldstein** (3rd ed.)

- **Topics**:
  - Lagrangian/Hamiltonian mechanics.
  - Poisson brackets, canonical transformations.
- **Chapters**:
  - Ch. 1 (Lagrange's Equations), Ch. 2 (Hamilton's Principle).
- **Project**: Simulate a double pendulum's motion using Lagrangian mechanics (Python).

Weeks 3–10: Pure Quantum Mechanics
Textbook: *Introduction to Quantum Mechanics* by **David J. Griffiths** (3rd ed.)

Week	Topics	Chapters	Labs/Projects
3	**Wave Functions & Schrödinger Equation**	Ch. 1–2	Lab: Solve infinite potential well numerically.
4	**Formalism (Hilbert Space, Operators)**	Ch. 3	Project: Simulate expectation values for particle in a box.
5	**Angular Momentum & Spin**	Ch. 4	Lab: Visualize spin-½ states with Qiskit.

6	**Time-Independent Perturbation Theory**	Ch. 6	Project: Calculate energy shifts for Stark effect.
7	**Identical Particles**	Ch. 5	Lab: Simulate fermionic/bosonic distributions.
8	**Time-Dependent Perturbation Theory**	Ch. 9	Project: Model Rabi oscillations in a 2-level system.
9	**Scattering Theory**	Ch. 11	Lab: Simulate 1D scattering with COMSOL.
10	**Relativistic QM (Dirac Equation)**	Ch. 7 (supplement with online notes)	Case Study: Graphene's relativistic electrons.

Weeks 11–12: Applications in Advanced Hardware Production
Textbook: *Quantum Mechanics for Semiconductor Devices* by **Mitin, Kochelap, & Stroscio**

Week	**Topics**	**Key Concepts**	**Labs/Projects**
11	**Quantum Dots & Nanostructures**	- Quantum confinement - Single-electron transistors	Lab: Simulate quantum dot energy levels (COMSOL/NanoHub).
12	**Quantum Computing Hardware**	- Qubit fabrication (superconducting, spin) - Cryogenic CMOS integration	Final Project: Design a qubit control circuit for a semiconductor chip.

Additional Resources:

1. **Software**:
   a. **Qiskit Metal** (quantum device design).
   b. **COMSOL Multiphysics** (nanostructure simulations).
2. **Industry Papers**:
   a. Intel's quantum dot transistor research.
   b. IBM's quantum hardware roadmaps.

Key Connections:

- **Week 1 (Math) → Week 3 (Wavefunctions)**: Eigenvalue problems link matrices to Schrödinger solutions.
- **Week 2 (Hamiltonians) → Week 5 (Spin)**: Poisson brackets formalize commutators in quantum theory.
- **Week 12 (Qubit Fabrication)**: Applies quantum mechanics to design next-gen CPUs/GPUs.

Assessment:

- **Prerequisites**: Math/classical mechanics problem sets.
- **Core Quantum**: Weekly coding labs (Python/Qiskit), perturbation theory reports.
- **Hardware Apps**: Final project presentation on qubit circuit design.

Core Courses

1. Quantum Hardware Engineering

Topics:

- Superconducting qubits, photonic qubits, and spin qubits [914].
- Cryogenic systems, error correction (surface codes), and hybrid quantum-classical architectures [911].
- Hands-on labs using platforms like **Quantum Inspire** for programming quantum algorithms on real hardware [9].

- **Textbook**: *Quantum Computation and Quantum Information* (Nielsen & Chuang) [9].
- **Project**: Design a fault-tolerant qubit control circuit [914].

2. Advanced Materials for Next-Gen Hardware

- **Topics**:
  - Metamaterials, plasmonic structures, and 2D materials (e.g., graphene) 113.
  - Nanoelectromagnetics, photonic crystals, and terahertz systems 1.
  - Applications in RF, optical communications, and quantum sensing 113.
- **Case Study**: Design a metamaterial-based antenna for 6G networks 1.

3. Quantum Computing & Algorithms

- **Topics**:
  - Grover's, Shor's, and variational quantum algorithms 11.
  - Qiskit and CUDA programming for quantum-classical hybrid systems 117.
- **Lab**: Optimize a quantum machine learning model using NVIDIA's quantum tools 7.
- **Textbook**: *Programming Quantum Computers* (Johnston et al.) 11.

4. Semiconductor Physics & Device Fabrication

- **Topics**:
  - CMOS scaling, EUV lithography, and 3D chip stacking 14.
  - Quantum dots, single-electron transistors, and cryogenic CMOS integration 914.
- **Project**: Simulate a 3nm transistor node using TCAD tools 14.

5. Photonics & Quantum Optics

- **Topics**:
  - Laser systems, optical fibers, and integrated photonics 113.
  - Quantum key distribution (QKD) and photonic quantum computing 913.
- **Lab**: Build a quantum communication link using entangled photons 1.

Electives (Choose 2–3)

6. AI-Driven Hardware Design

- Use machine learning to optimize quantum error correction or chip layouts 711.
- **Tool**: NVIDIA's quantum simulation frameworks 7.

7. Sustainable Hardware Technologies

- Energy-efficient computing, recyclable materials, and green semiconductor manufacturing 10.
- **Case Study**: Decarbonizing data centers with quantum-inspired cooling systems 10.

8. Quantum Sensing & Metrology

- Atomic clocks, NV centers in diamond, and gravitational wave detectors 913.
- **Project**: Design a quantum sensor for medical imaging 14.

9. Ethics & Policy in Emerging Tech

- Quantum cybersecurity, AI ethics, and global standards for quantum infrastructure [10,11].

Capstone Project

- **Objective**: Solve a real-world problem using modern physics and hardware (e.g., quantum-resistant encryption for IoT devices or a low-power AI accelerator) [7,14].
- **Industry Collaboration**: Partner with companies like **NVIDIA**, **QuTech**, or **IBM Quantum** [7,9].

Skill Development

1. **Computational Tools**:
   a. Python, Qiskit, COMSOL, and ANSYS for simulations [9,11].
   b. CAD tools for photonic/quantum device design [1,13].
2. **Soft Skills**:
   a. Cross-disciplinary teamwork and science communication [10].

Future-Proofing Strategies

1. **Industry Certifications**:
   a. **NVIDIA Quantum Developer Certification** [7].
   b. **QTIndu Certificate** for EU-based quantum training [9].
2. **Conferences**:

a. Attend **QCrypt ’25** (quantum security) or **IEEE Quantum Week** 37.

Program Outcomes

- **Career Paths**: Quantum hardware engineer, photonics R&D scientist, AI accelerator designer 14.
- **Employers**: Palantir, Thorlabs, IBM Quantum, or startups in quantum tech 14.

Key Resources

- **Textbooks**:
  - *Metamaterials: Physics and Engineering Explorations* (Engheta & Ziolkowski) 1.
  - *Quantum Mechanics for Semiconductor Devices* (Mitin et al.) 9.
- **Online Courses**:
  - Coursera’s *Hands-on Quantum Error Correction* (free) 11.
  - TU Delft’s *Quantum Hardware* MOOC 9.

This curriculum blends theory, hands-on labs, and industry trends to prepare you for leadership roles in **quantum computing**, **advanced photonics**, and **sustainable hardware innovation**. Let me know if you’d like to refine specific modules! 🚀

Semester 1: Foundational Engineering & Applied Physics

1. **Engineering Mechanics & Materials**
   a. Builds core skills in statics, dynamics, and material behavior.
   b. Labs: Bridge truss analysis, composite material design.
2. **Thermodynamics & Statistical Physics**
   a. Covers energy systems, entropy, and microscopic/macroscopic physics.
   b. Projects: Rankine cycle optimization, Ising model simulation.
3. **Electronics & Hardware Production**
   a. Introduces circuit design, PCB fabrication, and microcontroller basics.
   b. Labs: Voltage regulator assembly, SPICE simulations.

Focus: Establishes mechanical, thermal, and electronic engineering fundamentals.

Semester 2: Advanced Hardware & Quantum Integration

1. **Quantum Computing & CPU/GPU Production**
   a. Explores quantum algorithms, semiconductor physics, and parallel computing.
   b. Projects: CUDA-accelerated quantum simulations, CPU pipeline design.
2. **Quantum Mechanics & Advanced Hardware Applications**
   a. Links quantum theory (Dirac equation, perturbation) to hardware (quantum dots, qubit fabrication).
   b. Labs: Quantum dot energy simulations, cryogenic CMOS design.
3. **Construction Elements & Engineering Technology**
   a. Applies structural systems, BIM, and sustainable practices to hardware infrastructure.
   b. Project: Code-compliant smart building design with IoT integration.

Focus: Merges quantum physics with hardware engineering and scalable infrastructure.

Rationale

1. **Semester 1** prepares you with:
   a. **Mathematical tools**: Stress-strain analysis, statistical mechanics.
   b. **Practical skills**: Circuit prototyping, material testing.
2. **Semester 2** builds on this with:
   a. **Quantum integration**: Applying quantum principles to semiconductor/GPU design.
   b. **Industry alignment**: Skills for roles in quantum hardware (IBM, NVIDIA) or sustainable construction tech.

Workload Balance

Semester	ECTS Estimate	Key Skills Gained
1	27–30 ECTS	Mechanical modeling, energy systems, PCB design.
2	27–30 ECTS	Quantum algorithm coding, chip fabrication, BIM workflows.

Capstone Opportunity
Combine projects from **Semester 2** into a final deliverable, e.g.:

- Design a **quantum sensor** with cryogenic cooling, using skills from *Quantum Mechanics* and *Electronics*.
- Optimize a **sustainable data center** with quantum-inspired cooling (thermodynamics) and IoT-enabled construction (BIM).

Also, here's a **4-week intensive bridge course** focused on **workshop practices, experimental design, and safety protocols** for cryogenics and advanced hardware fabrication. This ensures you're prepared to handle hazardous materials, complex setups, and high-stakes experiments without "blowing up the block":

Course 7: Experimental Design & Safety for Advanced Hardware
Duration: 4 weeks (condensed 12-week workload)
Focus: Safe handling of cryogenics, precision tools, and failure analysis.

Week 1: Workshop Safety & Risk Assessment
Topics:

1. **Safety Protocols**:
    a. PPE (face shields, cryogenic gloves, aprons).
    b. Hazard communication (GHS labels, SDS for liquid nitrogen/helium).
    c. Emergency procedures (spill containment, fire suppression).
2. **Workshop Tools**:
    a. Proper use of lathes, mills, and laser cutters.
    b. Electrical safety for high-voltage circuits.
3. **Risk Assessment Frameworks**:

    a. HAZOP (Hazard and Operability Study).
    b. Fault tree analysis for cryogenic systems.

Lab:

- Perform a safety audit of a mock lab (identify risks like unsecured gas cylinders, improper LN2 storage).

Key Resource:

- *Prudent Practices in the Laboratory* (National Research Council).

Week 2: Cryogenic Handling & Material Compatibility
Topics:

1. **Cryogenics 101**:
    a. Safe transfer/storage of LN2 (77K) and LHe (4K).
    b. Oxygen deficiency hazards (ODH) monitoring.
2. **Material Selection**:
    a. Thermal contraction/expansion (avoid plastics that shatter at low temps).
    b. Cryogenic adhesives and seals.
3. **Emergency Shutdowns**:
    a. Quench recovery in superconducting systems.
    b. Ventilation protocols for helium leaks.

Lab:

- Practice LN2 transfer using proper Dewars and phase separators.

Case Study:

- Lessons from the **Large Hadron Collider (LHC)** quench incident.

Week 3: Experimental Design & Failure Analysis
Topics:

1. **Design of Experiments (DOE)**:
    a. Variables, controls, and replication in cryogenic setups.
    b. Taguchi methods for robustness.
2. **Failure Modes**:
    a. Thermal stress fractures.
    b. Vacuum failures (e.g., outgassing in cryostats).
3. **Root Cause Analysis (RCA)**:
    a. Fishbone diagrams, 5 Whys.

Lab:

- Dissect a failed cryogenic component (e.g., a cracked superconducting coil).

Project:

- Design a failsafe for a dilution refrigerator cooling loop.

Week 4: Advanced Fabrication & Troubleshooting
Topics:

1. **Precision Machining**:
   a. Tolerances for cryogenic seals (<0.1mm gaps).
   b. Avoiding thermal shorts in multi-layer insulation (MLI).
2. **Vacuum Systems**:
   a. Leak detection (helium mass spectrometers).
   b. Pumping down cryostats without contamination.
3. **Troubleshooting Workflows**:
   a. Using thermal cameras to detect cold spots.
   b. Interpreting pressure/temperature logs.

Capstone Project:

- Build and test a small-scale cryogenic setup (e.g., a superconducting loop with safety interlocks).

Deliverable:

- Submit a safety-compliant design report and present failure-mitigation strategies.

Key Tools & Certifications

- **Tools**:
  - COMSOL Multiphysics (thermal stress simulations).
  - Fluke thermal cameras, helium leak detectors.
- **Certifications**:
  - OSHA 10-Hour General Industry Certification (optional but recommended).
  - Cryogenic Safety Training (CERN/NIST modules).

How This Bridges to Your Other Courses

1. **Thermodynamics/Stats**: Apply entropy principles to predict heat leaks.
2. **Quantum Hardware**: Safely integrate cryogenic control circuits into qubit designs.
3. **Electronics**: Avoid thermal runaway in cryogenic CMOS.

Assessment

- **Lab Reports**: 40% (safety audits, LN2 transfer logs).
- **Capstone Project**: 50% (design robustness, safety compliance).
- **Safety Quizzes**: 10%.

Key Differences from Arts-Based Assessment

1. **Exams Dominate (70–80% of Grade)**: Tests rigorous problem-solving under time constraints.
2. **Derivations Required**: Prove equations (e.g., Navier-Stokes for fluid flow) rather than descriptive answers.
3. **Quantitative Labs**: Reports graded on error analysis and statistical validity, not just completion.
4. **Strict Grading Curve**: Top 15% earn As, reflecting competitive MSc standards.

Here's a **detailed grading schema** for your six courses, aligned with the coursework, projects, and exams we've structured. This follows a **Master of Science** framework, emphasizing theoretical rigor, practical execution, and quantitative analysis:

1. Engineering Mechanics & Materials

Assessment	Weight	Description
Midterm Exam	35%	Problems on forces, moments, truss analysis, stress-strain relationships.
Final Exam	35%	Beam bending, composite mechanics, failure theories (von Mises/Tresca).
Bridge Truss Report	15%	Validate truss forces using ANSYS/MATLAB; error analysis.
Composite Panel Project	10%	Design and test a composite material (e.g., carbon fiber).
Lab Participation	5%	Active engagement in tensile testing, shear force experiments.

2. Construction Elements & Engineering Technology

Assessment	Weight	Description
Midterm Exam	35%	Load-bearing systems, soil mechanics, HVAC principles.
Final Exam	35%	Building codes, sustainability (LEED), AI/AR in construction.

MEP Plan Design	15%	Revit/BIM design of plumbing/electrical systems.
Drone Mapping Report	10%	Accuracy analysis of drone-generated site maps.
Code Compliance Quiz	5%	Short-answer questions on OSHA/ISO standards.

3. Thermodynamics & Statistical Physics

Assessment	Weight	Description
Midterm Exam	35%	Carnot/Rankine cycles, entropy calculations, Maxwell-Boltzmann distributions.
Final Exam	35%	Partition functions, Bose-Einstein condensation, Ising model phase transitions.
Rankine Cycle Optimization	15%	MATLAB/Python code to maximize thermal efficiency.
Ising Model Simulation	10%	Code submission (Python) with magnetization vs. temperature plots.
Lab Participation	5%	PVT experiments, statistical mechanics derivations.

4. Electronics & Hardware Production

Assessment	Weight	Description
Midterm Exam	35%	Op-amp circuits, BJT/MOSFET biasing, Kirchhoff's laws.
Final Exam	35%	Power regulation, digital logic, Gerber file standards.
PCB Design & Assembly	15%	Fabricate and test a custom PCB (e.g., voltage regulator).
Active Filter Report	10%	Validate filter performance using SPICE simulations.
Soldering Practical	5%	Precision assembly of SMT components.

5. Quantum Computing & CPU/GPU Production

Assessment	Weight	Description
Midterm Exam	35%	Quantum gates, Shor's algorithm, semiconductor band theory.
Final Exam	35%	CUDA programming, lithography defects, GPU memory hierarchy.
Grover's Algorithm Code	15%	Implement and benchmark on IBM Quantum/Qiskit.

GPU Thermal Analysis	10%	Optimize CUDA kernel and analyze heat dissipation.
Case Study Presentation	5%	TSMC's 3nm node fabrication process.

6. Quantum Mechanics & Advanced Hardware Applications

Assessment	Weight	Description
Midterm Exam	35%	Schrödinger equation solutions, angular momentum, perturbation theory.
Final Exam	35%	Dirac equation, quantum confinement, relativistic QM applications.
Quantum Dot Simulation	15%	COMSOL/NanoHub model of energy levels in nanostructures.
Qubit Control Circuit	10%	Design cryogenic-compatible control logic for superconducting qubits.
Research Essay	5%	Discuss quantum mechanics in spintronics or graphene.

Key Notes

1. **Exams Dominate (70% Combined)**: Midterms test foundational theory; finals assess advanced applications.
2. **Projects (25–30%)**: Graded on technical rigor, error analysis, and innovation.
3. **Practical/Lab Work (5–10%)**: Emphasizes hands-on precision (e.g., soldering, ANSYS simulations).
4. **Peer Review**: For group projects (e.g., drone mapping), peer evaluations adjust individual grades.

ECTS Credit Allocation

- Each **12-week course = 10 ECTS** (Total: **60 ECTS** for all six courses).
- **1 ECTS ≈ 25–30 hours of work** (lectures, labs, self-study).

Here's a structured **Year 2 Master's Program** focused on **Quantum Hardware, Advanced Materials, and Semiconductor Technologies**,. The program balances theoretical depth, computational modeling, and hands-on fabrication labs.

Program Structure
Total ECTS: 60 (10 ECTS per course × 6 courses)
Duration: Two semesters (3 courses per semester).

Semester 3: Core Advanced Courses
1. Quantum Hardware Engineering (10 ECTS)
Textbook: *Quantum Computation and Quantum Information* (Nielsen & Chuang)
Topics:

- Superconducting qubits, photonic qubits, spin qubits.
- Cryogenic systems (dilution refrigerators), surface code error correction.
- Hybrid quantum-classical architectures (e.g., quantum control loops).
  Projects/Labs:
- Design a fault-tolerant qubit control circuit (Qiskit Metal).
- Lab: Program a 5-qubit algorithm on **Quantum Inspire** or IBM Quantum.
  Assessment:
- **Midterm Exam** (30%): Qubit coherence times, error correction math.
- **Final Exam** (30%): Cryogenic integration challenges, hybrid architectures.
- **Control Circuit Design** (25%): Cryogenic compatibility and noise mitigation.
- **Lab Reports** (15%): Algorithm benchmarking and error rates.

2. Advanced Materials for Next-Gen Hardware (10 ECTS)
Textbook: *Materials Science and Engineering* (Callister & Rethwisch) + Research Papers
Topics:

- Metamaterials (negative refraction, cloaking).
- 2D materials (graphene, MoS_2) for quantum sensing.
- Photonic crystals and terahertz systems.
  Projects/Labs:
- Case Study: Design a metamaterial-based antenna for 6G networks (COMSOL).
- Lab: Fabricate and test a graphene-based RF device.
  Assessment:
- **Midterm Exam** (30%): Metamaterial design principles, plasmonics.
- **Final Exam** (30%): 2D material properties, terahertz applications.
- **Antenna Design Report** (25%): Simulated performance vs. specs.
- **Lab Participation** (15%): RF testing accuracy.

3. Semiconductor Physics & Device Fabrication (10 ECTS)
Textbook: *Modern Semiconductor Devices* (Chenming C. Hu)
Topics:

- EUV lithography, 3D chip stacking (TSMC’s 3nm node).

- Quantum dots, cryogenic CMOS (Intel's Horse Ridge).
  Projects/Labs:
- Simulate a 3nm transistor node using **TCAD Tools** (Silvaco).
- Lab: Characterize a single-electron transistor at 4K.
  Assessment:
- **Midterm Exam** (30%): MOSFET scaling, quantum confinement.
- **Final Exam** (30%): Cryogenic CMOS noise analysis.
- **TCAD Simulation Report** (25%): Leakage current optimization.
- **Lab Report** (15%): I-V curves for quantum dot devices.

Semester 4: Specialization & Electives
4. Quantum Computing & Algorithms (10 ECTS)
Textbook: *Programming Quantum Computers* (Johnston et al.)
Topics:

- Grover's, Shor's, and variational quantum algorithms.
- Hybrid quantum-classical programming (Qiskit + CUDA).
  Projects/Labs:
- Lab: Optimize a quantum ML model (e.g., QSVM) using NVIDIA CUDA-Q.
- Project: Implement a quantum error-corrected algorithm.
  Assessment:
- **Midterm Exam** (30%): Algorithm complexity, gate decomposition.
- **Final Exam** (30%): Hybrid programming challenges.
- **ML Model Report** (25%): Speedup vs. classical benchmarks.
- **Code Submission** (15%): Error correction efficiency.

5. Photonics & Quantum Optics (10 ECTS)
Textbook: *Optics* (Hecht) + Research Papers
Topics:

- Quantum key distribution (QKD), entangled photon sources.
- Integrated photonics (silicon photonics, laser systems).
  Projects/Labs:
- Lab: Build a QKD link using entangled photons (Optical bench setup).
- Case Study: Design a photonic quantum computing chip (Lumerical FDTD).
  Assessment:
- **Midterm Exam** (30%): Laser physics, beam propagation.
- **Final Exam** (30%): QKD protocols, photonic integration.
- **QKD Lab Report** (25%): Bit error rate analysis.
- **Chip Design Proposal** (15%): Loss and coupling efficiency.

6. Elective: AI-Driven Hardware Design (10 ECTS)
Textbook: *Machine Learning for Engineers* (Osvaldo Simeone)
Topics:

- ML for quantum error correction (e.g., surface code decoding).
- AI-optimized chip layouts (NVIDIA's cuQuantum).
  Projects/Labs:
- Train a neural network to predict lithography defects.
- Optimize a qubit control pulse using reinforcement learning.
  Assessment:
- **Midterm Exam** (30%): ML basics, neural network architectures.
- **Final Exam** (30%): AI applications in semiconductor fab.
- **Defect Prediction Model** (25%): Accuracy vs. TCAD data.
- **Control Pulse Report** (15%): Fidelity improvements.

Key Features

1. **Tool Integration**:
   a. **COMSOL/ANSYS** for metamaterials and photonics.
   b. **Qiskit/CUDA** for quantum-classical programming.
   c. **TCAD Tools** for semiconductor simulation.
2. **Industry Alignment**:
   a. Projects mirror challenges at IBM Quantum, TSMC, and NVIDIA.
3. **Safety**: Cryogenic and laser labs include protocols from the bridge course.

Career Pathways

- **Quantum Hardware Engineer** (Google Quantum AI, IBM).
- **Semiconductor Process Engineer** (TSMC, Intel).
- **Photonics R&D Scientist** (Huawei, Thorlabs).

1. Quantum Hardware Engineering
Textbook: *Quantum Computation and Quantum Information* (Nielsen & Chuang)

We	Topics	Textbook Chapters	Labs/Projects

e k			
1	Introduction to quantum hardware (qubit types, coherence times)	Ch. 1 (Introduction), Ch. 7 (Quantum Noise)	Lab: Explore IBM Quantum Lab interface.
2	Superconducting qubits (transmon design, Josephson junctions)	Ch. 4.4 (Quantum Circuits), Ch. 8 (Quantum Error Correction)	Simulate transmon qubit in Qiskit Metal.
3	Photonic qubits (single-photon sources, linear optics)	Ch. 7.4 (Photonic Qubits), Ch. 10 (Quantum Communication)	Lab: Entangle photons using an optical bench.
4	Spin qubits (quantum dots, nitrogen-vacancy centers)	Ch. 6.2 (Spin Systems), Ch. 7.5 (Solid-State Qubits)	Simulate spin qubit dynamics with QuTiP (Python).
5	Cryogenic systems (dilution refrigerators, thermal management)	Supplemental Papers (e.g., *IEEE Quantum Cooling Systems*)	Case Study: Analyze cooling requirements for IBM Quantum’s processors.
6	**Midterm Exam**: Qubit physics, cryogenic basics.		
7	Surface code error correction (stabilizers, syndrome measurement)	Ch. 10.6 (Topological Codes), Ch. 11 (Fault-Tolerant Quantum Computation)	Lab: Implement surface code on a 5-qubit simulator.
8	Fault-tolerant architectures (logical qubits, magic state distillation)	Ch. 11.3 (Threshold Theorem), Ch. 12 (Quantum Cryptography)	Project: Design a logical qubit circuit (Qiskit).
9	Hybrid quantum-classical systems (control loops, real-time feedback)	Ch. 4.5 (Hybrid Systems), Supplemental (NVIDIA Quantum Control Papers)	Lab: Integrate classical PID control with quantum measurements.
10	Quantum networking (repeaters, entanglement swapping)	Ch. 12.5 (Quantum Repeaters), *Nature Photonics Review*	Case Study: Analyze Quantum Internet protocols.
11	**Project Work**: Fault-tolerant control circuit design.		
12	**Final Exam + Project Presentation**		Submit circuit design report and present to peers.

2. Advanced Materials for Next-Gen Hardware
Textbook: *Materials Science and Engineering* (Callister & Rethwisch) + Research Papers

Week	Topics	Textbook Chapters	Labs/Projects
1	Introduction to metamaterials (negative refraction, cloaking)	Ch. 20 (Optical Properties), Supplemental (*Science*: Metamaterial Cloaking)	Lab: Simulate cloaking in COMSOL.
2	Plasmonic structures (surface plasmons, SERS)	Ch. 18.10 (Plasmonics), *ACS Nano Review*	Fabricate a plasmonic nanoparticle array (cleanroom lab).
3	2D materials (graphene, MoS_2 synthesis)	Ch. 12.5 (Graphene), *Nature Materials* (2D Material Synthesis)	Lab: Exfoliate graphene and characterize with AFM.
4	Photonic crystals (bandgap engineering)	Ch. 21.8 (Photonic Crystals), Supplemental (Lumerical FDTD Guide)	Simulate photonic bandgaps using Lumerical FDTD.
5	Terahertz systems (sources, detectors, imaging)	Ch. 19 (Electrical Properties), *IEEE Terahertz Applications*	Case Study: Terahertz imaging for medical diagnostics.
6	**Midterm Exam**: Metamaterials, plasmonics, 2D materials.		
7	Quantum sensing with 2D materials (spin qubits, NV centers)	Ch. 20.6 (Quantum Sensors), *Physical Review Applied* (NV Center Papers)	Lab: Measure magnetic fields with a diamond NV center.
8	Metamaterial antennas (6G, beamforming)	Supplemental (*IEEE Antennas & Propagation*), *6G White Papers*	Project: Design a 6G antenna (COMSOL RF Module).
9	Lab: Fabricate and test a graphene-based RF device.		
10	Terahertz communication systems	*Nature Communications* (Terahertz Networks)	Case Study: Huawei's terahertz wireless research.
11	**Project Work**: Optimize antenna design for 6G specs.		

12	**Final Exam + Project Presentation**		Submit antenna design report and demo simulations.

3. Semiconductor Physics & Device Fabrication
Textbook: *Modern Semiconductor Devices* (Chenming C. Hu)

Week	Topics	Textbook Chapters	Labs/Projects
1	Semiconductor fundamentals (band theory, doping)	Ch. 1 (Crystal Structure), Ch. 2 (Carrier Statistics)	Lab: Measure resistivity of Si wafers.
2	CMOS scaling challenges (short-channel effects, leakage)	Ch. 6 (MOSFET Basics), Ch. 7 (Scaling Limits)	Simulate MOSFET scaling in Silvaco TCAD.
3	EUV lithography (physics, mask design)	Ch. 3.4 (Lithography), Supplemental (*ASML EUV Whitepapers*)	Case Study: ASML's EUV machines.
4	3D chip stacking (TSVs, hybrid bonding)	Ch. 10 (Advanced Packaging), *IEEE 3D Integration Conference*	Lab: Analyze thermal stress in stacked dies (ANSYS).
5	Quantum dots (confinement, single-electron transistors)	Ch. 5.3 (Quantum Effects), *Applied Physics Letters* (Quantum Dot Devices)	Simulate quantum dot energy levels (NanoHub).
6	**Midterm Exam**: CMOS scaling, lithography, quantum dots.		
7	Cryogenic CMOS (Intel's Horse Ridge, noise modeling)	Ch. 9 (Low-Temperature Electronics), *Intel Cryogenic CMOS Reports*	Lab: Characterize CMOS behavior at 4K.
8	Advanced packaging (chiplets, interposers)	Ch. 10.5 (Chiplets), Supplemental (AMD Chiplet Design Guides)	Project: Design a chiplet-based processor layout.
9	Lab: Fabricate a single-electron transistor (cleanroom).		
10	Defect engineering (dislocations, annealing)	Ch. 4 (Defects), *TSMC Defect Mitigation Strategies*	Case Study: TSMC's defect reduction strategies.

11	**Project Work**: Simulate 3nm transistor node (Silvaco).		
12	**Final Exam + Project Presentation**		Submit TCAD simulation report and present optimization results.

4. Quantum Computing & Algorithms
Textbook: *Programming Quantum Computers* (Johnston et al.)

Week	Topics	Textbook Chapters	Labs/Projects
1	Quantum algorithm basics (oracle models, complexity classes)	Ch. 1 (Introduction), Ch. 2 (Qubits)	Lab: Implement a simple quantum oracle (Qiskit).
2	Grover's algorithm (database search, amplitude amplification)	Ch. 5 (Grover's Algorithm)	Lab: Speed up unstructured search with Grover.
3	Shor's algorithm (factoring, QFT)	Ch. 6 (Shor's Algorithm)	Lab: Factor small integers using IBM Quantum.
4	Variational quantum algorithms (VQE, QAOA)	Ch. 9 (Hybrid Algorithms)	Lab: Optimize a molecule's energy with VQE.
5	Hybrid quantum-classical programming (Qiskit + CUDA)	Ch. 10 (Quantum-Classical Integration)	Lab: Accelerate quantum simulations with NVIDIA GPUs.
6	**Midterm Exam**: Grover, Shor, variational algorithms.		
7	Quantum machine learning (QSVM, quantum neural networks)	Ch. 11 (Quantum Machine Learning)	Project: Train a QSVM for image classification.
8	Error correction in algorithms (surface code integration)	Ch. 7 (Error Correction)	Lab: Benchmark error rates with/without correction.
9	Quantum optimization (portfolio optimization, logistics)	Ch. 8 (Optimization)	Case Study: D-Wave's quantum annealing.
10	Lab: Optimize a quantum ML model (NVIDIA CUDA-Q).		
11	**Project Work**: Implement error-corrected Shor's algorithm.		

12	**Final Exam + Project Presentation**		Submit code and report on algorithm efficiency.

5. Photonics & Quantum Optics
Textbook: *Optics* (Hecht) + Research Papers

Week	Topics	Textbook Chapters	Labs/Projects
1	Laser physics (population inversion, cavity modes)	Ch. 13 (Laser Basics)	Lab: Align a He-Ne laser and measure beam profiles.
2	Optical fibers (modes, dispersion)	Ch. 5 (Fiber Optics)	Lab: Measure attenuation in fiber optic cables.
3	Integrated photonics (silicon photonics, waveguides)	Ch. 6 (Guided Waves), Supplemental (*Nature Photonics* Silicon Photonics Review)	Simulate a waveguide in Lumerical MODE.
4	Quantum key distribution (BB84 protocol, E91)	Ch. 12 (Quantum Optics), *Physical Review Letters* (BB84 Protocol)	Lab: Build a QKD link with entangled photons.
5	Photonic quantum computing (cluster states, boson sampling)	*Science* (Photonic Quantum Computing), *Xanadu Boson Sampling Papers*	Case Study: Xanadu's photonic quantum processors.
6	**Midterm Exam**: Lasers, fibers, QKD.		
7	Nonlinear optics (second-harmonic generation, SPDC)	Ch. 7 (Nonlinear Optics)	Lab: Generate entangled photon pairs via SPDC.
8	Quantum metrology (squeezed states, Heisenberg limit)	Ch. 14 (Quantum Metrology), *Nature Physics* (Squeezed Light)	Project: Design a squeezed-light gravitational wave detector.
9	Lab: Characterize a photonic quantum chip (cleanroom).		
10	Quantum repeaters (entanglement purification, memory)	*Physical Review X* (Quantum Repeaters)	Case Study: Chinese Quantum Network Advances.

11	**Project Work**: Design a photonic quantum computing chip.		
12	**Final Exam + Project Presentation**		Submit chip design proposal and present QKD lab results.

6. Elective: AI-Driven Hardware Design
Textbook: *Machine Learning for Engineers* (Osvaldo Simeone)

Week	Topics	Textbook Chapters	Labs/Projects
1	Introduction to ML in hardware design (neural networks, optimization)	Ch. 1 (ML Basics), Ch. 2 (Supervised Learning)	Lab: Train a neural network on MNIST dataset.
2	ML for quantum error correction (surface code decoding)	Ch. 6 (ML for Quantum Systems), *Nature Quantum Information* (ML in QEC)	Lab: Decode surface code errors using a CNN.
3	AI-optimized chip layouts (NVIDIA's cuQuantum)	Ch. 7 (AI in Semiconductor Design), Supplemental (NVIDIA cuQuantum Documentation)	Lab: Optimize qubit placement with reinforcement learning.
4	Predictive maintenance for cryogenic systems	Ch. 8 (Time-Series Forecasting), *IEEE Reliability Journal*	Case Study: Predictive maintenance in IBM Quantum labs.
5	Lab: Train a neural network to predict lithography defects.		
6	**Midterm Exam**: ML basics, quantum error correction, chip layout.		
7	Reinforcement learning for control pulse optimization	Ch. 9 (Reinforcement Learning), *Physical Review Research* (RL in Quantum Control)	Lab: Optimize a qubit control pulse using RL.
8	Generative AI for material discovery	Ch. 10 (Generative Models), *Advanced Materials* (AI-Driven Material Synthesis)	Project: Generate novel metamaterial designs with GANs.
9	Lab: Simulate AI-generated materials in COMSOL.		

10	Case Study: NVIDIA’s AI-driven quantum simulations	Supplemental (NVIDIA Quantum Whitepapers)	
11	**Project Work**: Finalize AI-optimized chip layout.		
12	**Final Exam + Project Presentation**		Submit defect prediction model and control pulse report.

Key Notes

1. **Supplemental Readings**: Include research papers (e.g., *Nature*, *Physical Review*) for cutting-edge applications.
2. **Lab/Project Alignment**: Chapters directly support hands-on work (e.g., Ch. 5 of *Programming Quantum Computers* for Grover’s Lab).
3. **Adjustments**: If textbook chapters don’t fully cover topics, supplemental materials are added (e.g., ASML EUV whitepapers).