Bachelor of Science in Quantum Systems Engineering

Program Description

The Bachelor of Science in Quantum Systems Engineering (QSE) is a first-of-its-kind interdisciplinary program that seeks to equip students for careers in emerging industries focused on quantum information, science and technology. It encompasses a wide range of disciplines that include physics, electrical engineering, computer science, mechanical engineering, engineering design and mathematics, and is a quintessential interdisciplinary program across many Mines departments. Its main objective is to train versatile engineers able to work in the highly dynamic environment of quantum and quantum-adjacent companies ranging from early startups to more established, yet still R&D intensive, companies.

Quantum Systems Engineering applies quantum physics and engineering principles to design and build practical quantum technologies like quantum sensors, quantum communication networks, and other quantum devices. The degree involves translating theoretical quantum mechanical principles into practical applications, and develop skills to interface quantum systems with software, electronic and digital infrastructures.

Program Educational Objectives

In addition to contributing toward achieving the educational objectives described in the Mines Graduate Profile, the QSE program is dedicated to additional educational objectives.

The program prepares graduates who, based on factual knowledge and other skills necessary to construct an appropriate understanding of quantum phenomena in applied contexts, will:

1. Obtain a range of positions in industry or positions in government facilities or pursue graduate education in engineering, science or related fields.
2. Communicate and perform effectively within the criteria of their chosen careers.
3. Engage in appropriate professional societies and continuing education activities.
4. Participate ethically as members of the global society.

Student Learning Outcomes

Each BS Quantum Systems Engineering graduate will have:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3. an ability to communicate effectively with a range of audiences.
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Primary Contact

Dr. Fred Sarazin, Director of Quantum
https://www.mines.edu/academics/program/quantum-systems-engineering/

Curriculum

The Quantum Systems Engineering degree program offers students a combination of courses that includes mathematics, basic and advanced sciences, computer science, and fundamental and advanced engineering practices.

Students complete fundamental engineering courses across the breadth of traditional engineering disciplines and pursue advanced disciplinary studies through additional engineering and science electives. This curricular structure emphasizes engineering's breadth as well as commonalities among different engineering disciplinary approaches. Integrated with these traditional technical engineering requirements, students also learn about the human dimensions of engineering problem solving by drawing on perspectives from the social sciences, humanities, and design.

A key uniqueness of this degree program is the extensive degree of *integration* of technical and non-technical engineering skillsets in response to real-world problems throughout various experiential learning environments, including laboratory and design experiences. This approach allows students to apply lessons from their coursework to genuine, complex problems, increasing and solidifying students' understanding of that content and providing an engaging and balanced theoretical and practical education. The degree culminates in the Capstone Design sequence, where students draw together the entirety of their educational experience to solve client-sponsored engineering problems in quantum technology.

Bachelor of Science in Quantum Systems Engineering: Degree Requirements

The curriculum comprises seven groups of coursework and experiential learning for a total of **129 credits**

First Year

		lec	lab	sem.hrs
MATH111	CALCULUS FOR SCIENTISTS AND ENGINEERS I			4.0
CHGN121	PRINCIPLES OF CHEMISTRY I			4.0
HASS100	NATURE AND HUMAN VALUES			3.0
CSCI128	COMPUTER SCIENCE FOR STEM			3.0
CSM101	FRESHMAN SUCCESS SEMINAR			1.0
S&W	SUCCESS AND WELLNESS			1.0

MATH112	CALCULUS FOR SCIENTISTS AND ENGINEERS II			4.0
CSCI200	FOUNDATIONAL PROGRAMMING CONCEPTS & DESIGN			3.0
HASS215	FUTURES			3.0
PHGN100	PHYSICS I - MECHANICS			4.0
EDNS151	CORNERSTONE - DESIGN I			3.0
				33.0

Sophomore

Fall		lec	lab	sem.hrs
MATH213	CALCULUS FOR SCIENTISTS AND ENGINEERS III			4.0
MATH225	DIFFERENTIAL EQUATIONS			3.0
CEEN241	STATICS			3.0
PHGN200	PHYSICS II-ELECTROMAGNETISM AND OPTICS			4.0
CSM202	INTRODUCTION TO STUDENT WELL-BEING AT MINES			1.0
				15.0

Spring		lec	lab	sem.hrs
MATH332	LINEAR ALGEBRA			3.0
CSCI210	SYSTEMS PROGRAMMING			3.0
PHGN215	ANALOG ELECTRONICS			4.0
PHGN300	PHYSICS III-MODERN PHYSICS I			3.0
OR PHGN310	HONORS PHYSICS III-MODERN PHYSICS			
MEGN261	THERMODYNAMICS I			3.0
				16.0

Summer		lec	lab	sem.hrs
PHGN384	FIELD SESSION TECHNIQUES IN PHYSICS (New version specifically redesigned for this program)			3.0
				3.0

Junior

Fall		lec	lab	sem.hrs
CSCI341	COMPUTER ORGANIZATION			3.0
EENG284	DIGITAL LOGIC			4.0
EENG307	INTRODUCTION TO FEEDBACK CONTROL SYSTEMS			3.0
PHGN315	ADVANCED PHYSICS LAB I			2.0
EDNS220	PROBLEM FRAMING & STAKEHOLDER ENGAGEMENT (Takes the place of CULTURE AND SOCIETY (CAS) Mid-Level Restricted Elective)			3.0
				15.0

Spring		lec	lab	sem.hrs
EENG383	EMBEDDED SYSTEMS			4.0
EBGN321	ENGINEERING ECONOMICS			3.0
PHGN320	MODERN PHYSICS II: BASICS OF QUANTUM MECHANICS			4.0
EDNS311	(Systems Engineering (New, similar to EDNS310)			3.0
PHGNXXX	Quantum Devices Laboratory (NEW)			3.0
				17.0

Senior

Fall		lec	lab	sem.hrs
EDNS491	CAPSTONE DESIGN I			3.0
EENG421	SEMICONDUCTOR DEVICE PHYSICS AND DESIGN			3.0
PHGN417	FUNDAMENTALS OF QUANTUM INFORMATION			3.0
CAS Elective	Culture and Society (CAS) Mid-Level Restricted Elective			3.0
Technical Elective	Technical Elective I			3.0
				15.0

Spring		lec	lab	sem.hrs
EDNS492	CAPSTONE DESIGN II			3.0
CSCI581	QUANTUM PROGRAMMING (Reformat at 4xx-level)			3.0
CAS Elective	CULTURE AND SOCIETY (CAS) 400-Level Restricted Elective			3.0
FREE	Elective I			3.0
FREE	Elective II			3.0
				15.0

Total Semester Hrs: 129.0

The degree includes the Mines Core Curriculum:

- Math, Basic Sciences, Computing: 26 credits
- Design and Innovation: 3 credits
- Culture and Society: 18 credits
- Success and Wellness: 3 credits
- FREE Electives: 6 credits

Beyond the Core, there are an additional 20 credits of Mathematics, Physics and Computer Science courses, 50 credits of Engineering and Design courses, and 3 credits of Technical Electives.

Technical Electives

The 3 credits of Technical Electives and 6 credits of Free Electives can be selected from the below list of courses. Students can choose to focus on a particular thread in Computer Science, Electrical Engineering, Mechanical Engineering, or Physics, to further specialize in a particular technical domain. Students can also choose to be more versatile and adaptive by selecting a set of three courses across these disciplines.

CSCI404	ARTIFICIAL INTELLIGENCE	3.0
CSCI410	ELEMENTS OF COMPUTING SYSTEMS	3.0
CSCI470	INTRODUCTION TO MACHINE LEARNING	3.0
EENG385	ELECTRONIC DEVICES AND CIRCUITS	4.0
EENG433	ACTIVE RF & MICROWAVE DEVICES	3.0
EENG484	ADVANCED DIGITAL DESIGN	3.0

MEGN351	FLUID MECHANICS	3.0
MEGN461	THERMODYNAMICS II	3.0
MEGN423	APPLIED COMPUTATIONAL FLUID DYNAMICS	3.0
PHGN435	INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY	3.0
PHGN440	SOLID STATE PHYSICS	3.0
PHGN466	MODERN OPTICAL ENGINEERING	3.0
PHGN480	LASER PHYSICS	3.0

Major GPA

The Undergraduate Council considered the policy concerning required major GPAs and which courses are included in each degree's GPA. While the GPA policy has not been officially updated, in order to provide transparency, council members agreed that publishing the courses included in each degree's GPA is beneficial to students.

The following list details the courses that are included in the GPA for this degree:

- PHGN100 through PHGN599
- EENG100 through EENG599
- CSCI100 through CSCI599
- MEGN100 through MEGN599
- EDNS100 through EDNS599

COURSES

MATH111. CALCULUS FOR SCIENTISTS AND ENGINEERS I. 4.0 Semester Hrs.
This is the first course in the calculus sequence. Topics include elements of plane geometry, functions, limits, continuity, derivatives and their application, definite and indefinite integrals; 4 hours lecture; 4 semester hours. Approved for Colorado Guaranteed General Education transfer. Equivalency for GT-MA1. Prerequisites: precalculus.
Course Learning Outcomes

- Recall derivatives and antiderivatives of algebraic, trigonometric, exponential, and log functions.
- Compute limits using algebraic techniques and L'Hôpital's rule. Compute derivatives using the power, product, quotient, and chain rule. Compute integrals using the Fundamental Theorem of Calculus, power rule, and u-substitution.
- Interpret the meaning of a limit, derivative, and integral in both geometric and physical contexts.
- Approximate functions, derivatives, and integrals using tangent lines, secant lines, and Riemann sums.
- Apply definitions and theorems to draw mathematical conclusions and justify computational results.
- Identify and apply techniques to solve problems from science, engineering, and economics.
- Communicate written mathematical arguments and statements that use standard notation and terminology, are logically ordered, and are clear and complete.

CHGN121. PRINCIPLES OF CHEMISTRY I. 4.0 Semester Hrs.
Study of matter and energy based on atomic structure, correlation of properties of elements with position in periodic chart, chemical bonding, geometry of molecules, phase changes, stoichiometry, solution chemistry, gas laws, and thermochemistry. 3 hours lecture, 3 hours lab; 4 semester hours. Approved for Colorado Guaranteed General Education transfer. Equivalency for GT-SC1.
Course Learning Outcomes

- Design and conduct experiments to predict and explain simple chemical and physical processes.
- Calculate or measure quantities using the correct precision and units.
- Explain the general quantum mechanical model for an atom and perform simple spectroscopy calculations.
- Predict the products and calculate amounts of substances in a chemical reaction.
- Describe the trends in periodic properties of elements and explain why they occur.
- Identify the primary types of bonds in a substance, and types of intermolecular forces, if present.
- Explain molecular-level differences between solids, liquids, gases for pure ionic and covalent substances.
- Calculate amount of energy flow during a chemical reaction or phase change, classifying it as heat or work.
- Determine 3D shape and polarity of small molecules and polyatomic ions to predict trends in properties.
- Explain in basic terms how each concept above applies to modern science or engineering issues.

HASS100. NATURE AND HUMAN VALUES. 3.0 Semester Hrs.
Equivalent with CSM191,CSM192,HNRS105,HNRS115,HNRS198A,LAIS100,
Nature and Human Values (NHV) is a writing-intensive course, workshop, and discussion seminar that focuses on ethics and inquiry and uses humanities perspectives to examine big questions about the interdependence of human life, society, and the environment. The class links personal, professional, and environmental ethics to engineering, energy, and emerging technologies. Written and oral communication are stressed as a crucial component of professional and civic dialogue, while encouraging critical reading, thinking, and conversation about students' ethical obligations as world citizens with broader moral, social, and environmental responsibilities to stakeholders. The culminating research paper asks that students consider the ethical dimensions of their arguments within science and engineering contexts while engaging different viewpoints, evaluating sources, and supporting an original position. 3 hours seminar; 3 semester hours. Prerequisites: None. Corequisites: None.
Course Learning Outcomes

- Demonstrate understanding of major ethical theories and concepts and apply them to current and past debates on technology, resource use, and environmental issues.
- Read and think critically about course reading assignments and lecture topics; discover personal biases and values, diverse perspectives, and rhetorical strategies.
- Construct original written and oral arguments about course topics that are supported by relevant experts and accurately cited evidence.
- Find and employ relevant research to writing assignments on engineering, ethics, and the environment; consistently and correctly cite use of sources in-text and in bibliographies.
- Develop clear, readable, grammatical written work through a process of drafting and revision to produce strong summaries, analyses of texts, and researched arguments.
- Demonstrate understanding of the impact of engineering and applied science in social, ethical, and environmental contexts.

- Develop habits of mind while completing the coursework, such as curiosity, openness, engagement, creativity, persistence, responsibility, academic integrity, flexibility, and metacognition to help in a variety of learning contexts.

CSCI128. COMPUTER SCIENCE FOR STEM. 3.0 Semester Hrs.
Introduction to programming. Intended for students with no prior experience. Teaches basic programming constructs including data types, conditionals, loops, file I/O, functions, and objects in Python 3. Also covers topics vital to STEM computing, such as data science, best practices for code development, and software ethics. Prerequisite: None Co-requisite: None.
Course Learning Outcomes

- Analyze a simple empirical problem, break it down into smaller more manageable components, and design algorithmic solutions to these subproblems
- Implement an existing prompt, plan, or design into programmatically correct Python code that produces the expected text, file, or graph output
- Communicate in the language of programming with a computer and other programmers through code reading, writing, and critique
- Critically discuss and reflect on the role technology has in modern society, and the positive and negative impacts their software may have on future users
- Model how basic numeric and non-numeric data is represented in a computer; identify when, why, and how these physical representations diverge from their conceptual equivalents
- Navigate and utilize a computer file system through a GUI, the text console, and code
- Demonstrate effective debugging practices in an IDE to find, characterize, and correct code errors

MATH112. CALCULUS FOR SCIENTISTS AND ENGINEERS II. 4.0 Semester Hrs.
Equivalent with MATH122,
This is the second course in the calculus sequence. Topics include vectors, applications and techniques of integration, infinite series, and an introduction to multivariate functions and surfaces. 4 hours lecture; 4 semester hours. Approved for Colorado Guaranteed General Education transfer. Equivalency for GT-MA1. Prerequisites: Grade of C- or better in MATH111.
Course Learning Outcomes

- COMPUTATIONS: Perform computations with integrals, sequences, series, vectors, vector-valued functions, and polar coordinates.
- APPLICATIONS: Construct and interpret mathematical objects (integrals, sequences, series, vectors, vector-valued functions, parameterizations, and polar coordinate representations) to describe physical or mathematical quantities.
- REASONING: Apply definitions and theorems to draw mathematical conclusions and justify computational results.
- WRITING: Communicate written mathematical arguments and statements that are complete and logically ordered through the use of standard notion and terminology.

CSCI200. FOUNDATIONAL PROGRAMMING CONCEPTS & DESIGN. 3.0 Semester Hrs.
This course teaches students C++, how to manage memory properly & efficiently at run time, the principles of object-oriented programming, and how to create an algorithm using data structures & abstraction to solve a problem. Recursive data structures & algorithms will be constructed & analyzed when solving problems. Initial principal components of software engineering and design will be introduced and used when drafting a solution to a problem. Programs will be developed using a command line interface. Prerequisite: CSCI101 or CSCI128.
Course Learning Outcomes

- Design an algorithm to solve a problem by breaking the overarching problem into smaller modular components using abstraction and object-oriented design with inheritance.
- Translate the algorithm into a program using proper C++ syntax and fundamental programming constructs (e.g. control structures, I/O, classes).
- Recite & apply frequently used Linux command line commands and compile a program using a command line build system.
- Diagram memory usage, dynamically allocate & deallocate objects at run-time using "The Big Three," and trace the call stack of a program’s run-time.
- Define recursion and construct common recursive data structures (e.g. linked list, stack, queue) & algorithms (e.g. search & sort).
- Diagram & construct dynamically allocated data structures (e.g. array, vector, string), recursive data structures, (e.g. linked list, stack, queue), and implement common list operations (e.g. traversal, insertion, removal)
- Define "Big-O" notation, list complexities in increasing order, and analyze an algorithm to compute its run-time performance & memory complexities

HASS215. FUTURES. 3.0 Semester Hrs.
FUTURES invites students to envision possibilities around critical issues related to the future of science and engineering. It is central to the Mines core curriculum and encouraged during the first years at Mines. Guided by four instructors who share perspectives from a wide range of humanities, social science, and applied disciplines, students will explore future-oriented themes at the forefront of advances in science, engineering, technology and society, such as Energy Futures, Technology Futures, and Critical Resource Sustainability, among others. By the end of the course students will gain skills in integrating multiple perspectives and connecting them to their own interests and trajectory at Mines and beyond. Prerequisites: None. Co-requisites: None.
Course Learning Outcomes

- EXPLORATION: Explore and pursue academic interests and passions.
- VALUES IDENTIFICATION: Reflect on different learning experiences to integrate new learning with prior personal interests, needs, background, and prior experiences to enhance their own personal Mines journey and post-Mines career
- INTERDISCIPLINARY INTEGRATION: Integrate perspectives and tools from the sciences, engineering, design, business, humanities, arts, and social sciences to enhance disciplinary and professional awareness.
- BUILDING COMMUNITY & CONVERSATION: Collaborate effectively with and be supportive of communities and individuals with diverse perspectives, experiences, and backgrounds.
- DEFINE CHALLENGES & OPPORTUNITIES: Identify interconnections among technical and societal dimensions of problem identification and solution.
- PERSPECTIVE TAKING: Explore challenges from a variety of perspectives and through multiple representational modalities.

- FUTURE ORIENTATION: Practice envisioning future possibilities in science and engineering while using relevant foundational past and present knowledge.
- IMPACT POTENTIAL: Build skills around developing and refining products which contribute to impacting and creating the future.

PHGN100. PHYSICS I - MECHANICS. 4.0 Semester Hrs.
A first course in physics covering the basic principles of mechanics using vectors and calculus. The course consists of a fundamental treatment of the concepts and applications of kinematics and dynamics of particles and systems of particles, including Newton's laws, energy and momentum, rotation, oscillations, and waves. Approved for Colorado Guaranteed General Education transfer. Equivalency for GT-SC1. Prerequisite: MATH111. Co-requisite: MATH112 or MATH122.
Course Learning Outcomes

- No change

EDNS151. CORNERSTONE - DESIGN I. 3.0 Semester Hrs.
Equivalent with EPIC151,
(I, II, S) Design I teaches students how to solve open-ended problems in a hands-on manner using critical thinking and workplace skills. Students work in multidisciplinary teams to learn through doing, with emphasis on defining and diagnosing the problem through a holistic lens of technology, people and culture. Students follow a user-centered design methodology throughout the process, seeking to understand a problem from multiple perspectives before attempting to solve it. Students learn and apply specific skills throughout the semester, including: communication (written, oral, graphical), project management, concept visualization, critical thinking, effective teamwork, as well as building and iterating solutions.
Course Learning Outcomes

- Identify, breakdown, and define open-ended problems.
- Research the context and background of problems and solutions, including user needs and technical requirements, through scholarly and authoritative sources, and stakeholder input.
- Design solutions through a cycle of testing, refining, iterating, and feedback.
- Equitably contribute to team efforts from start to end on a collaborative project, and participate in learning activities and coaching activities in the team.
- Apply common workplace practices, tools and software in a semester-long team project, including project planning tools, team management tools, tools to generate solution alternatives, decision analysis methods, risk analysis methods, and value proposition analysis/baseline comparison.
- Present technical ideas and solutions graphically, orally, written, and through prototype demonstrations
- Visually depict ideas to teammates, supervisors, and stakeholders through the use of field sketching for the purposes of communication as well as idea development and development through iteration.
- Model and communicate formalized design ideas through the use of standardized engineering graphics conventions as applied to engineering sketching and computer-aided design/solid modeling software

MATH213. CALCULUS FOR SCIENTISTS AND ENGINEERS III. 4.0 Semester Hrs.
Equivalent with MATH223,
This is the third course in the calculus sequence, focused on multivariable calculus. Topics include partial derivatives, multiple integrals, and vector calculus. 4 hours lecture; 4 semester hours. Approved for Colorado Guaranteed General Education transfer. Equivalency for GT-MA1. Prerequisites: Grade of C- or better in MATH112 or MATH122. Corequisites: CSCI128 or CSCI102.
Course Learning Outcomes

- Graph functions of two variables in three-dimensions by using formulaic function knowledge, traces, and contour maps and extend this understanding to functions of three variables.
- Calculate partial derivatives and use them to solve applied problems.
- Construct and evaluate multiple integrals in appropriate coordinate systems such as rectangular, polar, cylindrical and spherical coordinates and apply them to solve problems involving volume, surface area, flux, density, and/or center of mass.
- Identify and use key theorems from vector calculus such as the Fundamental Theorem for Line Integrals, Green's Theorem, Stokes' Theorem, and/or the Divergence Theorem as appropriate to solve applied problems.

MATH225. DIFFERENTIAL EQUATIONS. 3.0 Semester Hrs.
Equivalent with MATH235,
This course is an introduction to ordinary differential equations. Topics include classical techniques for first and higher order equations and systems of equations. Laplace transforms, phase-plane and stability analysis of non-linear equations and systems, applications from physics, mechanics, electrical engineering, and environmental sciences. 3 hours lecture; 3 semester hours. Prerequisites: Grade of C- or better in MATH112 or MATH122. Co-requisites: CSC128 or CSCI102.
Course Learning Outcomes

- Investigate the models of physical systems such as exponential and logistic growth, Newton's Law of Heating/Cooling, Mixing (Tank) problems, spring mass systems, LRC circuits, and predator/prey models using first and second order differential equations.
- Apply classical techniques such as Separation of Variables, Integrating Factors, the Method of Undetermined Coefficients, Bernoulli substitutions, and Laplace Transforms to solve first and second order ordinary differential equations.
- Use eigenvalues and eigenvectors to solve 2x2 linear, constant-coefficient, homogeneous systems of differential equations; interpret the corresponding phase portraits for linear systems; use linearization to analyze the stability of critical points for nonlinear two dimensional systems.
- Apply the concepts of linearity, superposition, existence, and uniqueness of solutions to solve linear differential equations.

CEEN241. STATICS. 3.0 Semester Hrs.
Forces, moments, couples, equilibrium, centroids and second moments of areas, volumes and masses, hydrostatics, and friction. Applications of vector algebra to structures. 3 hours lecture; 3 semester hours. Prerequisite: PHGN100 and credit or concurrent enrollment in MATH112.
Course Learning Outcomes

- Develop two- and three-dimensional particle free body diagrams and use scalar approaches in two-dimensions and vector approaches in three-dimensions to solve for unknown forces for systems with pulleys and springs.
- Calculate the moment of a force in two-dimensional scalar and three-dimensional vector notation and correlate force couples to couple moments.

- Resolve forces, distributed loads, and couple moments into an equivalent resultant system as either a concentrated force at a calculated location or as a concentrated force and a couple moment at a specified location.
- Identify translational and rotational support reactions and construct free body diagrams for two- and three-dimensional statically determinant rigid body systems and use equations of equilibrium to solve associated support reactions.
- Use the equations of force and moment equilibrium to solve for unknowns in statically determinate beams, trusses, frames, machines, sliding friction, friction on flat belts, discrete loaded cables, cables subject to distributed loads, and systems with hydrostatic fluid pressure on flat, vertical, sloping, and curving surfaces.
- Solve for the internal shear force, normal force, and bending moment in a structural or mechanical member; express these concepts in the form of an equation; and graphically construct shear and moment diagrams.
- Determine centroids with the composite area method and the integration method and determine moments of inertia via the parallel axis theorem to develop Mohr's circle and interpret values for the principle moments of inertia and moments of inertia for any inclined axes.

PHGN200. PHYSICS II-ELECTROMAGNETISM AND OPTICS. 4.0 Semester Hrs.
Continuation of PHGN100. Introduction to the fundamental laws and concepts of electricity and magnetism, electromagnetic devices, electromagnetic behavior of materials, applications to simple circuits, electromagnetic radiation, and an introduction to optical phenomena. Prerequisite: Grade of C- or higher in PHGN100. Co-requisite: MATH213 or MATH223.

CSM202. INTRODUCTION TO STUDENT WELL-BEING AT MINES. 1.0 Semester Hr.
How do you feel when you're stressed? How do you feel when you're thriving? When do you feel resilient? What do you do to get through tough times? How do you celebrate when things are good? What do you do to try to achieve balance in your life? This course will help you answer these questions and lay the foundation for all Orediggers to identify, practice, and build skills that are needed to support your own holistic well-being during your time at Mines and beyond. Even if you have it all figured out, you can use the information and skills practiced in this course to support your friends and classmates who may need assistance. You will identify and understand seven interconnected dimensions of well-being (physical, emotional, social, environmental, spiritual, financial, and intellectual), as well as best evidence for behaviors that support your wellness in these various ways. This course will focus on health and wellness concepts important in making informed choices about your well-being, as well as the utilization of appropriate resources when help is needed. By the end of the course, you will develop a well-being plan with tangible strategies to help you thrive throughout your life.
Course Learning Outcomes

MATH332. LINEAR ALGEBRA. 3.0 Semester Hrs.
Systems of linear equations, matrices, determinants and eigenvalues. Linear operators. Abstract vector spaces. Applications selected from linear programming, physics, graph theory, and other fields. Prerequisite: CSCI128; MATH112, MATH122, or PHGN100.
Course Learning Outcomes

- Perform basic matrix and vector operations, including row reducing matrices, adding/multiplying matrices, calculating determinants, determining eigenvalues/eigenvectors, computing orthogonal projections, and computing matrix decompositions.
- Recall/restate basic definitions and theorems of linear algebra to determine properties of matrices and sets of vectors.
- Communicate linear algebra concepts using proper terminology and notation.
- Utilize matrix and vector operations to solve applied problems including least squares approximation and orthogonal projection.
- Compute a singular value decomposition and use the result to solve an applied problem and determine properties of a matrix.

CSCI210. SYSTEMS PROGRAMMING. 3.0 Semester Hrs.
The Systems Programming course will teach students how to become proficient with using a Linux operating system from the command line and programming Linux systems. Topics will include: shell scripts; compiling and linking programs; redirecting input and output; controlling jobs from the command line; using advanced SSH functions such as port forwarding and dynamic proxying; file system hierarchy;, package management; kernel compilation; network management; C programming with dynamic memory management, function pointers, c-style polymorphism, recursive functions, and data structures; learning how to use a code repository maintenance tool, such as git, from the command line effectively; security, privacy, and encryption concepts; inter-process communication and client-server architectures. Prerequisite: CSCI200.
Course Learning Outcomes

- Identify, select, and apply appropriate Linux commands for file, process, and network management.
- Utilize the command line by designing and creating shell scripts; compiling and linking programs; redirecting input and output of processes; and executing commands for controlling jobs/processes.
- Explain the purpose of and apply advanced SSH functions such as port forwarding, dynamic proxying, effectively.
- Administer a Linux system applying knowledge of the file system hierarchy, package management, kernel compilation, and network management.
- Design and write C programs composed of dynamic memory management, function pointers, c-style polymorphism, recursive functions, and data structures.
- Examine the capabilities of a code repository maintenance tool, such as git, through command line version control.
- Select and implement appropriate security, privacy, and encryption protocols at the operating system level.
- Design and implement programs with client-server architecture using inter-process communication.
- Discuss and apply appropriate time and project management strategies through the development of multiple substantial programming projects throughout the semester.

PHGN215. ANALOG ELECTRONICS. 0-4 Semester Hr.
Introduction to analog devices used in modern electronics and basic topics in electrical engineering. Introduction to methods of electronics measurements, particularly the application of oscilloscopes and computer based data acquisition. Topics covered include circuit analysis, electrical power, diodes, transistors (FET and BJT), operational amplifiers, filters, transducers, and integrated circuits. Laboratory experiments in the use of basic electronics for physical measurements. Emphasis is on practical knowledge gained in the laboratory, including prototyping,

troubleshooting, and laboratory notebook style. 3 hours lecture, 3 hours lab; 4 semester hours. Prerequisite: PHGN200.

PHGN310. HONORS PHYSICS III-MODERN PHYSICS. 3.0 Semester Hrs.

Equivalent with PHGN300,
The third course in introductory physics with in depth discussion on special relativity, wave-particle duality, the Schroedinger equation, electrons in solids, quantum tunneling, nuclear structure and transmutations. Registration is strongly recommended for declared physics majors and those considering majoring or minoring in physics. 3 hours lecture; 3 semester hours. Prerequisite: PHGN200; Concurrent enrollment in MATH225.

MEGN261. THERMODYNAMICS I. 3.0 Semester Hrs.

This course is a comprehensive treatment of thermodynamics from a mechanical engineering point of view. Topics include: Thermodynamic properties of substances inclusive of phase diagrams, equations of state, internal energy, enthalpy, entropy, and ideal gases; principles of conservation of mass and energy for steady-state and transient analyses; First and Second Law of thermodynamics, heat engines, and thermodynamic efficiencies; Application of fundamental principles with an emphasis on refrigeration and power cycles. May not also receive credit for CBEN210. Prerequisite: MATH213 (C- or better).

Course Learning Outcomes

- Identify the boundary of a system by drawing a control surface and label the transfer of mass and energy across the control surface for a given process.
- Apply balance equations (mass, energy, and entropy) to analyze steady and unsteady processes, relating a system's inputs and outputs (heat, work, and mass transfer) and material properties (temperature, pressure, etc.) with one another.
- Determine the properties of pure substances using equations of state, property tables, software tools, or thermodynamic surfaces, choosing an appropriate method.
- Use the 1st and 2nd law of thermodynamics to identify possible and impossible processes.
- Apply the concept of isentropic efficiency to compare actual and ideal devices.
- Use the concepts of thermal efficiency and coefficient of performance to analyze the performance of power cycles (power plants and internal combustion engines), and assess the performance by comparing to other cycles, to theoretical limits, and to practical material and economic limitations.
- Represent thermodynamic processes in multiple formats, by drawing process schematics, drawing thermodynamic property (P-v and T-s) diagrams, applying balance equations, and writing for diverse audiences (science and non-science).
- Design and analyze thermodynamic systems (cycles and other devices) to meet heating, cooling, and/or power needs for a specified application.

PHGN384. FIELD SESSION TECHNIQUES IN PHYSICS. 6.0 Semester Hrs.

Introduction to the design and fabrication of engineering physics apparatus. Intensive individual participation in the design of machined system components, vacuum systems, electronics, optics, and application of computer interfacing systems and computational tools. Supplementary lectures on safety, laboratory techniques and professional development. Visits to regional research facilities and industrial plants. 6 semester hours. Prerequisites: PHGN300 or PHGN310, PHGN215.

Course Learning Outcomes

- Give students a working knowledge of the practical aspects of materials, instrumentation and phenomena associated with laboratory practice.
- Train students in the use of important experimental and data analysis devices and tools.
- Show students how working physicists operate and to help them achieve professional standards in work practice and communication.

CSCI341. COMPUTER ORGANIZATION. 3.0 Semester Hrs.

Covers the basic concepts of computer architecture and organization. Topics include machine level instructions and operating system calls used to write programs in assembly language, computer arithmetics, performance, processor design, and pipelining techniques. This course provides insight into the way computers operate at the machine level. Prerequisite: CSCI210 OR CSCI262.

Course Learning Outcomes

- Program in RISC-V assembly language
- Translate between C programs and RISC-V assembly code
- Translate between RISC-V assembly code and RISC-V machine code
- Represent a number using IEEE 754 floating point standard
- Describe how a CPU performs addition, subtraction, multiplication, and division
- Evaluate CPU performance
- Design a single-cycle processor and its control
- Design pipelining techniques to speed up a single-cycle processor
- Elaborate how memory hierarchy works

EENG284. DIGITAL LOGIC. 4.0 Semester Hrs.

This course is an introduction to digital logic design. Students will start to learn how to design combinational logic circuit using Kmaps, manipulate these expressions using Boolean algebra and then produce basic building blocks like decoders and adders. Next students will focus on sequential logic circuits with basic memory elements, then design sequential building blocks like counters and registers and then to design finite state machines. Students will then learn how to combine basic building blocks with finite state machines to create complex functionality. Students will implement their design using a hardware description language and download these designs on FPGAs. Prerequisite: CSCI261 (C- or better) or CSCI200 (C- or better). Co-requisite: EENG282 or EENG281 or PHGN215.

Course Learning Outcomes

- Convert between numbering representations.
- Design a combinational logic circuit from a word statement to a circuit diagram.
- Manipulate a logic function in any of its representations; word statement, truth table, symbolic, and circuit diagram.
- Determine SOPmin and POSmin realizations of logic function with or without don't cares.
- Build and operate adders, comparators, multiplexers and decoders.
- Determine output behavior of D,T,SR,JK; latches, clock latches and flip flops.
- Build and operate registers, shift registers, counters, tri-state logic and RAMs.
- Design Finite State Machines using a dense or Ones Hot encoding.

- Implement complex digital systems using the datapath and control design approach.

EENG307. INTRODUCTION TO FEEDBACK CONTROL SYSTEMS. 3.0 Semester Hrs.
System modeling through an energy flow approach is presented, with examples from linear electrical, mechanical, fluid and/or thermal systems. Analysis of system response in both the time domain and frequency domain is discussed in detail. Feedback control design techniques, including PID, are analyzed using both analytical and computational methods. Prerequisite: EENG281 or EENG282 or PHGN215 (C- or better) and MATH225 or MATH235.
Course Learning Outcomes

- Develop mathematical models for linear dynamic systems (mechanical, electrical, fluid, and/or thermal).
- Analyze and predict the behavior of linear systems using both time domain and frequency domain tools.
- Design feedback compensators to achieve a specified performance criterion using both time domain and frequency domain techniques.
- Analyze and design feedback control systems using Matlab.

PHGN315. ADVANCED PHYSICS LAB I. 2.0 Semester Hrs.
(WI) Introduction to laboratory measurement techniques as applied to modern physics experiments. Experiments from optics and atomic physics. A writing-intensive course with laboratory and computer design projects based on applications of modern physics. 1 hour lecture, 3 hours lab; 2 semester hours. Prerequisite: PHGN300/310, PHGN384.

EDNS220. PROBLEM FRAMING & STAKEHOLDER ENGAGEMENT. 3.0 Semester Hrs.
How should design engineers frame problems and identify opportunities for change within sociotechnical systems? Students learn design methods to frame problems at multiple levels and scales, from the individual end user to high-level regulatory structures. Students actively engage with diverse stakeholders throughout the process to explore problem spaces, identify opportunities for design interventions, and examine potential avenues for solutions. Thematic areas such as sustainability, regenerative development, socioecological systems, and community engagement will drive students to look beyond the technical dimensions of problems to incorporate social, regulatory and location speci#c experiences into their problem framing methods. Prerequisites: EDNS151, HASS100, OR HNRS105 OR HNRS120.
Course Learning Outcomes

- Describe social and technical interconnections of real-world design practice by exploring organizational contexts and stakeholder perspectives.
- Apply sociotechnical, environmental and economic reasoning to consider values in the context of design systems thinking.
- Identify and interpret ethical implications of designs.
- Practice empathy and listening to better understand stakeholder needs and concerns.

EENG383. EMBEDDED SYSTEMS. 4.0 Semester Hrs.
The design and implementation of systems consisting of analog and digital components with a microcontroller to perform a dedicated task. Student will implement systems using a variety of microcontroller subsystems including timers, PWM, ADC, serial communication subsystems and interrupts. Students will learn embedded systems programming techniques like, fixed-point math, direct digital synthesis, lookup tables, and row scanning. Student will program the microcontroller using a high-level programming language like C or C++. Prerequisite: EENG281 or EENG282 or PHGN215 (C-or better) and EENG284 or PHGN317 (C-or better).
Course Learning Outcomes

- Write C-code to manipulate pins of the PIC.
- Write code to communicate using serial protocols. I can write a program with one or more interrupt sources.
- Write a program with shared variables between main and an ISR.
- Design an anti-alias filter for an ADC.
- Write code to interface to the PIC ADC subsystem.
- Write code to interface to the PIC timer subsystems.
- Build a system to generate analog output from the PIC.
- Write code on the PIC to communicate to a PC.
- Write code to manipulate fixed-point format numbers.
- Design a direct digital synthesis system using a PIC.
- Can search technical documents to find needed information.

EBGN321. ENGINEERING ECONOMICS. 3.0 Semester Hrs.
Equivalent with CHEN421,
Time value of money concepts of present worth, future worth, annual worth, rate of return and break-even analysis applied to after-tax economic analysis of mineral, petroleum and general investments. Related topics on proper handling of (1) inflation and escalation, (2) leverage (borrowed money), (3) risk adjustment of analysis using expected value concepts, (4) mutually exclusive alternative analysis and service producing alternatives.

PHGN320. MODERN PHYSICS II: BASICS OF QUANTUM MECHANICS. 4.0 Semester Hrs.
Introduction to the Schroedinger theory of quantum mechanics. Topics include Schroedinger's equation, quantum theory of measurement, the uncertainty principle, eigenfunctions and energy spectra, anular momentum, perturbation theory, and the treatment of identical particles. Example applications taken from atomic, molecular, solid state or nuclear systems. 4 hours lecture; 4 semester hours. Prerequisite: PHGN300, PHGN310, and MATH332, MATH342.

EDNS491. CAPSTONE DESIGN I. 3.0 Semester Hrs.
Equivalent with EGGN491,
(WI) This course is the first of a two-semester capstone course sequence giving the student experience in the engineering design process. Realistic open-ended design problems are addressed for real world clients at the conceptual, engineering analysis, and the synthesis stages and include economic and ethical considerations necessary to arrive at a final design. Students are assigned to interdisciplinary teams and exposed to processes in the areas of design methodology, project management, communications, and work place issues. Strong emphasis is placed on this being a process course versus a project course. This is a writing-across-the-curriculum course where students' written and oral communication skills are strengthened. The design projects are chosen to develop student creativity, use of design methodology and application of prior course work paralleled by individual study and research. 2 hours lecture; 3 hours lab; 3 semester hours. Prerequisite: For BSME students, completion of MEGN301; for BSCE students, completion of Engineering Field Session, Civil, CEEN 331; for BSENV completion of Engineering Field Session, Environmental, CEEN 330; for BSDE students, EDNS 220 and Senior Standing; and for all other students completion of Field Session appropriate to the student's specialty and consent of instructor. Co-requisite: For BSME students, MEGN481; for BSCE students, any one of CEEN443, CEEN445, CEEN442, or CEEN415; for BSEE

students, EENG 350 and EENG 389 plus any one of EENG 391, EENG 392, EENG 393, or EENG 394.
Course Learning Outcomes

EENG421. SEMICONDUCTOR DEVICE PHYSICS AND DESIGN. 3.0 Semester Hrs.
This course will explore the field of semiconductors and the technological breakthroughs which they have enabled. We will begin by investigating the physics of semiconductor materials, including a brief foray into quantum mechanics. Then, we will focus on understanding pn junctions in great detail, as this device will lead us to many others (bipolar transistors, LEDs, solar cells). We will explore these topics through a range of sources (textbooks, scientific literature, patents) and discuss the effects they have had on Western society. As time allows, we will conclude with topics of interest to the students (possibilities include quantum devices, MOSFETs, lasers, and integrated circuit fabrication techniques). Prerequisite: PHGN200. 3 hours lecture; 3 semester hours.
Course Learning Outcomes

- Understand the phenomena in semiconductor devices that lead to their terminal characteristics (I-V and C-V curves) relevant for circuit applications.
- Analyze the transport of charge carriers in semiconductor devices when subjected to electromagnetic fields and predict their behavior.
- Design models for semiconductor devices that correlate terminal characteristics with device geometry, material parameters such as doping, mobility, and carrier lifetime, and ambient conditions including temperature.
- Simulate device characteristics using TCAD tools like Silvaco Victory to validate and the developed models.

PHGN417. FUNDAMENTALS OF QUANTUM INFORMATION. 3.0 Semester Hrs.
This course serves as a broad introduction to quantum information science, open to students from many backgrounds. The basic structure of quantum mechanics (Hilbert spaces, operators, wavefunctions, entanglement, superposition, time evolution) is presented, as well as a number of important topics relevant to current quantum hardware (including oscillating fields, quantum noise, and more). Finally, we will survey the gate model of quantum computing, and study the critical subroutines which provide the promise of a quantum speedup in future quantum computers. Prerequisite: MATH332 or MATH342.
Course Learning Outcomes

- 1. Construct Hilbert spaces, operators, wavefunctions and predict the outcome of measurements
- 2. Identify the key ways in which quantum mechanics differs from classical mechanics: entanglement and superposition
- 3. Simulate time evolution in quantum systems
- 4. Diagonalize simple quantum Hamiltonians and predict their spectra
- 5. Simulate oscillating fields in quantum systems
- 6. Implement simple calculations using the gate model of quantum computing. They will also learn how to use ancilla qubits, and how to construct arbitrary operations from one- and two-qubit gates
- 7. Identify mechanisms for a quantum speedup in quantum algorithms, learned through a survey of some of the most famous ones

EDNS492. CAPSTONE DESIGN II. 0-3 Semester Hr.
(WI) This course is the second of a two-semester sequence to give the student experience in the engineering design process. Design integrity and performance are to be demonstrated by building a prototype or model, or producing a complete drawing and specification package, and performing pre-planned experimental tests, wherever feasible, to verify design compliance with client requirements. 1 hour lecture; 6 hours lab; 3 semester hours. Prerequisite: EDNS491.

CSCI581. QUANTUM PROGRAMMING. 3.0 Semester Hrs.
This course serves as an introduction to programming quantum computers. Students will receive an in depth education in quantum algorithms and their design, and then break into teams to learn the API of a commercially available quantum computing system. They will use this system to write and test simple quantum algorithms, and debug their code to improve its performance against noise and other error sources. Prerequisite: PHGN519.
Course Learning Outcomes

- Building on the education received in Fundamentals of Quantum Information, students will learn:
- 1. How to write and implement simple quantum algorithms,
- 2. Understand mechanisms by which a quantum speedup can be obtained
- 3. Use and execute code on an API of publicly available quantum hardware (e.g. IBM’s qiskit, Rigetti’s Forest, Google’s forthcoming Cirq, and many more)
- 4. “Debug” their code to improve its performance given the realities of noise and gate error

Director

Fred Sarazin