Rose-Hulman Institute of Technology Course Catalog

Biochemistry

Graduates with a degree in biochemistry will be well prepared for employment, graduate study in biochemistry or other chemistry-related fields, or professional school. Biochemists are employed in research, quality control, design, sales and management. Many graduates pursue masters and doctoral degrees in biochemistry, medicinal chemistry, and in other life science fields. A biochemistry degree is excellent preparation for medical school and related fields, and also for careers in business, law or education.

The curriculum at Rose-Hulman Institute of Technology provides a rigorous introduction to all subdisciplines of chemistry along with biochemistry and applied biology. Students have access to modern instrumentation along with a well-equipped biochemistry lab. Rose-Hulman students are introduced to modern computational methods beginning in the sophomore year. There are many opportunities for research or other individual projects, and students are encouraged to present their results at regional and national chemistry conferences. Close interaction with engineering departments provides students with a point of view not available at most other undergraduate institutions.

Student Outcomes

Student Outcomes are statements that describe what students are expected to have by the time of graduation.

1. An ability to design and conduct experiments as well as to analyze and interpret data.
2. An ability to recognize the professional and ethical responsibilities of a biochemist.
3. An ability to communicate effectively in presentations and reports.
4. An ability to recognize biochemistry practices outside of the academic environment.
5. An ability to operate safely and effecitvely in a biochemistry laboratory.

List of Required Chemistry Courses

Course	Numbers	Credits
General Chemistry	111, 113, 115	12
Organic Chemistry	251, 252, 253	12
Analytical Chemistry	225, 326, 327	12
Physical Chemistry	361, 362, 463	12
Inorganic Chemistry	441	4
Biochemistry	330, 331, 430, 433	13

Research	291, 395, 490, 491, 495, 496, 497	11
Career Preparation	200	1
Electives		11
Total		**88**

Summary of minimum graduation requirements:

Course or areas	Required	Elective	Total
Chemistry	77	11	88
Physics	12	0	12
Mathematics	19	0	19
Biology	16	0	16
Humanities, Social Sciences, and the Arts	8	28	36
Math/ Science Elective*	0	4	4
Electives	0	16	16
College and Life Skills	1	0	1
Total	**133**	**59**	**192**

Plan of Study

Freshman

Fall

Course	Credit
CHEM 111* General Chemistry I	4
MA 111 Calculus I	5
RHIT 100 Foundations for Rose-Hulman Success	1
HUM H190 First-Year Writing Seminar or HSSA Elective	4
	Total Credits: 14

Winter

Course	Credit
CHEM 113* General Chemistry II	4
MA 112 Calculus II	5
PH 111 Physics I	4
BIO 110 Cell Structure & Function	4
	Total Credits: 17

Spring

Course	Credit
CHEM 115 General Chemistry III	4
MA 113 Calculus III	5
PH 112 Physics II	4
HSSA Elective	4
	Total Credits: 17

Sophomore

Fall

Course	Credit
CHEM 251 Organic Chemistry I	3
CHEM 251L Organic Chemistry I Lab	1
CHEM 225 Analytical Chemistry	4
MA 223 or MA 381 Eng. Stats or Prob. Stats.	4
BIO 210 Mendelian & Molecular Genetics	4
	Total Credits: 16

Winter

Course	Credit
CHEM 200 Career Preparation	1
CHEM 252 Organic Chemistry II	3
CHEM 252L Organic Chemistry II Lab	1
CHEM 291 Intro to Undergradute Research	3
Math/Science Elective***	4
BIO 220 Prokaryotic Cell & Molecular Biology	4
	Total Credits: 16

Spring

Course	Credit
CHEM 253 Organic Chemistry III	3
CHEM 253L Organic Chemistry III Lab	1
HSSA Elective	4
BIO 230 Eukaryotic Cell & Mol. Biology	4
ENGL H290 Technical Communication (or HSSA Elective)	4
	Total Credits: 16

Junior

Fall

Course	Credit
PH 113 Physics 3	4
CHEM 330 Biochemistry I	4
CHEM 361 **Physical Chemistry I	4
CHEM 395 Chemistry Seminar	0
CHEM 490 Research Rotation	2
HSSA Elective	4
	Total Credits: 18

Winter

Course	Credit
CHEM 326 Bioanalytical Chemistry	4
CHEM 362 **Physical Chemistry II	4
CHEM 331 Biochemistry II	4
CHEM 490 Research Rotation	2
HSSA Elective	4
	Total Credits: 18

Spring

Course	Credit
CHEM 463 Physical Chemistry 3	4
CHEM 430 Advanced Biochemistry	4
CHEM 433 Biochemistry Lab	1
CHEM 490 Research Rotation	2
CHEM 327 Adv Analytical Chemistry	4
	Total Credits: 15

Senior

Fall

Course	Credit
CHEM 441 Inorganic Chemistry I	4
CHEM 495 Chemistry Seminar	0
CHEM Advanced Chemistry Elective	4
HSSA Elective	4
Free Elective	4
	Total Credits: 16

Winter

Course	Credit
CHEM 496 Chemistry Seminar	0
CHEM Advanced Chemistry Elective	3
Free Elective	4
HSSA Elective	4
##Advanced Biology, Chemistry, Biochemistry Elective	4
	Total Credits: 15

Spring

Course	Credit
CHEM 491 Senior Thesis	1
CHEM 497 Chemistry Seminar	1
HSSA Elective	4
Free Elective	4
Free Elective	4
	Total Credits: 14

NOTES

Two degree or double major programs in biochemistry and either chemistry or biochemistry and molecular biology is not allowed.

*Subject to approval, CHEM 112 may be substituted for CHEM 111 and CHEM 113.

**CHE 303, CHE 304 and CHEM 360 may be substituted for CHEM 361 and CHEM 362.

***Math/ScienceElective defined as 200 level or above coursework with any of the following prefixes: BIO, BMTH, CSSE, GEOL, ECONS, MA, or PH

^Students must complete at least 3 credits of CHEM 490 prior to the Spring quarter of their senior year.
Students may count up to 8 credits of research toward their electives, of which no more than 2 credits can come from CHEM 290.

##Research and independent study do not meet this requirement.

Biochemistry Course Descriptions

CHEM 111 General Chemistry I 3R-0L-3C F,W,S
Prerequisites: There are no prerequisites for this course.
Corequisites: CHEM 111L
Topics include stoichiometry, nomenclature, phases, and writing balanced chemical equations. Quantum theory is introduced in relation to chemical applications. Atomic structure is introduced. Bonding principles and molecular structure are discussed in terms of Lewis Dot Structures, Valence Bond Theory, VSEPR Theory, Hybridization, and Molecular Orbital Theory.

CHEM 111L General Chemistry I Laboratory 0R-3L-1C F,W,S
Prerequisites: There are no prerequisites for this course.
Corequisites: CHEM 111
Fundamental chemistry laboratory skills are introduced along with data analysis in support of topics presented in CHEM111 recitation.

CHEM 112 Chemistry Honors 4R-3L-5C F
Prerequisites: Advanced placement
Corequisites: There are no corequisites for this course.
An accelerated course covering topics in CHEM 111 and CHEM 113. Upon successful completion of this course, an additional 3 credits will be awarded. Enrollment is limited to those students who complete the Rose-Hulman online Chemistry Advanced Placement Examination given prior to the freshman orientation period.

CHEM 113 General Chemistry II 3R-0L-3C W,S
Prerequisites: CHEM 111, and CHEM 111L
Corequisites: CHEM 113L
Topics in this course include the fundamentals of thermodynamics and kinetics. The fundamentals of chemical equilibrium are introduced. Definitions of acid and bases are discussed utilizing the Bronsted-Lowry and Lewis models. Nuclear chemistry is also included.

CHEM 113L General Chemistry II Laboratory 0R-3L-1C W,S
Prerequisites: CHEM 111, and CHEM 111L
Corequisites: CHEM 113
Fundamental chemistry laboratory skills are introduced along with data analysis in support of topics presented in CHEM113 recitation.

CHEM 115 General Chemistry III 3R-0L-3C W, S
Prerequisites: CHEM 113, and CHEM 113L or CHEM 112
Corequisites: CHEM 115L
Topics in this course include acid-base reactions, electrochemistry, and coordination chemistry.

CHEM 115L General Chemistry III Laboratory 0R-3L-1C W,S
Prerequisites: CHEM 113, and CHEM 113L or CHEM 112
Corequisites: CHEM 115
Fundamental chemistry laboratory skills are introduced along with data analysis in support of topics presented in CHEM113 recitation.

CHEM 199 Professional Experience 1R-0L-1C
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.

The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

CHEM 200 Career Preparation 1R-0L-1C W

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

This course is for chemistry and biochemistry majors to be taken in the second year. The course addresses career choices, summer opportunities, employment and graduate school preparation, and curriculum vitae and resumes preparation. Cross-listed with MA200, and SV200.

CHEM 210 Chemistry of Poisons and Potions 2R-0L-2C SeeDept

Prerequisites: CHEM 111, and CHEM 111L

Corequisites: There are no corequisites for this course.

This course examines chemical agents found in medicinal plants and their use in different contexts. Specifically, we will investigate the chemical characteristics of these agents commonly used by humans through cultural practices.

CHEM 211 Chemistry of Food and Cooking 2R-0L-2C See Dept.

Prerequisites: CHEM 111, and CHEM 111L

Corequisites: There are no corequisites for this course.

This course is for chemistry and biochemistry majors to be taken in the second year. The course addresses career choices, summer opportunities, employment and graduate school preparation, and curriculum vitae and resumes preparation. Cross-listed with MA200, and SV200.

CHEM 212 Chemistry of Sport 2R-0L-2C SeeDept

Prerequisites: CHEM 111, and CHEM 111L

Corequisites: There are no corequisites for this course.

This course will take a molecule-focused look at the overlap of chemistry and sports. The course will look at types of performance-enhancing drugs and their history, mechanisms of action, claims of efficacy, and detection using case studies

CHEM 213 Chemistry of Art 2R-0L-2 SeeDept

Prerequisites: CHEM 111, and CHEM 111L

Corequisites: There are no corequisites for this course.

Topics include stoichiometry, nomenclature, phases, and writing balanced chemical equations. Quantum theory is introduced in relation to chemical applications. Atomic structure is introduced. Bonding principles and molecular structure are discussed in terms of Lewis Dot Structures, Valence Bond Theory, VSEPR Theory, Hybridization, and Molecular Orbital Theory.

CHEM 225 Analytical Chemistry 3R-0L-3C F,S

Prerequisites: CHEM 115, and CHEM 115L

Corequisites: CHEM 225L

This laboratory-driven course is an introduction to classical and modern quantitative analysis with emphasis on calculations, separations, and precise and accurate measurements. Theoretical and practical perspectives of chemical analysis are considered. Chemical instrumentation includes recording pH/mV meters, constant rate burets, colorimeters, spectrophotometers, high performance liquid chromatographs and gas-liquid chromatographs.

CHEM 225L Analytical Chemistry Laboratory 0R-3L-1C F,S

Prerequisites: CHEM 115, and CHEM 115L

Corequisites: CHEM 225
This course represents the laboratory component of analytical chemistry. Practicums are part of the grade along with reports.

CHEM 251 Organic Chemistry I 3R-0L-3C F,W

Prerequisites: CHEM 113, and CHEM 113L or CHEM 112
Corequisites: CHEM 251L
An introduction to the classification of organic compounds, their structural features, including stereochemistry, and concepts related to reaction mechanisms and synthetic methods as it relates to compounds with biochemical relevance.

CHEM 251L Organic Chemistry I Laboratory 0R-3L-1C F,W

Prerequisites: CHEM 113, and CHEM 113L or CHEM 112
Corequisites: CHEM 251
Organic Laboratory techniques are developed along with appropriate spectroscopic methods. Assessment is in part via practicums. Computational chemistry methods and green chemistry approaches are also introduced.

CHEM 252 Organic Chemistry II 3R-0L-3C W,S

Prerequisites: CHEM 251, and CHEM 251L
Corequisites: CHEM 252L
Continuation of Organic Chemistry I with greater emphasis on reaction mechanisms and synthesis, and an introduction to the methods used to determine structure, including IR and NMR spectroscopy and mass spectrometry.

CHEM 252L Organic Chemistry II Laboratory 0R-3L-1C W,S

Prerequisites: CHEM 251, and CHEM 251L
Corequisites: CHEM 252
A continuation of CHEM251L where additional, more complicated synthetic techniques and methods along with additional spectroscopic techniques are introduced. Assessment is in part via practicums.

CHEM 253 Organic Chemistry III 3R-0L-3C S

Prerequisites: CHEM 252, and CHEM 252L
Corequisites: CHEM 253L
Study of carbanions, classical and non-classical carbocations, polyfunctional compounds, heterocyclics, orbital symmetry and more advanced reaction mechanisms, molecular rearrangements and syntheses.

CHEM 253L Organic Chemistry III Laboratory 0R-4L-1C S

Prerequisites: CHEM 252, CHEM 252L
Corequisites: CHEM 253
Project based laboratory where techniques and skills developed in the previous organic laboratories are applied to more open-ended problems.

CHEM 270 Special Topics in Chemistry (1-4)R-0L-(1-4)C See Dept

Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
Studies in topics of current chemical interest not addressed in other named courses. A maximum of 4 total credit hours of CHEM270 and CHEM276 can be counted towards a chemistry major.

CHEM 276 Special Topics in Chemistry with Laboratory (0-3)R-(3-6)L-(1-4)C

Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
Studies in topics of current chemical interest not addressed in other named courses. This course will have a laboratory component. A maximum of 4 total credit hours of CHEM270 and CHEM276 can be counted towards a chemistry major.

CHEM 290 Chemical Research 0R-(4-8)L-(1-2)C F, W, S
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Research performed under the direction of a faculty member selected by mutual agreement. This course is designed for research performed before taking CHEM291. Students may register for 1 to 2 credit hours per quarter.
CHEM 291 Introduction to Chemical Research 2R-4L-3C W
Prerequisites: CHEM 113, and CHEM 113L or CHEM 112 declared chemistry or biochemistry major.
Corequisites: There are no corequisites for this course.
Students will be introduced to skills necessary for conducting chemical research. Students will gain proficiency in: (1) literature searching of primary, secondary, and tertiary sources emphasizing the use of online databases; (2) laboratory skills involving synthesis, characterization, analysis, and keeping a notebook; (3) safety practice including MSDS interpretation; and (4) ethical conduct in collecting and reporting data and results. Students will also discuss research projects with at least three faculty members and be required to attend all seminars during the quarter.
CHEM 326 Bioanalytical Chemistry 3R-4L-4-C W
Prerequisites: CHEM 225, and CHEM 225L
Corequisites: There are no corequisites for this course.
Addresses instrumental methods of analysis applicable to biochemistry including instrument design, operating principles, theory and application. Topics include molecular spectroscopic techniques in the infrared, visible and ultraviolet regions, including luminescence and Raman spectroscopy. Separation techniques including liquid chromatography and capillary electrophoresis are also addressed.
CHEM 327 Advanced Analytical Chemistry 3R-4L-4C S
Prerequisites: CHEM 326, There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Addresses theory, operating principles, and application of instrumental methods for chemical analysis in the areas of atomic spectroscopy, x-ray techniques, gas chromatography and electroanalytical methods.
CHEM 330 Biochemistry I 4R-0L-4C F,S
Prerequisites: CHEM 251
Corequisites: There are no corequisites for this course.
Includes the structure and function of biological molecules, enzyme kinetics and mechanisms, and the reactions, strategy, and regulation of carbohydrate metabolism.
CHEM 331 Biochemistry II 4R-0L-4C W
Prerequisites: CHEM 330, and BIO 210
Corequisites: There are no corequisites for this course.
Includes the reactions, strategy, and regulation of the major metabolic pathways in humans and of selected pathways in plants, and the storage, repair, and transmission of genetic information.
CHEM 360 Introduction to Physical Chemistry for Engineers 4R-0L-4C W,S
Prerequisites: CHE 303, CHE 304, and CHEM 115
Corequisites: There are no corequisites for this course.
Introduction to quantum chemistry, statistical thermodynamics, electrochemistry, chemical kinetics, surface chemistry and colloid science.
CHEM 361 Physical Chemistry I 4R-2L-4C F
Prerequisites: CHEM 115, and CHEM 115L, and MA 113, and MA 223 or MA 381*
See notes below

Corequisites: There are no corequisites for this course.
Covers the laws of thermodynamics, free energy, gases, phase equilibria and solutions. Emphasizes the applications of differential and integral calculus and includes an introduction to statistical thermodynamics and surface chemistry. The laboratory will meet for 4 hours on alternate weeks and will investigate topics associated with thermodynamics and phase equilibrium.

Prerequisite Notes:
CHEM 115/115L, MA 113 and either MA 223 or MA 381

CHEM 362 Physical Chemistry II 3R-2L-4C W

Prerequisites: CHEM 361

Corequisites: There are no corequisites for this course.

Covers chemical equilibria, statistical mechanics, kinetics and electrochemistry. The laboratory will meet for 4 hours on alternate weeks.

CHEM 391 Research Proposal 1R-0L-1C F, W, S

Prerequisites: CHEM 291

Corequisites: There are no corequisites for this course.

Students will take online lessons related to the generation and communication of research ideas culminating in the production of a research proposal. The research proposal will be written under the direction of a faculty member of record for the student's CHEM490 or by other faculty member selected by mutual agreement.

CHEM 395 Chemistry Seminar 0R-0L-0C F

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

Students will be required to attend and/or present research seminars, the number to be determined by the department. The students will register for the course in the fall of the third year and if all the requirements are met, the students will receive a grade of Satisfactory. Failure to meet the requirements during the fall quarter will result in No Grade and the student must complete the requirements by the end of the third year. If the requirements are not completed by the end of the third year, a grade of Unsatisfactory is assigned and must be rectified to meet graduation requirements.

CHEM 420 Electronics for Scientists 3R-4L-4C See Dept

Prerequisites: CHEM 326 or CHEM 327 or consent of instructor

Corequisites: There are no corequisites for this course.

A fundamental course on understanding important electronic systems as they pertain to chemical signals and instrumentation. Topics include analog systems (RC circuits, diodes, transistors, and operational amplifiers), digital systems (logic gates, shift registers, and lock-in amplifiers), and signal enhancement and noise reduction modules. The laboratory component will showcase basic circuit design and construction, and will culminate with a student-built chemical instrument.

CHEM 421 Biochemical Mass Spectrometry 1R-0L-1C See Dept

Prerequisites: CHEM 330

Corequisites: There are no corequisites for this course.

This course will explore the theoretical basis and practical aspects of mass spectrometry, with an emphasis on their use for analysis of biological molecules. Topics include ionization mechanisms and methods for sample preparation and mass spectral analysis, and the course will include a project.

CHEM 422 Fluorescence Spectroscopy 1R-0L-1C See Dept

Prerequisites: CHEM 330

Corequisites: There are no corequisites for this course.
This course will explore the theoretical basis and practical aspects of fluorescence spectroscopy, with an emphasis on their use for analysis of biological molecules. Topics include mechanisms of fluorescence excitation and emission, quenching processes, anisotropy, and time-resolved fluorescence, and the course will include a project.

CHEM 423 NMR Spectroscopy 1R-0L-1C See Dept

Prerequisites: CHEM 252

Corequisites: There are no corequisites for this course.
This course is designed to provide the basic training and tools necessary to operate the 300MHz Bruker NMR and the associated ICON software. Additionally, the focus will be on sample preparation, acquisition, analysis, and processing of 1H NMR, 13C NMR, COSY and HETCOR (2D NMR), DEPT-90, DEPT-135, heteronuclear NMR, and applications of NMR to related fields. The course will consist primarily of basic and practical NMR instruction.

CHEM 424 Absorption Spectroscopy 2R-0L-2C See Dept

Prerequisites: CHEM 326 or CHEM 327

Corequisites: There are no corequisites for this course.
This course looks at absorption spectroscopy from the microwave to x-ray relating spectra to the molecular and/or atomic processes. The course will consist of both instruction and a project of student choice involving absorption process.

CHEM 425 Raman Spectroscopy 1R-0L-1C SeeDept

Prerequisites: CHEM 225

Corequisites: There are no corequisites for this course.
This course explores various theoretical and practical aspects of Raman spectroscopy including fundamental vibrational modes of molecules and selection rules, the physicochemical origin of Raman scattering, Raman spectrometers, lasers, resonance Raman spectroscopy, surface-enhanced Raman spectroscopy (SERS), and applications of Raman spectroscopy. The course includes an independent project in which a Raman spectrum is acquired for a sample of interest.

CHEM 426 Microfluidics 1R-0L-1C SeeDept

Prerequisites: CHEM 225

Corequisites: There are no corequisites for this course.
This course explores various theoretical and practical aspects of microfluidics. The course addresses the benefits and challenges of microfluidics in chemistry and chemical analysis and the materials and processes available for fabricating microfluidic devices. General characteristics of microfluidic devices including fluid flow regimes, heat transfer and diffusion are addressed as well as practical applications of microfluidic devices and how various functions like valving and detection are performed. The course includes an independent project involving the design and fabrication of a microfluidic device.

CHEM 427 HPLC 1R-0L-1C SeeDept

Prerequisites: CHEM 225

Corequisites: There are no corequisites for this course.
This course will explore various theoretical and practical aspects of HPLC including a review of separation parameters, equilibrium types, retention mechanisms, stationary phases and their performance, mobile phases and their properties and choosing an appropriate separation type.

CHEM 428 Trace Metal Detection 1R-0L-1C SeeDept

Prerequisites: CHEM 225

Corequisites: There are no corequisites for this course.

This course aims at providing students with fundamental skills and knowledge in trace metal analysis, for environmental and biological samples. The course will enable students to understand, develop and execute analytical protocols involving recent trace metal analysis methodologies and instrumentation using voltammetry. Students will learn by lectures, class activities, and homework assignments and how to optimize conditions to obtain sufficient analytical performance parameters in terms of selectivity, detection limit, cost, and analysis time.

CHEM 429 Capillary Electrophoresis 1R-0L-1C SeeDept

Prerequisites: CHEM 225

Corequisites: There are no corequisites for this course.

This course will explore various theoretical principles and chemical/biochemical applications of capillary electrophoresis. Main emphasis will focus on the choice of CE as an alternative form for separations for biochemical samples. Students will learn by lectures, class activities, homework assignments and how to optimize experimental conditions to achieve a good separation.

CHEM 430 Advanced Biochemistry 4R-0L-4C S

Prerequisites: CHEM 330

Corequisites: There are no corequisites for this course.

An in-depth exploration of selected topics from the current biochemistry scientific literature, including molecular mechanisms of infectious diseases and genetic disorders, methods for rational drug design, and relationships between structure and function for biological molecules.

CHEM 433 Biochemistry Laboratory 0R-3L-1C S

Prerequisites: CHEM 330

Corequisites: There are no corequisites for this course.

Fundamental techniques employed in isolation, characterization and study of biomolecules, and enzyme kinetics. Techniques used may include homogenization, solvent extraction, centrifugation, salt fractionation, chromatography, and electrophoresis.

CHEM 441 Inorganic Chemistry I 4R-0L-4C F

Prerequisites: CHEM 252, CHEM 362, CHEM 360

Corequisites: There are no corequisites for this course.

The chemistry of non-metals. This course consists of a systematic study of the properties and reactions of the elements and their compounds based upon modern theories of the chemical bond, as well as from the viewpoint of atomic structure and the periodic law.

CHEM 442 Inorganic Chemistry II 3R-4L-4C W

Prerequisites: CHEM 441

Corequisites: There are no corequisites for this course.

The chemistry of metals. Modern theories such as valence bond, molecular orbital, electrostatic and ligand field are used to explain the properties of complex ions. Synthesis and characterization of complexes are done in the lab.

CHEM 451 Organic Structure Determination 2R-8L-4C See Dept

Prerequisites: CHEM 253 or instructor consent

Corequisites: There are no corequisites for this course.

Chemical and spectroscopic identification of organic compounds. Study of nuclear magnetic resonance and mass spectrometry, infrared spectroscopy and other techniques applied to structure elucidation and stereochemistry.

CHEM 463 Quantum Chemistry & Molecular Spectroscopy 4R-0L-4C S

Prerequisites: CHEM 111, CHEM 111L, PH 112, and MA 221

Corequisites: There are no corequisites for this course.
Covers elementary quantum mechanics with emphasis on applications in molecular structure.

CHEM 470 Special Topics in Chemistry (1-4)R-0L-(1-4)C See Dept

Prerequisites: or instructor consent
Corequisites: There are no corequisites for this course.
Studies in advanced topics of current chemical interest not addressed in other named courses.

CHEM 476 Special Topics in Chemistry with Laboratory (0-3)R-(3-6)L-(1-4)C See Dept

Prerequisites: To be taken concurrently with the appropriate elective not accompanied by an identified laboratory component.
Corequisites: There are no corequisites for this course.
Studies in advanced topics of current chemical interest not addressed in other named courses. This course will have a laboratory component.

CHEM 477 Directed Study in Chemistry (1-4)R-0L-(1-4)C F, W, S

Prerequisites: or instructor consent
Corequisites: There are no corequisites for this course.
Allows individual study in a topic not usually offered. A student may take 1 to 4 credits. A maximum of 4 credits is permitted.

CHEM 490 Chemical Research Rotation 1R-4L-2C F, W, S

Prerequisites: CHEM 291
Corequisites: There are no corequisites for this course.
Open-ended research projects performed as part of a research group. The students will gain proficiency in advanced lab techniques, the scientific method, data management and communication.

CHEM 491 Senior Thesis 1R-0L-1C F, W, S

Prerequisites: CHEM 490
Corequisites: There are no corequisites for this course.
Students will publish a thesis on their undergraduate research or a literature review of an advanced topic mutually agreed upon with the instructor.

CHEM 495 Chemistry Seminar 0R-0L-0C F

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Students will be required to attend research seminars. If the requirement is not completed by the end of the quarter, a grade of Unsatisfactory is assigned and must be rectified to meet graduation requirements.

CHEM 496 Chemistry Seminar 0R-0L-0C W

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Students will be required to attend research seminars. If the requirement is not completed by the end of the quarter, a grade of Unsatisfactory is assigned and must be rectified to meet graduation requirements.

CHEM 497 Senior Presentation 1R-0L-1C F, W, S

Prerequisites: CHEM 490
Corequisites: There are no corequisites for this course.
Students will deliver a professional seminar on their undergraduate research or a review of an advanced topic mutually agreed upon with the instructor.

CHEM 499 Independent Chemical Research 0R-(4-8)L-(1-2)C F, W, S

Prerequisites: CHEM 291

Corequisites: There are no corequisites for this course.
Research performed under the direction of a faculty member selected by mutual agreement. Students may register for 1 or 2 credit hours per quarter.

CHEM 520 Electronics for Scientists 3R-4L-4C See Dept

Prerequisites: CHEM 326 or CHEM 327 or consent of instructor
Corequisites: There are no corequisites for this course.
A fundamental course on understanding important electronic systems as they pertain to chemical signals and instrumentation. Topics include analog systems (RC circuits, diodes, transistors, and operational amplifiers), digital systems (logic gates, shift registers, and lock-in amplifiers), and signal enhancement and noise reduction modules. The laboratory component will showcase basic circuit design and construction, and will culminate with a student-built chemical instrument. For graduate credit there will be an additional project beyond the requirements for CHEM420. A student may not take both CHEM420 and CHEM520 for credit.

CHEM 530 Advanced Biochemistry 4R-0L-4C S

Prerequisites: CHEM 330
Corequisites: There are no corequisites for this course.
An in-depth exploration of selected topics from the current biochemistry scientific literature, including molecular mechanisms of infectious diseases and genetic disorders, methods for rational drug design, and relationships between structure and function for biological molecules. Students enrolled in CHEM 530 must complete a project not covered in CHEM 430. A student may not receive credit for both CHEM 430 and CHEM 530.

CHEM 531 Biochemical Instrumentation 3R-4L-4C See Dept

Prerequisites: BIO 210, and CHEM 330
Corequisites: There are no corequisites for this course.
This project-based course includes approaches for the analysis of biochemical experimental problems, experimental design for molecular biology and biochemistry, and the theoretical basis and practical aspects of operating instruments used in biochemical research.

CHEM 532 Biochemical Pharmacology 4R-0L-4C See Dept

Prerequisites: CHEM 330
Corequisites: There are no corequisites for this course.
Topics include medicinal chemistry and molecular pharmacology. The topics will also include a survey of potential drug targets, the molecular interactions between drugs and their targets, the drug discovery and development process and case studies of drugs treating diseases such as cancer, bacterial and viral infection, and neurological disorders.

CHEM 534 Biochemical Physiology 4R-0L-4C SeeDept

Prerequisites: CHEM 330
Corequisites: There are no corequisites for this course.
An application of the principles of biochemistry to understanding the chemical aspects of the functioning of living organisms. This course covers topics related to the molecular mechanisms involved in the maintenance of physiological homeostasis, and when appropriate examines current research in the relevant systems. These mechanisms will be organized by the chemical signaling systems responsible for integrating and communicating the response to internal changes and external stimuli.

CHEM 535 Toxicology for Chemists 4R-0L-4C SeeDept

Prerequisites: CHEM 251
Corequisites: There are no corequisites for this course.

A fundamental course on the interaction of chemical agents with the human body. Topics include toxic thresholds and dose-response relationships, toxicological mechanisms of action, and models for physical and aquatic toxicities. Students engage in quantitative structure-activity relationship (QSAR) modeling and hazard assessment.

CHEM 545 Organometallic Chemistry 4R-0L-4C See Dept

Prerequisites: CHEM 115, and CHEM 252

Corequisites: There are no corequisites for this course.

A survey of the chemistry of main group organometallic compounds and organo-transition metal complexes. Reaction mechanisms and uses in organic synthesis and catalysis are studied.

CHEM 552 Synthetic Organic Chemistry 4R-0L-4C See Dept

Prerequisites: CHEM 253

Corequisites: There are no corequisites for this course.

A survey of contemporary methodology in organic synthesis. Retrosynthetic analysis, functional group transformations, condensation chemistry, and organometallic reagents will be stressed. Includes computer assisted synthesis.

CHEM 554 Theoretical Organic Chemistry 4R-0L-4C See Dept

Prerequisites: CHEM 253, and CHEM 361 or CHEM 360 or permission of instructor

Corequisites: There are no corequisites for this course.

Study of physical and chemical methods used to investigate organic reaction mechanisms; the chemistry of carbenes; organic photochemistry.

CHEM 556 Green Chemistry 4R-0L-4C SeeDept

Prerequisites: CHEM 252

Corequisites: There are no corequisites for this course.

Advanced topics in green chemistry including industrial applications, atom economy, safer solvent substitutions, alternatives assessment, green metrics (PMI, E#factor), and a brief introduction to chemical toxicology.

CHEM 561 Advanced Physical Chemistry 4R-0L-4C SeeDept

Prerequisites: CHEM 463, and CHEM 360 or CHEM 362

Corequisites: There are no corequisites for this course.

Addresses a variety of topics in quantum mechanics, statistical thermodynamics or kinetics.

CHEM 570 Special Topics in Chemistry (1-4)R-0L-(1-4)C See Dept

Prerequisites: permission of instructor

Corequisites: There are no corequisites for this course.

Studies in advanced topics of current chemical interest not addressed in other named courses. If cross-listed with CHEM470, students in CHEM570 will need to complete an additional project.

CHEM 581 Polymer Chemistry 3R-4L-4C See Dept

Prerequisites: CHEM 252 Junior class standing

Corequisites: There are no corequisites for this course.

Polymer synthesis, reactions, and characterization techniques. Structure/property relationships and morphology will be discussed, both for industrially relevant polymers as current topics of from the recent literature. Laboratory sequence consists of polymer synthesis and characterization.

CHEM 582 Physical Properties of Polymeric Materials 4R-0L-4C See Dept

Prerequisites: CHEM 361 or CHEM 360

Corequisites: There are no corequisites for this course.

In this course the physical properties of polymeric systems will be defined in terms of the models that have been used to characterize them. The behavior of isolated polymers and polymers in solution will be mapped to macroscopic properties of bulk polymeric systems using theories such as Rotational Isomeric State and Flory's Lattice model. Methods of molecular weight determination will be fully developed. Phase transitions will be characterized and related to polymeric and monomeric structural features. Theories of elasticity and viscoelastic behavior will be used to explain macroscopic behaviors of polymeric materials.

CHEM 595 Chemistry Seminar 0R-0L-0C F

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

Chemistry graduate students will be required to attend research seminars. If the requirement is not completed by the end of the quarter, a grade of Unsatisfactory is assigned and must be rectified to meet graduation requirements.

CHEM 596 Chemistry Seminar 0R-0L-0C W

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

Chemistry graduate students will be required to attend research seminars. If the requirement is not completed by the end of the quarter, a grade of Unsatisfactory is assigned and must be rectified to meet graduation requirements.

CHEM 597 Chemistry Seminar 0R-0L-0C S

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

Chemistry graduate students will be required to attend research seminars. If the requirement is not completed by the end of the quarter, a grade of Unsatisfactory is assigned and must be rectified to meet graduation requirements.

CHEM 599 Thesis Research As assigned F, W, S

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

Graduate students only. Credits as assigned; however, not more than 12 credits will be applied toward the requirements of the M.S. degree.

CHEM 699 Professional Experience 1R-0L-1C See Dept

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The work experiences should be informative or integral to the advancement or completion of the student's program requirements. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

Biology

The twenty-first century will see unparalleled advances in the biological sciences that will greatly impact the way we live. The areas of functional genomics and proteomics will drive discoveries in molecular medicine, gene therapy, and tissue engineering. Drug discovery will be facilitated by the elucidation of new target molecules and many pharmaceutical compounds will be produced using biological processes. Environmental management, remediation, and restoration will also advance as a result of new techniques and perspectives that emerge from the century of biology. Biologists will be at the forefront of the advances that will drive progress in medical, agricultural, environmental, and related industries.

The biology program will equip biologists with the deep biological understanding along with chemistry, mathematics, and physics background needed to solve biotechnological problems in the coming decades. The program will prepare graduates for professional careers in government and industrial research laboratories, and in the biotechnology and health-related industries. Those wishing to continue their studies in graduate or health professions programs will be exceptionally well qualified to do so.

Biology Learning Objectives

Upon graduation, Rose-Hulman Biology students will be able to

1. identify questions of interest to the scientific community.
2. develop and implement a strategy to answer open-ended questions or achieve a goal through scientific investigation or experimentation.
3. develop evidence-based conclusions through a process of informed evaluation and judgement.
4. communicate with a range of audiences through a variety of media.
5. demonstrate integrity with respect to ethical and professional responsibilities.
6. exhibit growth as a person and professional using appropriate learning strategies.
7. use examples from molecules to ecosystems to illustrate core concepts of biology.

Math requirements in BIO can be satisified via one of the following course sequences:

Sequence 1 (Probability and Statistics Focus)
MA 223 Engineering Statistics
and
MA 482 Biostatistics
and either
MA 485 Applied Linear Regression -or- MA487 Design of Experiments

Sequence 2 (Modeling Focus)
MA 221 Matrix Algebra and Differential Equations I
and
MA 222 Matrix Algebra and Differential Equations II
and
MA 223 Engineering Statistics

A BIO science/technical elective is any Rose-Hulman course that has a prefix of BE, BIO, BMTH, CE, CHE, CHEM, CSSE, ECE, GEOL, MA, ME, PH, OE, EP, ES, EM or any EMGT course that is not cross-listed with a course offered by the HSSA Department. Courses that do not count as science or technical electives are those courses with AS, MS, GRAD and all HSSA Department course prefixes.

SUMMARY

Required BIO courses	**52 credits**
BIO electives	12 credits
Free electives	8 credits

Required CSSE	4 credits
HSSA electives	24 credits
Required HSSA	12 credits
Required MA, CHEM, PH	59 credits
Required RHIT 100	1 credit
Sci/Tech electives	16 credits
Total	**188 credits**

Biochemistry & Molecular Biology (Second Major Only)

Student Learning Outcomes

Upon graduation, Rose-Hulman Biochemistry and Molecular Biology students will be able to

1. Solve problems by applying core concepts of biochemistry and molecular biology.
2. Explain and and apply techniques related to the manipulation and analysis of cells and biomolecules.
3. Communicate complex scientific findings and ideas from the discipline of biochemistry and molecular biology through a variety of media.

The biochemistry & molecular biology program exists to give students an opportunity to augment their education in this technologically-important field. To support this effort, Rose-Hulman provides students with access to a modern and well-equipped biochemistry lab, along with an excellent biological sciences facility.

Biochemistry & molecular biology is available to Rose-Hulman students as a second major. This means that the student will receive a first degree in some other discipline and then can augment their education with this program. Students whose first degree programs are in chemistry or chemical engineering will find the program easiest since there is considerable overlap between those programs and the biochemistry & molecular biology requirements. Students from other disciplines are also encouraged to participate, but will have to take more courses. All students are encouraged to take individual courses in the program, regardless of whether or not they wish to fulfill the second major requirements, or to participate in related research projects under faculty supervision.

Two degree or double major programs in Biochemistry & Molecular Biology and Biochemistry are not allowed.

Required Courses

Course	Description	Hours
CHEM 111, 113, 115	General Chemistry	12
CHEM 251, 252, 253	Organic Chemistry	9
CHEM 251L, 252L, 253L	Organic Chemistry Lab	3
CHEM 330, 430, 433	Biochemistry	9
CHEM 361, 362 or CHEM 360, CHE303, CHE304	Physical Chemistry or Physical Chemistry and Thermodynamics	8 or 12

BIO 110, 120, 130	Biology	12
BIO 210	Genetics	4
BIO 220, 230	Molecular Biology	8
BIO 411	Genetic Engineering	4
Total		**69 or 73**

Elective Courses

Choose 12 credits* from the following courses:

Course	Description
BIO 330	Evolutionary Biology
BIO 421	Microbiology
BIO 431	Genomics and Proteomics
BIO 441	Virology
BIO 451	Cancer Biology
BIO 492	Directed Study in Biology
CHEM 225	Analytical Chemistry
CHEM 291	Introduction to Research
CHEM 331	Biochemistry II
CHEM 431	Biochemical Instrumentation
CHEM 451	Organic Structure Determination
CHEM 290 or	
CHEM 490	Chemical Research
PH 302	Biophysics

Total Credits for Second Major 81

**Students with a major in chemistry need to take 8 credits of electives, with 4 credits from the BIO electives listed, and 4 credits chosen from any BIO or BE course.*

STUDENTS WITH A MAJOR IN BIOLOGY must take 12 credits of electives, with 8 credits from the elective courses listed above with a CHEM prefix, and 4 credits from any 300 level or above BIO course (total: 29 hours required beyond Biology major).

Biology Minor

Biology is an exciting subject that has applications relevant to all other fields of study at the Institute. Students who are interested in enriching their major area of study with a knowledge of life sciences can do so with the Biology Minor. With proper course selection, the Minor will provide another marketable dimension to any Bachelor of Science degree granted by the Institute.

The Minor in Biology has the following requirements.

1. All students must complete BIO110 (Cell Structure and Function) or BIO130 (Evolution and Diversity) and four more courses in biology (BIO) or allied areas, above those courses already specifically required to fulfill the student's major, subject to the following requirements:

    a. At least three of the four electives must be BIO courses.
    b. At least three of the electives must be 200-level or above.
2. Students electing to pursue the minor in Biology must follow a plan of study that is approved by the Minor Advisor. Current advisor information and a form for the planning and approval of a minor can be obtained from the BBE Department Secretary.

Allied area courses could include:

BE310	Analysis of Physiological Systems I		
BE320	Analysis of Physiological Systems II	HUM H239	Intro to Science, Technology, and Society
BE570	Intro to Tissue Engineering	PHIL H402	Philosophy of Science
BMTH310	Mathematical Biology	PSYC S410	Computational Psychology
BMTH311	Systems Biology	MA482/BE482	Bioengineering Statistics
BMTH312	Bioinformatics	ME447	Visualizing Data
BMTH413	Computational Biology	PH302	Biophysics
CE460	Intro to Environmental Engineering	PHIL H201	Bioethics
CHE545	Intro to Biochemical Engineering	PSYC S220	Social Psychology
CHEM264	Intro to Environmental Science	PSYC S240	Abnormal Psychology
CHEM330	Biochemistry	PSYC S310	Methods for Studying Human Behavior
CHEM430	Advanced Biochemistry		

Additional courses not listed here can be considered on a case-by-case basis.

Biochemistry & Molecular Biology Minor

Completion of BIO110, CHEM111, CHEM113 and CHEM115. In addition, the student must complete five courses from the following list that are not already named required courses by the student's major or minor programs:

Course	Description
BIO 210	Mendelian and Molecular Genetics
BIO 220 or	Prokaryotic Cell and Molecular Biology
BIO 230	Eukaryotic Cell and Molecular Biology
BIO 411 or	Genetic Engineering
BIO 431	Genomics and Proteomics
CHEM 230 or	Introduction to Organic Chemistry and Biochemistry
CHEM 251 and	Organic Chemistry I
CHEM 252	Organic Chemistry II
CHEM 330	Biochemistry
CHEM 430 with	Advanced Biochemistry
CHEM 433	Biochemistry Laboratory

Biology is an exciting subject that has applications relevant to all other fields of study at the Institute. Students who are interested in enriching their major area of study with a knowledge of life sciences can do so with the Biology Minor. With proper course selection, the Minor will provide another marketable dimension to any Bachelor of Science degree granted by the Institute.

Plan of Study

Freshman

Fall

Course	Credit
BIO 130 Evolution and Diversity	4
CHEM 111 General Chemistry	4
MA 111 Calculus I	5
RHIT 100 Foundations for Rose-Hulman Success	1
	Total Credits: 14

Winter

Course	Credit
BIO 110 Cell Structure & Function	4

CHEM 113 General Chemistry II	4
MA 112 Calculus II	5
HUM H190 First-Year Writing Seminar	4
	Total Credits: 17

Spring

Course	Credit
BIO 120 Comparative Anatomy & Physiology	4
CSSE 120 Intro to Software Development	4
MA 113 Calculus III	5
HSSA Elective	4
	Total Credits: 17

Sophomore

Fall

Course	Credit
BIO 210 Genetics	4
CHEM 251 Organic Chemistry I	3
CHEM 251L Organic Chemistry I Laboratory	1
PH 111 Physics I	4
MA 223 Engineering Statistics I	4
	Total Credits: 16

Winter

Course	Credit
BIO 220 Microbiology	4
CHEM 252 Organic Chemistry II	3
CHEM 252L Organic Chemistry II Lab	1
PH 112 Physics II	4
ENGL H290 Technical and Professional Communication	4
	Total Credits: 16

Spring

Course	Credit
BIO 230 Cell Biology	4
CHEM 330 Biochemistry I	4
Math Elective	4

HSSA Elective	4
	Total Credits: 16

Junior

Fall

Course	Credit
BIO 320 Ecology	4
BIO Elective	4
HSSA Elective	4
BIO 399 Practice of Science	4
	Total Credits: 16

Winter

Course	Credit
BIO 330 Evolutionary Biology	4
BIO 496 Senior Thesis Research I	2
CHEM 331 Biochemistry II	4
Math Elective	4
	Total Credits: 14

Spring

Course	Credit
BIO 310 Plant Structure & Function	4
BIO 497 Senior Thesis Research II	4
PHIL H201 Bioethics	4
HSSA Elective	4
	Total Credits: 16

Senior

Fall

Course	Credit
BIO 498 Senior Thesis Research III	4
Science/Technical Elective	4
Science/Technical Elective	4
Free Elective	4
	Total Credits: 16

Winter

Course	Credit
BIO 499 Senior Thesis Research IV	2
Science/Technical Elective	4
BIO Elective	4
HSSA Elective	4
	Total Credits: 14

Spring

Course	Credit
BIO Elective	4
Science/Technical Elective	4
HSSA Elective	4
Free Elective	4
	Total Credits: 16

NOTES

A BIO science/technical elective is any Rose-Hulman course that has a prefix of BE, BIO, BMTH, CE, CHE, CHEM, CSSE, ECE, GEOL, MA, ME, PH, OE, EP, ES, EM or any EMGT course that is not cross-listed with a course offered by the HSSA Department. Two of the four science/technical electives must be 300-level or above, to allow BIO students to specialize in a supporting topic. Courses that do not count as science or technical electives are those courses with AS, MS, GRAD and all HSSA Department course prefixes.

Biology - Course Descriptions

BIO 101 Essential Biology 3R-3L-4C F, W, S

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Surveys basic concepts in the biological sciences and describes how new advances related to these concepts affect contemporary society. Students who have completed BIO110, BIO120 or BIO130 cannot receive credit for taking BIO101.

BIO 102 Nutrition 4R-0L-4C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
This course surveys essential concepts in the nutritional sciences, including food composition, diet construction and analysis, physiological processes, and special nutritional needs for certain groups. This course counts as a free elective, not a BIO elective, for BIO and BE majors.

BIO 103 Core Biology Advances and Applications 04R-0L-4C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
This course promotes comprehension of core biological concepts and systems to enable a more sophisticated understanding of advances in biology and applications of biological sciences. Current advances in our understanding of living systems and the application of biotechnologies to various challenges in medicine, forensics, agriculture,

and energy are also discussed. This course counts as a free elective, not a BIO elective, for BIO and BE majors.

BIO 104 Science in Practice 4R-0L-4C

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

This course explores the dispositions and applications of science relevant to understanding a broad range of popular scientific topics. Major concepts include distinguishing science from pseudoscience, information flow and use in science, misinformation tactics used to advance dubious science, and the influence of perspective on interpretation of both science and non-science information. This course counts as a free elective, not a BIO elective, for BIO and BE majors.

BIO 105 Human Health and Disease 4R-0L-4C

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

This course examines the human body in states of health and disease. Various diseases such as infections, cancer, heart disease, genetic conditions, and autoimmunity and the mechanisms leading to these diseases are studied. This course counts as a free elective, not a BIO elective, for BIO and BE majors.

BIO 107 Introduction to Environmental Science 4R-0L-4C W

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

This course examines major themes that cut across environmental topics (e.g. human influence) and uses a variety of specific environmental scenarios like food production, water resources, and energy systems to explore those themes. This course counts as a free elective, not a BIO elective, for BIO majors.

BIO 110 Cell Structure and Function 3R-3L-4C F,W

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

This course explores cellular and molecular biology structures, mechanisms, and laboratory techniques with respect to five core concepts: (1) evolution, (2) structure/function interdependence, (3) information flow, (4) bioenergetics and (5) systems perspective and interdependence.

BIO 120 Comparative Anatomy & Physiology 3R-3L-4C S

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

This course surveys animal tissues and organ systems and laboratory techniques (including dissections and recordings from biological specimens/living tissues) with respect to five core concepts: (1) evolution, (2) structure/function interdependence, (3) information flow, (4) bioenergetics, and (5) systems perspective and interdependence.

BIO 130 Evolution and Diversity 3R-3L-4C F

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

This course explores ecological and evolutionary patterns and processes, including field and laboratory approaches to develop knowledge with respect to five core concepts: (1) evolution, (2) structure/functio interdependence, (3) information flow, (4) bioenergetics, and (5) systems perspective and interdependence.

BIO 191 Special Topics in Biology XR-0L-XC

Prerequisites: Arranged prerequsite by consent of instructor
Corequisites: There are no corequisites for this course.
Introduces structures, mechanisms, and laboratory techniques in cellular and molecular biology. Discusses biomolecules, bioenergetics, biosynthesis, enzymatic function, genetics, and cellular regulatory systems.

BIO 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

BIO 205 Cellular Physiology 4R-0L-4C F

Prerequisites: BIO 110 F,W
Corequisites: There are no corequisites for this course.
The flow of information in biological systems provides a framework for detailed discussion of cell structure and function, with particular attention paid to the physiology of excitable cells. Cellular communication and the interactions of cells in tissues and the immune system are also examined. Reproduction and organismal development will also be addressed at the cellular level. A student who earns credit for BIO205 cannot earn credit for BIO230 without approval of the department head.

BIO 210 Mendelian & Molecular Genetics 3R-3L-4C F

Prerequisites: BIO 110 F,W or instructor consent
Corequisites: There are no corequisites for this course.
A discussion of Mendelian genetics including the molecular mechanisms of nuclear and cytoplasmic inheritance. Information flow and control of gene expression are addressed at the molecular level. Basic genetic techniques are covered in both lecture and laboratory.

BIO 220 Microbiology 3R-3L-4C W

Prerequisites: BIO 110 F,W or instructor consent.
Corequisites: There are no corequisites for this course.
Discusses the essential properties of eubacteria and archea. Bacterial nutrition, growth, genetics and structural and metabolic diversity are discussed in detail. The basics of virology are also addressed. Fundamental laboratory methodologies are also covered.

BIO 230 Cell Biology 3R-3L-4C S

Prerequisites: BIO 110 F,W or instructor consent
Corequisites: There are no corequisites for this course.
Examines the structure and function of various eukaryotic cells. Biomembranes, organelles, the cytoskeleton, energetics, protein sorting, signal transduction and cell interactions are discussed in detail. Essential methods in cell biology are addressed in both lectures and laboratories.

BIO 310 Plant Structure & Function 3R-3L-4C S (alternate years)

Prerequisites: BIO 130F or instructor consent.
Corequisites: There are no corequisites for this course.
Surveys the structure, physiology, diversity, evolution, and ecological importance of plants and related groups of organisms.

BIO 320 Ecology 3R-3L-4C F (alternate years)
Prerequisites: BIO 130F or instructor consent
Corequisites: There are no corequisites for this course.
Surveys adaptations of organisms, population dynamics, species interactions, and the structure and function of natural communities and ecosystems.

BIO 330 Evolutionary Biology 4R-0L-4C W (alternate years)
Prerequisites: BIO 130F or instructor consent
Corequisites: There are no corequisites for this course.
Surveys three major themes of evolutionary biology: adaptation, diversity of life, and the shared characteristics of life. Mechanisms of evolution, speciation, phylogeny, and macroevolutionary processes are discussed.

BIO 340 Introduction to Biomedical Research: Clinical Methodology 1R-1L-1C
Prerequisites: BIO 120S and Jr/Sr standing or consent of instructor.
Corequisites: There are no corequisites for this course.
Designed to introduce biology/bioengineering students to the basics of biomedical research using the clinical methodology typical of patient sample analysis. Students will learn to relate testing procedures with specific diseases and to use data obtained from laboratory testing to understand more about specific patient health problems.

BIO 350 Principles of Synthetic Biology 2R-0L-2C W
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
This course provides an introduction to feedback control systems. These systems will be characterized with respect to their time response, stability, and steady-state error. Design compensation will be used to improve the performance of a system. When possible, examples of biological control systems will be considered.

BIO 351 Synthetic Biology Design 2R-0L-2C S
Prerequisites: BIO 350W
Corequisites: There are no corequisites for this course.
Open to all majors. This course focuses on the design of novel biological parts, devices and systems, and their use in engineering cell function. Bioengineering principles and the design of genetic logic circuits, memory modules, biosensors and other cellular devices will be addressed. For the final project, students will design a novel biological system that meets the standards and goals of the International Genetically Engineered Machine Competition.

BIO 352 Synthetic Biology Laboratory 4C (studio format, 4 days x 3 hrs) Su1
Prerequisites: Instructor Consent
Corequisites: There are no corequisites for this course.
Open to all majors. This project-based studio laboratory course focuses on the fundamental laboratory techniques employed in the synthetic biology laboratory. Relevant background and theory will be discussed and applied in the hands-on learning of core laboratory techniques. In practice, students will build and test novel genetic devices designed to advance the current International Genetically Engineered Machine Competition (iGEM) Team project. Significant contribution to the project will earn students membership on the Rose-Hulman iGEM team and attribution in iGEM competition materials.

BIO 399 Practice of Science 4R-0L-4C
Prerequisites: ENGL H290F, W, S, and MA 223F,W,S or consent of instructor
Corequisites: There are no corequisites for this course.

This course focuses on skills required for implementing scientific research, including reading the primary literature, experimental design, scientific writing, oral presentations, research proposal writing, poster presentations, and investigation of research programs (through seminars or individual meetings). Each student chooses a project and research mentor by the end of the course.

BIO 410 Infection and Immunity 4R-0L-4C

Prerequisites: BIO 110 F,W or instructor consent

Corequisites: There are no corequisites for this course.

Discussion of various pathogens, how they cause disease, and how they elicit the innate and adaptive immune responses employed to combat them. Cellular and molecular mechanisms of immunity are addressed, as is the epidemiology of various human diseases.

BIO 411 Genetic Engineering 4R-0L-4C

Prerequisites: BIO 205F or BIO 210F or consent of instructor

Corequisites: There are no corequisites for this course.

Discusses the basics of molecular biology and the genetic and molecular techniques used to engineer prokaryotic and eukaryotic cells, plants, and animals for the production of useful traits or compounds. The application of DNA technology to the diagnosis and treatment of disease is also addressed.

BIO 421 Applied Microbiology 4R-0L-4C

Prerequisites: BIO 110 F,W *Arranged prerequisite or instructor consent

Corequisites: There are no corequisites for this course.

Discusses the fundamental biology of microprobes and the processes underlying their use in the production of chemicals, therapeutics and foods. The basics of microbial ecology and the environmental applications of microbial biotechnology are also discussed.

BIO 431 Genomics and Proteomics 4R-0L-4C S

Prerequisites: BIO 205F or BIO 210F or consent of instructor

Corequisites: There are no corequisites for this course.

Exploration of the methodologies used to generate systems-level sets of genetic and protein data, and the tools used to access and analyze the prodigious amounts of data emerging from such projects. The application of these technologies to investigate biological questions and model complex biological systems is also discussed.

BIO 441 Virology 3R-3L-4C

Prerequisites: BIO 110 F,W or instructor consent

Corequisites: There are no corequisites for this course.

Virology focuses on the study of viruses as well as non-viral entities such as prions and viroids. In this course, students will learn about the structures, genomes, replication strategies, and pathogenic mechanisms of various viruses. Viruses causing diseases of medical and economic importance will be emphasized. In addition, the techniques used to study viruses and the uses of viruses in the treatment of disease will be addressed.

BIO 451 Cancer Biology 4R-0L-4C

Prerequisites: BIO 205F or BIO 210F or consent of instructor

Corequisites: There are no corequisites for this course.

This course focuses on cancer at the molecular and cellular level. Specific cellular molecules and the changes to these cellular molecules that contribute to transformational and immortalization of cells and tumor progression will be studied. The mechanisms behind these molecular changes, cancer promotion and initiation events, and cancer molecule-specific treatment options will be addressed. In addition, students will study a variety of specific cancer types.

BIO 461 Evolutionary Medicine 4R-0L-4C

Prerequisites: BIO 130F*, and BIO 205F* or BIO 210F* *Arranged prerequisite or instructor consent.

Corequisites: There are no corequisites for this course.

This course examines medicine and medical practice from the perspective of evolutionary constraints, challenges, and diversity. Topics include theoretical foundations of the field, cancer patterns, mental health, genetic disease, evolutionary health promotion, and others.

BIO 471 Genetic & Molecular Analysis of Inherited Human Disease 4R-0L-4C S

Prerequisites: BIO 205F* or BIO 210F* *Arranged prerequisite or consent of instructor

Corequisites: There are no corequisites for this course.

Strategies and methods used to identify and understand the genetic and molecular bases of inherited human disease are addressed. Topics include, human population genetics, pedigrees, genetic and physical mapping of human genes, linkage analysis, and diagnostic testing. Primary literature is routinely utilized.

BIO 491 Special Topics in Biology XR-0L-XC

Prerequisites: Arranged prerequisite or instructor consent

Corequisites: There are no corequisites for this course.

Covers upper level material of mutual interest to student and instructor which cannot be acquired in any other listed BIO course.

BIO 492 Directed Study in Biology XR-XL-XC

Prerequisites: Arranged prerequisite or instructor consent

Corequisites: There are no corequisites for this course.

Covers biology material of mutual interest to the student and instructor which cannot be experienced in any other listed BIO course. A student may take between 1-4 credits in any given term, and a maximum of 8 credits of this course are permitted. Prior approval of the BBE department is required to use this course to fulfill BIO elective credit requirements.

BIO 496 Senior Thesis Research I 0R-6L-2C F,W,S

Prerequisites: BIO 399F and consent of instructor

Corequisites: There are no corequisites for this course.

Initiation of senior thesis under the direction of an BBE faculty mentor. Major tasks include creation and submission of a research proposal and piloting procedures. Additional requirements for adequate progress determined by each faculty mentor.

BIO 497 Senior Thesis Research II 0R-12L-4C F,W,S

Prerequisites: BIO 399F and consent of instructor

Corequisites: There are no corequisites for this course.

Continuation of research under the direction of an BBE faculty mentor. Major tasks include data acquisition and methodological refinement. Additional requirements for adequate progess determined by each faculty mentor.

BIO 498 Senior Thesis Research III 0R-12L-4C F,W,S

Prerequisites: BIO 399F and consent of instructor

Corequisites: There are no corequisites for this course.

Continuation of research under the direction of an BBE faculty mentor. Major tasks include data acquisition and preliminary analysis. Additional requirements for adequate progress determined by each faculty mentor.

BIO 499 Senior Thesis Research IV 0R-6L-2C W
Prerequisites: BIO 399F and consent of instructor
Corequisites: There are no corequisites for this course.
Completion of senior thesis under the direction of an BBE faculty mentor. Major tasks include final analysis, public presentation of results, and submission of the written thesis. Additional requirements for adequate progress determined by each faculty mentor.

Biomathematics

MISSION STATEMENT

An increasing number of problems in the biological sciences are being solved using sophisticated mathematical and computational tools. The biomathematics degree blends mathematics, biology, and computer science in preparation for continued graduate studies and for careers in the quantitative life sciences. The degree's mission is to provide a world class undergraduate education in applied mathematics used in support of the life sciences.

The degree's mission is supported and motivated by these facts:

- Biological data is being generated with unprecedented precision and in unfathomable volumes.
- Quantifying biological observations requires mathematical and statistical analysis.
- The basic principles of complex biological systems support mathematical and computational modeling, which can lead to testable hypotheses and new discoveries.

PROGRAM GOALS AND OBJECTIVES

The biomathematics degree will provide a broad based undergraduate experience that 1) prepares students with a rigorous education in applied mathematics, 2) educates students in the fundamental principles of biology, 3) trains students to work in a computational arena, 4) introduces students to several of the sister disciplines of computational biology, mathematical biology, bioinformatics, systems biology, and biostatistics, and 5) guides students through an advanced undergraduate research project. The degree will also liberally educate students through the study of the humanities and social sciences. Students of the program will be encouraged to participate in external and internal research programs and industrial internships and/or co-ops.
Graduates of the biomathematics program will have an ability to:

1. Mathematically model, solve, and analyze problems in biomathematics.
2. Implement computational approaches to solve and analyze problems in biomathematics.
3. Write lucidly about biomathematics.
4. Speak fluently and coherently about biomathematics.
5. Synthesize new and previous knowledge through a capstone experience.

PROGRAM OUTCOMES
Graduates will be prepared for graduate study in any of the sister fields as well as for careers in the quantitative life sciences. Each graduate will complete a capstone research experience that will culminate in a written report and a public presentation.

***Requirements: 3 Free Electives 12 hours, 3 MA Electives 12 hours, 5 Tech Electives 20 hours, 1 Domain Elective 4 hours**

SUMMARY OF GRADUATION REQUIREMENTS		
HSSA	Standard requirement, one course must be ENGL H290	36 hours
RHIT	RHIT 100	1 hour
Math Core	MA 111, 112, 113, 200, 221, 222, 332, 371 or 373, 381, and 223 or 382	40 hours
Biomath Core	BMTH 311, BMTH 312, BMTH 413, and one of BMTH 301 OR BMTH 302	16 hours
Basic Science	BIO 110, 130, 120 or 210, 220, and 230 CHEM 111, 113 PH 111, 112 one of CHEM 251 or PH 113	40 hours
Computer Science	CSSE 120	4 hours
Capstone Experience	BMTH 496, 497, 498	8 hours
Domain Elective	Any of the following, with no course substitutions permitted. BIO 330 Evolutionary Biology 4R-0L-4C W (alternate years) Prereq. BIO 130 CHEM 330 Biochemistry I 4R-0L-4C F,S Prereq. CHEM 251 CSSE 304 Programming Language Concepts 4R-0L-4C W Prereq. CSSE 230 and CSSE 280 MA 366 Introduction to Real Analysis 4R-0L-4C W Prereq. MA 371 and either MA 275 or MA 276	4 hours
Math Electives	Any mathematics course numbered 300 or above, or MA 275, or MA 276	8 hours

Biomathematics Electives	Any BMTH course numbered 300 or above, or MA 482	4 hours
Technical Electives	Courses numbered 200 or above in the physical sciences, life sciences, computer science, or engineering. Coursework in mathematics and biomathematics is not allowed.	20 hours
Free Electives		12 hours
Total		**193 hours**

FOCUS AREAS

Students earning a major in Biomathematics are encouraged to gain depth in a particular mathematical or scientific area. By pursuing focused coursework in the following suggested areas, students will advance their preparation for graduate studies or careers in mathematical life sciences. Gaining depth through advanced electives also provides biomathematics students with an opportunity to apply knowledge gained through BMTH coursework. The following focus areas are illustrative examples to consider.

Applied Mathematics

BE 350 Biocontrol Systems
MA 275/375 Discrete and Combinatorial Algebra I/II
MA 332 Intro. to Computational Science [required for major]
MA 330 Vector Calculus
MA 342 Computational Modelings
MA 366 Real Analysis
MA 367 Functions of a Complex Variable
MA 436 Introduction to Partial Differential Equations
MA 472 Graph Theory
MA 491 Introduction to Mathematical Modeling

Biochemistry

BMTH 312 Bioinformatics
BMTH 310 Mathematical Biology
CHEM 251/252/253 Organic Chemistry I/II/III
CHEM 326 Bioanalytical Chemistry
CHEM 330/331 Biochemistry I/II
CHEM 430 Advanced Biochemistry

Bioinformatics & Biostatistics

BMTH 312 Bioinformatics
MA 381 Intro. to Probability with Statistics [required for major]
MA 382 Intro. to Statistics with Probability
MA 382 Engineering Statistics II
MA 386 Statistical Programming
MA 482 Bioengineering Statistics

Biomechanics

BE 361 Biomaterials
BE 525 Biomedical Fluid Mechanics
BE 534 Soft Tissue Mechanics
BE 539 Multiscale Biomechanics
BE 545 Orthopedic Biomechanics

Biophysics

PH 302 Biophysics
BE 525 Biomedical Fluid Mechanics

Cellular and Molecular Biology

BIO 220/230 Prokaryotic/Eukaryotic Cell and Molecular Biology [required for major]
BIO 205 Cellular Physiology
BIO 411 Genetic Engineering
BIO 421 Applied Microbiology
BIO 431 Genomics and Proteomics
BMTH 310 Mathematical Biology
CHEM 455 Natural Products [offered irregularly]

Computational Biology

BMTH 310 Mathematical Biology
BMTH 413 Computational Biology
CSSE 220 Object Oriented Software Development
CSSE 333 Database Systems
CSSE 403 Programming Language Paradigms
CSSE 431 Artificial Intelligence
MA/CS 335 Introduction to Parallel Computing
MA 342 Computational Modeling
MA 433 Numerical Analysis
MA 435 Finite Difference Methods
MA/CS 473 Design and Analysis of Algorithms

Ecology

BIO 130 Evolution and Diversity
BIO 264 Introduction to Environmental Science
BIO 320 Ecology
BMTH 310 Mathematical Biology

CHEM 371 Environmental Analytical Chemistry

Epidemiology & Pathology

BE 310/320 Analysis of Physiological Systems I/II
BIO 410 Infection and Immunity
BIO 441 Virology
BIO 451 Cancer Biology
BIO 461 Evolutionary Medicine
BIO 471 Genetic and Molecular Analysis of Inherited Human Disease
BMTH 310 Mathematical Biology

Evolution

BIO 130 Evolution and Diversity
BIO 330 Evolutionary Biology
BIO 461 Evolutionary Medicine
SV 386 Human Evolution

Imaging and Optics

BE 435 Biomedical Optics
ECE 480 Introduction to Image Processing
BE 541 Medical Imaging Systems
MA 429 Mathematical Methods of Image Processing
PH 302 Biophysics

Medicine

BIO 120 Comparative Anatomy and Physiology
BIO 410 Infection and Immunity
BIO 441 Virology
BIO 451 Cancer Biology
BIO 461 Evolutionary Medicine
BIO 471 Genetic and Molecular Analysis of Inherited Human Disease
BE 541 Medical Imaging Systems
CHEM 251/252/253 Organic Chemistry I/II/III
CHEM 330/331 Biochemistry I/II
CHEM 420 Advanced Biochemistry

Physiology

BIO 120 Comparative Anatomy and Physiology
BIO 205 Cellular Physiology
BE 310/320 Analysis of Physiological Systems I & II
BE 520 Introduction to Brain Machine Interfaces

SECOND MAJOR IN BIOMATHEMATICS

The second major in biomathematics is open to all majors with the following requirements and restrictions. Eligibility and limitations

- The MA/BMTH double major must be separated by at least 24 hours.

REQUIREMENTS (72 HOURS)		
Math Core	MA 221. 332, 371 or 373, 381, and 223 or 382	20 hours
Biomath Core	BMTH 311, BMTH 312, BMTH 413, and one of BMTH 301 OR BMTH 302	16 hours
Math Electives	Any mathematics course numbered 300 or above, or MA275, or MA 276	8 hours

Biomathematics Electives	Any BMTH course numbered 300 or above, or MA482	4 hours
Biology	BIO 110 and three courses from different categories described below BIO 130 BIO 120 or 210 BIO 205 or 230 BIO 220	16 hours
Senior Capstone Experience	BMTH 496, 497, 498	8 hours

MINOR IN BIOMATHEMATICS

Any student not pursuing a major or second major in biomathematics may obtain a minor in biomathematics by taking the following courses:

REQUIREMENTS (47 HOURS)		
Math Core	MA 111, 112, 113, 221, 222, and 223 or 382	27 hours
Biomath Core	any three BMTH courses numbered 300 or above	12 hours
Biology	BIO 110 and one of BIO 205, 210, 220, 230	8 hours

Approval and Biomathematics Minor Form

All minors must be approved by the biomathematics minor advisor and the student's advisor. The department has a form for the planning and approval of a biomathematics minor.

Notes and Limitations on Requirements:

- Almost all students are required to take six foundational courses as a requirement for their major; therefore only five "extra courses" are required for most students.
- Only MA 111, MA 112, MA 113, MA 221, MA 222 and one of MA 223, MA 381, or MA 382 can be counted towards any combination of the multiple minors offered by the mathematics department.
- Biomathematics courses cannot be used to count toward both Free Mathematics Electives for a mathematics major and also towards a biomathematics minor.

Plan of Study

Freshman

Fall

Course	Credit
BIO 130 Evolution and Diversity	4

CHEM 111 General Chemistry	4
MA 111 Calculus I	5
HUM H190 First-Year Writing Seminar	4
RHIT 100 Foundations for Rose-Hulman Success	1
	Total Credits: 18

Winter

Course	Credit
PH 111 Physics I	4
CHEM 113 General Chemistry II	4
MA 112 Calculus II	5
BIO 110 Cell Structure and Function	4
	Total Credits: 17

Spring

Course	Credit
CSSE 120 Intro to Software Development	4
PH 112 Physics II	4
MA 113 Calculus III	5
HSSA	4
	Total Credits: 17

Sophomore

Fall

Course	Credit
BIO 210 Mendelian & Molecular Genetics	4
MA 221 Matrix Algebra & Differential Equations I	4
HSSA	4
PH 113 or CHEM 251 Add'l Science	4
	Total Credits: 16

Winter

Course	Credit
BIO 220 Microbiology	4
MA 222 Matrix Algebra & Differential Equations II	4
MA 381 Intro. to Probability	4

HSSA	4
MA 200 Career Preparation	1
	Total Credits: 17

Spring

Course	Credit
BIO 230 Cell Biology	4
MA 371 Linear Algebra	4
HSSA	4
BMTH 301 Intro to Biomath: Continuous Models	4
	Total Credits: 16

Junior

Fall

Course	Credit
BMTH 311 Systems Biology	4
MA 382 Intro. to Statistics w/Prob	4
HSSA	4
Elective*	4
	Total Credits: 16

Winter

Course	Credit
BMTH 312 Bioinformatics	4
MA 332 Intro to Computational Sci.	4
ENGL H290 Technical & Profess. Comm.	4
Elective*	4
	Total Credits: 16

Spring

Course	Credit
BMTH Elective	4
HSSA	4
Elective*	4
Elective*	4
	Total Credits: 16

Senior

Fall

Course	Credit
BMTH 496 Capstone Experience I	2
HSSA	4
Elective*	4
Elective*	4
	Total Credits: 14

Winter

Course	Credit
BMTH 497 Capstone Experience II	4
BMTH 413 Computational Biology	4
Elective*	4
Elective*	4
	Total Credits: 16

Spring

Course	Credit
BMTH 498 Capstone Experience III	2
Elective*	4
Elective*	4
Elective*	4
	Total Credits: 14

NOTES

*Requirements:	
3 Free Electives	12 hours
2 MA Electives	8 hours
5 Tech Electives	20 hours
1 Domain Elective	4 hours

Biomathematics - Course Descriptions

BMTH 199 Professional Experience 1R-0L-1C
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

BMTH 295 Research Seminar in Biomathematics 1R-0L-1C Arranged

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

A seminar-style course that introduces novel problems in biomathematics. Problems will be drawn from the modern literature in biomathematics, computational biology, bioinformatics, systems biology, and biostatistics. This course may be taken at most twice for credit.

BMTH 301 Introduction to Biomathematics: Continuous Models 4R-0L-4C (even years) S

Prerequisites: MA 222F,W,S

Corequisites: There are no corequisites for this course.

This course requires no previous knowledge of biology. The application of differential equations and probability to modeling and analyzing dynamic biological systems. Mathematical topics include ordinary and partial differential equations, dynamical systems, bifurcations, limit cycles, chaos, and probabilistic and stochastic modeling. Biological applications may include biochemistry, cell biology, epidemiology, neuroscience, ecology, biofluids, biomaterials, diffusion, and pattern formation.

BMTH 302 Introduction to Biomathematics: Discrete Models 4R-0L-4C (odd years) S

Prerequisites: MA 113F,W,S

Corequisites: There are no corequisites for this course.

This course requires no previous knowledge of biology. The application of discrete mathematics and computational algebra for modelling biological phenomena. Topics may include: gene regulatory networks, genomics, RNA folding, neuronal networks, infectious disease modeling, phylogenetics, and/or ecological networks. Students will also use software currently used in mathematical biology research for visualization, simulation, and analysis.

BMTH 311 Systems Biology 4R-0L-4C F (even years)

Prerequisites: MA 222F,W,S

Corequisites: There are no corequisites for this course.

The study of how to combine detailed biological information to build models of entire systems. Nearly any biological scale can be considered. For example, at the biochemistry level the course will consider topics such as gene regulatory networks, protein interaction networks, and metabolisms. Moving toward larger scales, systems biology can be used to study the growth of cancerous tumors, and on an even larger scale, the mating and social structure of populations. The course's focus is on how to use relational information to perform model based inquiries of an entire system.

BMTH 312 Bioinformatics 4R-0L-4C W (even years)

Prerequisites: CSSE 120F,W,S, and MA 381F,W,S

Corequisites: There are no corequisites for this course.

This course will study how to combine mathematical, statistical, probabilistic, and computational methods to analyze biological data. Example topics are sequence alignment, locating genes, structural alignment, microarray analysis, and drug design. The course emphasizes how to search and compare biological datasets to make scientific inferences.

BMTH 413 Computational Biology 4R-0L-4C W (odd years)

Prerequisites: MA 332F,W, and either BMTH 301S or BMTH 302S or BMTH 311F (even years) or BMTH 312W (even years)

Corequisites: There are no corequisites for this course.
The study of how to build and validate computational models to conduct biological studies. Ex-emplary topics include molecular dynamics, haplotyping, phylogenetics, neuroscience, and population dynamics. The course will consider the implementation and analysis of algorithms that are specifically germane to the life sciences.

BMTH 490 Topics in Biomathematics Variable Credit
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Varies

BMTH 496 Capstone Experience I 2C F
Prerequisites: Senior standing or permission of instructor.
Corequisites: There are no corequisites for this course.
Independent study in a thesis project to be directed by a faculty member. The project and faculty adviser are to be identified prior to starting BMTH 496, and a plan of study is to be agreed upon by the student and adviser prior to the initiation of the thesis sequence. The thesis will culminate in a written report and a public presentation/ defense that will be evaluated by a thesis committee consisting of at least the adviser and two other members of the faculty. BMTH 496/497/498 must be taken in consecutive quarters.

BMTH 497 Capstone Experience II 4C W
Prerequisites: BMTH 496F
Corequisites: There are no corequisites for this course.
Independent study in a thesis project to be directed by a faculty member. The project and faculty adviser are to be identified prior to starting BMTH 496, and a plan of study is to be agreed upon by the student and adviser prior to the initiation of the thesis sequence. The thesis will culminate in a written report and a public presentation/ defense that will be evaluated by a thesis committee consisting of at least the adviser and two other members of the faculty. BMTH 496/497/498 must be taken in consecutive quarters.

BMTH 498 Capstone Experience III 2C S
Prerequisites: BMTH 497W
Corequisites: There are no corequisites for this course.
Independent study in a thesis project to be directed by a faculty member. The project and faculty adviser are to be identified prior to starting BMTH 496, and a plan of study is to be agreed upon by the student and adviser prior to the initiation of the thesis sequence. The thesis will culminate in a written report and a public presentation/ defense that will be evaluated by a thesis committee consisting of at least the adviser and two other members of the faculty. BMTH 496/497/498 must be taken in consecutive quarters.

Biomedical Engineering

Biomedical engineers use science, engineering, and mathematics to understand and solve medical problems. We focus on improving people's quality of life. Biomedical engineers who specialize in biomechanics design and analyze biological systems or medical devices that have to do with forces, stresses, and strains. This includes studying the motions of bodies or joints, fluid flow, the deformation of tissues or materials, and the transport of molecules and chemicals through tissues and across membranes.

Biomedical engineers who specialize in bioinstrumentation use electronics and signal analysis to take measurements from and deliver stimuli to living cells and tissues. Examples include cochlear implants, pacemakers, and patient monitoring equipment. Biomedical engineers who specialize in biomaterials design and study materials to replace, repair, and interact with cells and tissues in the body. Examples include metal, ceramic, polymer, or tissue-engineered implants; these implants can be permanent or biodegradable. The United States Bureau of Labor Statistics has projected that jobs for biomedical engineers will increase by 23% between the years 2014 and 2024.

The biomedical engineering program at Rose-Hulman produces engineers with the medical and biological expertise needed to solve health care problems during careers in technical and health-related industries, as well as in government or industrial laboratories. Alumni wishing to continue their studies in graduate/professional school or health professions programs will be well-qualified to do so.

Biomedical Engineering Program Educational Objectives

Objectives are defined as "expected accomplishments of graduates during the first several years following graduation from the program."

- Alumni will be applying the knowledge and/or habits of mind gained from their study of biology, physiology, mathematics, physical science, and engineering, in a fulfilling and productive manner.
- Alumni will be working and communicating effectively with all of the people around them.
- Alumni will be serving society, through their professional and/or personal activities.
- Alumni will be solving open-ended problems, drawing from their experiences in using design principles subject to constraints.

Biomedical Engineering Student Outcomes

By the time students graduate with an undergraduate Biomedical Engineering degree from Rose-Hulman, they 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.

The biomedical engineering program is accredited by the Engineering Accreditation Commission of ABET, https://www.abet.org, under the commission's General Criteria and Program Criteria for Bioengineering and Biomedical and Similarly Named Engineering Programs.

The Advanced Individualized Mission

The Advanced Individualized Mission (AIM) provides a mechanism for students to customize advanced coursework to correspond with career goals defined by the student. Plans of study for a student's AIM must be reviewed by a committee of departmental faculty as part of BE238. A final deliverable for the AIM is due as part of BE438. Alterations to the AIM plan of study must be approved by the faculty committee.

The AIM plan of study must:

1. Comprise of 24 credits
2. Have a clearly identified theme,
3. Include a biomedical engineering component or application,
4. Include a minimum of 12 credits at 400 level or above, at least 8 of which must be engineering credits.
5. Not include any named required courses

Biomedical Engineering Thesis Option:

The biomedical engineering thesis option is intended for students who complete a substantive research project in this field. In order to complete this thesis option a student must:

1. Pass a minimum of 8 credit hours of BE 492.
2. Perform research in BE492 that involves the same research project and is completed under the direction of a departmental faculty mentor. None of these credits may be used to fulfill the biomedical engineering area elective requirement.
3. Complete the course, BE 499 Thesis Research, in which the thesis is written and submitted to the department, and an oral research presentation is given to a minimum of three departmental faculty members, including the student's advisor. Successful completion of the biomedical engineering thesis will be noted on the student's transcript.

Plan of Study

Freshman

Fall

Course	Credit
BE 100 Prob Solving in the Biological Sciences & Engineering	4
BE 118 Design Thinking and Communication	2

MA 111 Calculus I	5
RHIT 100 Foundations for Rose-Hulman Success	1
HUM H190 First-Year Writing Seminar	4
	Total Credits: 16

Winter

Course	Credit
BE 121 DC Circuits	2
BE 122 Systems Accounting and Modeling I	3
BE 128 Design Thinking and Realization	3
MA 112 Calculus II	5
PH 111 Physics I	4
	Total Credits: 17

Spring

Course	Credit
BE 131 AC Circuits	2
BE 132 Systems Accounting and Modeling II	3
BE 138 Design Thinking and Human-Centered Products	3
MA 113 Calculus III	5
PH 112 Physics II	4
	Total Credits: 17

Sophomore

Fall

Course	Credit
BE 211 Circuits Sensors and Measurements	3
BE 218 Design Methodologies	3
MA 221 Matrix Algebra & Differential Equations I	4
CHEM 111 General Chemistry I	3
CHEM 111L General Chemistry Lab	1
	Total Credits: 14

Winter

Course	Credit
BE 222 Mechanics of Materials	4
BE 228 Design Leadership and Teamwork	2
MA 222 Matrix Algebra & Differential Equations II	4
CHEM 113 General Chemistry II	3
CHEM 113L General Chemistry II Lab	1
BIO 110 Cell Structure and Function	4
	Total Credits: 18

Spring

Course	Credit
BE 232 Biomechanics	3
BE 233 Biomaterials	3
BE 238 Regulatory Affairs and Product Design	4
MA 223 Engineering Statistics	4
HSSA Elective	4
	Total Credits: 18

Junior

Fall

Course	Credit
BE 314 Musculoskeletal Systems Physiology with Applications	4
BE 315 Biomedical Engineering Lab I	2
BE 318 Medical Device Research and Design	3
BIO 130 Ecology and Evolution	4
ENGL H290 Technical & Professional Communication	4
	Total Credits: 17

Winter

Course	Credit
BE 321 Biosignal Processing	4
BE 324 Neural and Endocrine Systems Physiology with Applications	4
BE 328 Capstone Design I: Designing Products for the Real World	4

HSSA Elective	4
	Total Credits: 16

Spring

Course	Credit
BE 334 Cardiovascular, Respiratory and Renal Systems Physiology with Applications	4
BE 335 Biomedical Engineering Lab II	2
BE 338 Capstone Design II: Product Design and Prototyping	4
AIM Elective	4
HSSA Elective	4
	Total Credits: 18

Senior

Fall

Course	Credit
BE 418 Capstone Design III: Product Verification and Validation	4
AIM Elective	4
AIM Elective	4
HSSA Elective	4
	Total Credits: 16

Winter

Course	Credit
BE 428 Capstone Design IV: Integrated Product Design and Practice	2
AIM Elective	4
AIM Elective	4
HSSA Elective	4
	Total Credits: 14

Spring

Course	Credit
BE 438 Engineering Portfolio Development	2
AIM Eective	4
HSSA Elective	4
HSSA Elective	4

Total Credits: 14

Biomedical Engineering - Course Descriptions

BE 100 Problem Solving in the Biological Sciences & Engineering 3R-3L-4C F
Prerequisites: BE 1st year standing or permission of instructor
Corequisites: There are no corequisites for this course.
This course introduces students to computational tools for solving problems in biology and biomedical engineering. The primary thrust of the course is structured programming in MatLab. In addition, we will explore data description, the proper presentation of data, effective use of spreadsheet tools in data analysis, and structured programming.

BE 118 Design Thinking and Communication 1R-3L-2C F
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Engineers must be able to communicate their design ideas to others. This course focuses on the improvement of communication skills, including written and oral presentation, sketching, and solid modeling. Student groups work on projects with the goal of recognizing and developing behaviors associated with consensus decision-making and cooperative teamwork. Students also learn the steps of the engineering design process and fundamental machining techniques.

BE 121 DC Circuits 1R-3L-2C W
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
This course introduces the fundamentals of DC circuit design and analysis. DC circuit analysis tools such as Kirchhoff's laws, mesh and nodal analysis, superposition, and source transformations are introduced. In conjunction with BE128, students will complete projects that utilize microcontrollers and resistive sensors to interact with their environments.

BE 122 Systems Accounting and Modeling I 3R-0L-3C W
Prerequisites: MA 111F,W
Corequisites: There are no corequisites for this course.
BE122 introduces the systems accounting and modeling approach to solving problems. Conservation of mass, linear and angular momentum, and energy will be introduced and reinforced with examples. Same as ENGD205.

BE 128 Design Thinking and Realization 2R-3L-3C W
Prerequisites: There are no prerequisites for this course.
Corequisites: BE 121 1R-3L-2C W
This course explores elements of the engineering design process as a means of enhancing students' abilities to define problems, develop and evaluate creative alternatives, and effectively present technical information.

BE 131 AC Circuits 1R-3L-2C S
Prerequisites: BE 121W or ENGD 110W
Corequisites: There are no corequisites for this course.
This course introduces the fundamentals of AC circuit design and analysis. Topics include RLC circuits, equivalent impedance, phasor domain analysis (nodal analysis, mesh current, source superposition, source transformation), and Thevenin and Norton theorems. The concept of linear systems and the use of electronic components (op-amps, capacitors, inductors) for biosignal processing applications will also be

introduced. Students may not receive credit towards graduation for both BE131 and ES213.

BE 132 Systems Accounting and Modeling II 3R-0L-3C S

Prerequisites: BE 122W or EM 121F, W, S or ENGD 205W

Corequisites: BE 131 1R-3L-2C S

A common framework for engineering analysis is extended using the concepts of a system, accounting and conservation of extensive properties, constitutive relations, constraints, and modeling assumptions. Stress, strain, and deformation under axial loading are defined. Equilibrium is defined. Conservation equations for mass, charge, momentum and energy are developed. Applications are developed from multiple engineering disciplines. Students may not receive credit towards graduation for both BE132 and ES201. Same as ENGD215.

BE 138 Design Thinking and Human-Centered Products 2R-3L-3C S

Prerequisites: There are no prerequisites for this course.

Corequisites: BE 131 1R-3L-2C S

This project-based design course focuses on ensuring that products meet the needs of their users. The course incorporates observational methods, brainstorming, prototyping, user testing, business models, and the social, marketing, and engineering constraints that impinge upon products.

BE 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

BE 211 Circuits, Sensors, and Measurements 2R-3L-3C F

Prerequisites: BE 131S, and MA 112F,W,S

Corequisites: There are no corequisites for this course.

This course introduces the concepts of biomedical signal measurement and conditioning. Topics include amplifiers, filters and A/D converters, digital logic, biomedical sensors and uncertainty analysis. Matlab is used in the context of biosignal acquisition and visualization.

BE 218 Design Methodologies 2R-3L-3C F

Prerequisites: BE 138S

Corequisites: There are no corequisites for this course.

Introduction to the philosophy and goals of various design and research processes. Hands-on projects will serve as vehicles for design thinking, visualization, and methodology.

BE 222 Mechanics of Materials 4R-0L-4C W

Prerequisites: BE 132S or EM 121F, W, S or ENGD 215S

Corequisites: There are no corequisites for this course.

Description: Strength and elastic deflection of engineering materials due to loads applied in torsion, in bending, and in shear. Shear diagrams, bending moment diagrams, and area moments of inertia. Combined stresses and principal stresses. Applications to design of beams and shafts.

BE 228 Design Leadership & Teamwork 1R-3L-2C W

Prerequisites: BE 218F
Corequisites: There are no corequisites for this course.
This project-based course will help students develop skills in decision-making, leadership, and management of complex design projects.

BE 232 Biomechanics 3R-0L-3C S

Prerequisites: BE 211F, and either BE 222W or EM 204F, S
Corequisites: There are no corequisites for this course.
This course introduces students to the various interdisciplinary fields in biomechanics - such as orthopaedic biomechanics, biofluid mechanics, soft tissue mechanics, and the biomechanics of human movement. Specific topics include: statics/dynamics of the human body, kinematics during activity; the analysis of forces and stresses/strains in biological structures under loading; constitutive models for biological materials (e.g. bone, cartilage, tendon/ligament); and the relationship between structure and function in tissues and organs. Non-majors interested in taking this course should see the instructor.

BE 233 Biomaterials 3R-0L-3C W

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Structure-property relationships for metallic, polymeric, and ceramic biomaterials. Study of the interactions of these materials with the body and factors affecting the selection and design of materials for medical implants and devices.

BE 238 Regulatory Affairs & Product Design 3R-3L-4C S

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Students will build a fundamental understanding of how the FDA regulates medical devices in the United States, with an emphasis on pathways to market. Project is in conjunction with BE232 and BE233. Includes the submission and review process of a student's AIMS for BE majors (peer, career services, faculty, advisory board approval).

BE 314 Musculoskeletal Systems Physiology with Applications 4R-0L-4C F

Prerequisites: BIO 110 F,W, and BE 232S, and BE 233W
Corequisites: BE 315 1R-3L-2C F
An analysis of muscle, bone, and soft tissue physiology/mechanics from a quantitative, system-based approach with an emphasis on clinical applications.

BE 315 Biomedical Engineering Lab I 1R-3L-2C F

Prerequisites: BE 232S, and BE 233W
Corequisites: BE 314 4R-0L-4C F
This course emphasizes the fundamental concepts in biomechanics and biomaterials with an emphasis on musculoskeletal applications. Hands-on laboratory projects will be assigned which will require the student to use standard testing equipment and basic instrumentation to execute effective test methods. Written communication of experimental results is emphasized. Non-majors interested in taking this course should see the instructor.

BE 318 Medical Device Research & Design 2R-3L-3C F

Prerequisites: BE 238S
Corequisites: There are no corequisites for this course.
In this course students collaborate with clinicians, industry partners, and/or community partners to identify unmet clinical or research needs. Based on voice of the customer

feedback, stakeholder analysis, market analysis, and evaluation of the regulatory and technical landscape, teams will refine observed needs and present them to reviewers. Projects identified to have a significant impact, a committed team, and a viable market can be continued in BE328.

BE 321 Biosignal Processing 3R-3L-4C W

Prerequisites: BE 211F

Corequisites: BE 324 3R-3L-4C W

This course introduces the fundamentals of biomedical signal processing strategies. Topics include data acquisition, A/D and D/A conversion, FIR and IIR digital filter design, time-frequency analysis, and I/O interfaces. Multichannel data processing and high dimensional data analysis techniques are also introduced. Laboratories provide practical experience on the analysis of electrophysiological data, with special emphasis on neurological signals.

BE 324 Neural and Endocrine Systems Physiology with Applications 3R-3L-4C W

Prerequisites: BIO 110 F,W, and BE 211F, and BE 314F

Corequisites: There are no corequisites for this course.

An analysis of neural and endocrine physiology from a quantitative, systems-based approach.

BE 328 Capstone Design I: Designing Products for the Real World 3R-3L-4C W

Prerequisites: BE 118F, and BE 128W, and BE 211F, and BE 228W, and BE 232S, and BE 233W, and BE 318F

Corequisites: There are no corequisites for this course.

This course begins the capstone design sequence in biomedical engineering. Student teams develop design solutions from a set of client-specified needs, establish specifications, plan the project, schedule and efficiently use resources, examine the ethics and safety in engineering design, and work within explicit (or implicit) constraints, such as social, economic, manufacturing, etc. The course culminates with the presentation of the preliminary proposal for the capstone design project in biomedical engineering.

BE 334 Cardiovascular, Respiratory, and Renal Systems Physiology with Applications 3R-3L-4C S

Prerequisites: BIO 110 F,W, and BE 314F, and BE 315F

Corequisites: There are no corequisites for this course.

An analysis of cardiovascular, pulmonary, and renal physiology from a quantitative, systems-based approach with an emphasis on biomedical applications.

BE 335 Biomedical Engineering Lab II 1R-3L-2C S

Prerequisites: BE 315F

Corequisites: There are no corequisites for this course.

This course emphasizes experimental design and execution in biomechanics, biomaterials, and fluid mechanics with an emphasis on cardiovascular applications. Laboratory experiences will require the student to use standard testing equipment and basic instrumentation to execute effective test methods. Written communication as well as experimental design and execution is emphasized. Non-majors interested in taking this course should see the instructor.

BE 338 Capstone Design II: Product Design & Prototyping 3R-3L-4C S

Prerequisites: BE 328W

Corequisites: There are no corequisites for this course.

This course is a continuation of BE328. The student teams develop prototype solutions through implementation of the design plan from the previous course. This includes development of a test plan, modifications to the design project as needed, risk assessment, and evaluation of design performance relative to initial specifications. This course culminates in the submission of a functional prototype and updated design history files.

BE 350 Biocontrol Systems 4R-0L-4C

Prerequisites: BE 211F

Corequisites: There are no corequisites for this course.

This course provides an introduction to feedback control systems. These systems will be characterized with respect to their time response, stability, and steady-state error. Design compensation will be used to improve the performance of a system. When possible, examples of biological control systems will be considered.

BE 418 Capstone Design III: Product Verification and Validation 3R-3L-4C F

Prerequisites: BE 338S

Corequisites: There are no corequisites for this course.

This course is a continuation of BE338. The student teams iterate on the initial functional prototype based on client feedback, complete testing of the prototype solutions, and transfer the project results to their client. The course culminates with the submission of a critical design document.

BE 428 Capstone Design IV: Integrated Product Design & Practice 1R-3L-2C W

Prerequisites: BE 418F

Corequisites: There are no corequisites for this course.

This course is a continuation of BE418. Student teams finalize design prototypes, reflect on future product development opportunities, and complete documentation requirements to established standards and specifications. Students participate in a mentorship program with students enrolled in BE328 and begin development of a professional design portfolio.

BE 435 Biomedical Optics 3.5R-1.5L-4C

Prerequisites: PH 113S,F,W, and MA 221F,W,S or Senior/Graduate standing or consent of instructor

Corequisites: There are no corequisites for this course.

Optical techniques for biomedical applications and health care; laser fundamentals, laser interaction with biological cells, organelles and nanostructures; laser diagnostics and therapy, laser surgery; microscopes; optics-based clinical applications; imaging and spectroscopy, biophotonics laboratories. For graduate credit, students must do additional project work on a topic selected by the instructor. Cross-listed with OE 435.

BE 438 Engineering Portfolio Development 1R-3L-2C S

Prerequisites: BE 428W

Corequisites: There are no corequisites for this course.

Students complete a portfolio showcasing their engineering design work to further a specific professional goal. Examples of professional goals include developing a career plan, pursuing patent opportunities, or establishing a business plan for a start-up. Students participate in a mentorship program with students enrolled in BE338.

BE 482 Biostatistics 4R-0L-4C

Prerequisites: MA 223F,W,S or MA 382F and consent of instructor (cross listed with MA 482)

Corequisites: There are no corequisites for this course.

Hypothesis testing and confidence intervals for two means, two proportions, and two variances. Introduction to analysis of variance to include one factor and two factors (with interaction) designs. Presentation of simple linear and multiple linear regression modeling; development of analysis of contingency table to include logistic regression. Presentation of Log odds ratio as well as several non-parametric techniques of hypothesis testing and construction of non-parametric confidence intervals and correlation coefficients. Review of fundamental prerequisite statistics will be included as necessary.

BE 491 Special Topics in Biomedical Engineering XR-0L-XC

Prerequisites: Arranged prerequisite consent of instructor

Corequisites: There are no corequisites for this course.

Covers upper-level, undergraduate material of mutual interest to student and instructor which cannot be acquired in any other listed undergraduate BE course.

BE 492 Directed Study in Biomedical Engineering XR-XL-XC

Prerequisites: Arranged prerequisite consent of instructor

Corequisites: There are no corequisites for this course.

Covers biomedical engineering material of mutual interest to the student and instructor which cannot be experienced in any other listed BE course. A student may take between 1-4 credits in any given term.

BE 499 Thesis Research 0R-6L-2C F,W,S

Prerequisites: Junior or senior standing

Corequisites: There are no corequisites for this course.

Culmination of biomedical engineering thesis research in which a student writes and submits the senior thesis, following departmentally established guidelines, and gives an oral research presentation to at least three departmental faculty members, including the student's adviser. BE499 may not be used as a biomedical engineering area elective.

BE 515 Mechanobiology 4R-0L-4C S

Prerequisites: BE 232S or consent of instructor

Corequisites: There are no corequisites for this course.

This course will discuss the role physical forces play on biological processes and how mechanical stimuli can be utilized to improve tissue engineering, regenerative medicine, and rehabilitation strategies.

BE 516 Introduction to MEMS: Fabrication & Applications 3R-3L-4C S

Prerequisites: JR or SR standing

Corequisites: There are no corequisites for this course.

Properties of silicon wafers, wafer-level processes, surface and bulk micromachining, thin-film deposition, dry and wet etching, photolithography, process integration, simple actuators. Introduction to microfluidic systems. MEMS application: capacitive accelerometer, cantilever and pressure sensor. Students enrolled in BE516 must do project work on a topic selected by the instructor. Cross-listed with CHE 505, ECE 516, EP 510, and ME 516.

BE 520 Introduction to Brain Machine Interfaces 3R-3L-4C S

Prerequisites: BE 321W or ECE 380F,W

Corequisites: There are no corequisites for this course.

This course is an introduction to the basics of motor cortical functions related to voluntary and imagery movements, evoked response potentials, invasive vs. noninvasive electrode design considerations, quantitative EEG analysis techniques used in clinical settings, and the applications of brain-machine interfaces/brain-computer interfaces in the restoration of mobility, communication and motor function.

BE 535 Biomedical Optics 4R-0L-4C W

Prerequisites: PH 113S,F,W, MA 221F,W,S and SR standing or GR standing
Corequisites: There are no corequisites for this course.
Optical techniques for biomedical applications and health care; imaging modalities; laser fundamentals, laser interaction with biological cells, organelles and nanostructures; laser diagnostics and therapy, laser surgery; microscopes; optics-based clinical applications; imaging and spectroscopy; biophotonics. Students must do additional project work on a topic selected by the instructor. Students may not receive credit for both OE 435 and OE 535. Cross-listed with OE 535.

BE 541 Medical Imaging Systems 4R-0L-4C

Prerequisites: BE 321W* or ECE 300F, S or OE 392W (every other year)** *Graduate standing; or with a grade of B or better; or consent of instructor; **with a grade of B or better or Graduate standing.
Corequisites: There are no corequisites for this course.
Engineering principles of major imaging techniques/modalities for biomedical applications and health care including diagnostic x-ray, computed tomography, nuclear techniques, ultrasound, and magnetic resonance imaging. Topics include general characteristics of medical images; physical principles, signal processing to generate an image, and instrumentation of imaging modalities. Clinical applications of these technologies are also discussed. Cross-listed with ECE584 and OE584.

BE 543 Neuroprosthetics 3R-3L-4C

Prerequisites: BE 324W, and BE 211F
Corequisites: There are no corequisites for this course.
This course takes a detailed look at the state of the art in Neuroprosthetics design and applications. Topics include electrode design, sensory prosthetics, functional electrical stimulation, deep brain stimulation and other contemporary research topics.

BE 545 Orthopaedic Biomechanics 4R-0L-4C

Prerequisites: EM 203W or EM 204F, S, and BE 222W, and BE 232S or consent of instructor
Corequisites: There are no corequisites for this course.
This course covers current topics in orthopaedic biomechanics including the application of solid mechanics principles to musculoskeletal activities, orthopaedic implants, and fracture fixation devices. Topics include joint loading; composition and mechanical behavior of orthopaedic tissues; design/analysis of artificial joints and fracture fixation prostheses; osteoporosis and osteoarthritis; and finite element modeling.

BE 550 Research Methods in Biomechanics 3R-3L-4C W

Prerequisites: BE 232S or consent of instructor
Corequisites: There are no corequisites for this course.
Focuses on the wide range of research methods used in the field of biomechanics. Current literature will be reviewed to analyze the advantages and disadvantages of various research methodologies. Topics will vary based on student interests and background, but may include topics such as motion/force analysis, soft tissue and bone mechanics, joint biomechanics, analysis of joint replacements, and fracture fixation. Laboratory activities will reinforce the lecture topics and students will have the opportunity to investigate a biomechanics research topic in their area of interest.

BE 560 Tissue-Biomaterial Interactions 4R-0L-4C

Prerequisites: BE 233W or consent of instructor
Corequisites: There are no corequisites for this course.
Addresses interactions between living cells/tissues and implant biomaterials, stressing the importance of molecular- and cellular-level phenomena in initiating and propagating clinically relevant tissue- and systemic- level results.

BE 570 Introduction to Tissue Engineering 4R-0L-4C
Prerequisites: BIO 110 F,W, and BE 233W or CHE 315F,S or ME 328W Junior, Senior, or Graduate standing or permission of instructor
Corequisites: There are no corequisites for this course.
This course provides a broad overview of the latest developments in the field of tissue engineering. Normal structure and function of tissues and organs such as bone, cartilage, nerve, skin, and liver are discussed. Methods of engineering these tissues, or encouraging healing or regeneration that would not otherwise occur, is the focus of the course. The course takes the format of a graduate seminar, with students taking an active role in presenting material to the class and leading discussions.

BE 590 Thesis Research Credits as assigned F,W,S
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Credits as assigned: however, not more than 12 credits will be applied toward the requirements of an M.S. degree.

BE 597 Selected Topics Credits as assigned F,W,S
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Selected Topics for Graduate Students Credits as assigned. Maximum 4 credits per term.

Chemical Engineering

As has been done since we awarded the nation’s first degree in chemical engineering in 1889, the undergraduate program in chemical engineering undertakes to prepare individuals for careers in the chemical process industries. These include all industries in which chemical and energy changes are an important part of the manufacturing process, such as the petroleum, rubber, plastics, synthetic fiber, pulp and paper, fermentation, soap and detergents, glass, ceramic, photographic and organic and inorganic chemical industries. In view of the dynamic nature of this technology, the course of study stresses fundamental principles rather than technical details. It prepares the student either for advanced study at the graduate level or for immediate entrance into industry. Opportunities in the process industries are found in a variety of activities, including design, development, management, production, research, technical marketing, technical service, or engineering.

Mission: The mission of the Department of Chemical Engineering at Rose-Hulman Institute of Technology is to provide an excellent chemical engineering education through a combination of theory and practice that prepares students for productive professional careers including postgraduate studies.

Program Educational Objectives

Program Educational Objectives are broad statements that describe what graduates are expected to attain within a few years of graduation.

- Our graduates will attain a promotion and/or responsibilities beyond their entry-level position, or progress toward the completion of an advanced degree.
- Our graduates will continue to develop professionally.
- Our graduates will collaborate professionally within or outside of their organizations at a regional, national and/or international level.

Student Outcomes

Student Outcomes are statements that describe what students are expected to have by the time of graduation.

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

Curriculum

The curriculum covers a breadth of fundamental principles so that the chemical engineering graduates have a working knowledge of advanced chemistry, material and energy balances applied to chemical processes; thermodynamics; heat, mass, and momentum transfer; chemical reaction engineering; separation operations, process design and control. The program provides students with appropriate modern experimental and computing techniques in unit operation laboratory and requires them to work in teams and submit written and oral reports on their laboratory projects. A capstone experience in senior year gives students an opportunity to integrate their knowledge. Also included is the study of health, safety, environmental and ethical issues in the chemical engineering profession.

Graduate work leading to the degrees of Master of Science in chemical engineering or Master of Chemical Engineering provides a more thorough understanding of the discipline and enhances a student's ability to handle complex problems. A thesis is required for the Master of Science degree, but not for the Master of Chemical Engineering degree. Most recent graduate students have chosen research topics in biotechnology, polymers, or automatic control, but other specialties also are possible.

The chemical engineering program is accredited by the Engineering Accreditation Commission of ABET, https://www.abet.org, under the commission’s General Criteria and Program Criteria for Chemical, Biochemical, Biomolecular, and Similarly Named Engineering Programs.

CHEMICAL ENGINEERING

Depending on the students' schedules, elective courses may be taken in terms other than the ones designated.

Electives

Chemical Engineering students must complete 28 credits of electives in humanities and social sciences in addition to HUM H190 and ENGL H290. They are also required to take 24 credits of electives (8 credits of CHE electives, 8 credits of approved electives and 8 credits of free electives) in addition to the humanities and social sciences mentioned above. The courses listed below qualify as a CHE elective. In very specific circumstances, independent projects or other courses may qualify as a CHE elective if approved by the department.

CHE 310 Numerical Methods for Chemical Engineers
CHE 405 Introduction to MEMS: Fabrication and Applications
CHE 419 Advanced MEMS: Modeling and Packaging
CHE 430 Petrochemical Processes
CHE 441 Polymer Engineering
CHE 460 Particle Technology
CHE 461 Unit Operations in Environmental Engineering
CHE 462 Membrane Separations
CHE 465 Energy and the Environment
CHE 470 Safety, Health, and Loss Prevention
CHE 502 Transport Phenomena
CHE 504 Advanced Reactor Design
CHE 513 Advanced Thermodynamics
CHE 515 Nanomaterials Science and Engineering
CHE 525 Process Analytics
CHE 530 Petrochemical Processes
CHE 540 Advanced Process Control
CHE 545 Introduction to Biochemical Engineering
CHE 546 Bioseparations
CHE 562 Advanced Wastewater Treatment
CHE 563 Advanced Water Treatment

A minimum of eight credits, designated as approved electives, must be approved by the student's academic advisor. Approved electives can be chosen from economics, engineering, engineering management, mathematics (including biomathematics), or science courses. Students are encouraged to use their electives to focus their studies in a particular subject area.

The chemical engineering profession is rapidly changing and knowledge of specialty areas has become essential in the real world. Technical elective courses are intended to provide an opportunity to introduce students to a specialty area in science and engineering and help them to expand their knowledge and expertise in new areas of chemical engineering. Although it is recommended that a minimum of eight credit hours be focused in one subject area, students are encouraged to focus most or all of the 20 credit hours of electives in a particular subject area. In many cases students can use their electives to take a package of courses toward an area minor such as, biochemical engineering, applied biology, biomedical engineering, chemistry, environmental engineering, toward a certificate in semiconductor materials and devices, or toward an area of concentration (see below).

Undergraduate students have the opportunity to work on a research project under the guidance of one of the departmental faculty members. Students who are interested in learning about research should talk to members of the faculty to define a project of mutual interest and then enroll in CHE499, Directed Research. Credit hours of CHE499 can count toward an approved elective.

Minor in Chemical Engineering

The minor in chemical engineering is designed to introduce principles of chemical engineering to students majoring in other disciplines. Participation in this minor will help students to understand chemical engineering aspects of industrial processes and enter a graduate program in chemical engineering if they desire.

Students who complete the minor in chemical engineering during their sophomore and junior years open the possibility of taking some chemical engineering electives during their senior years.

The minor in chemical engineering has the following requirements:

CHE 201 Conservation Principles and Balances or equivalent
CHE 202 Basic Chemical Process Calculations
CHE 301 Fluid Mechanics or equivalent
CHE 303 Chemical Engineering Thermodynamics or equivalent
CHE 304 Multi-Component Thermodynamics
CHE 320 Fundamentals of Heat and Mass Transfer
CHE 321 Applications of Heat and Mass Transfer or equivalent

Completion of a minimum of 12 credit hours of courses with prefix CHE at 300 level or above is required toward the minor. Students interested in the CHE minor should consult the CHE Department Head and receive approval for equivalent courses to be considered.

Minor in Biochemical Engineering

The biochemical engineering minor provides students the ability to apply CHE principles to design and model biochemical systems. Applications include bioprocess design (e.g. chemical and pharmaceutical production), drug delivery, pharmacokinetics, genetic engineering, and synthetic biology.

To successfully complete a minor in Biochemical Engineering, a student must complete the following:

Four required courses:

- BIO110 - Cell Structure and Function
- CHEM330 - Biochemistry
- CHE545 - Introduction to Biochemical Engineering
- CHE 546 - Bioseparations

Elective courses totaling at least 8 credit hours taken from the following list (no more than 4 credit hours of electives chosen for the biochemical engineering minor can be used towards fulfilling the requirements of another minor program):

- BIO210 - Mendelian and Molecular Genetics
- BIO220 - Microbiology
- BIO230 - Cell Biology
- BIO411 - Genetic Engineering
- BIO421 - Applied Microbiology

- CHEM331 - Biochemistry II
- CHEM430 - Advanced Biochemistry
- CHEM433 - Biochemistry Lab (*recommended but not required for students who take CHEM430 - note that the CHEM433 course is only 1 credit*)
- CHEM532 - Biochemical Pharmacology
- MA482/BE482 - Biostatistics*
- BMTH301 - Introduction to Biomathematics:Continuous Models*
- BMTH302 - Introduction to Biomathematics: Discrete Models*
- BMTH311 - Systems Biology*
- BMTH312 - Bioinformatics*

* Only 4 credits of electives towards the minor may come from credits listed or cross-listed as MA or BMTH.

Other appropriate courses, typically biology or chemistry courses at the 400- or 500-level, may be used to fulfill the minor’s elective requirements with prior approval of the chemical engineering department head.

AREAS OF CONCENTRATION

Although it is not a requirement, students may pursue a concentration in one or more of the following areas. Students who complete the requirements of a concentration may receive, upon request, a letter from the Department Head that attests to the fact that the requirements have been completed. With proper planning, a student should be able to complete the requirements for an area of concentration without overload.

Advanced Chemical Engineering Analysis

Students need to take CHE 502 (Transport Phenomena) and 3 additional courses from the list below. Other courses may be substituted only with prior approval by the Department Head. No more than two courses with a MA prefix may be applied towards the concentration.

- CHE 310 Numerical Methods or MA 332 Introduction to Computational Science
- CHE 499 Directed Research (4 credit hours)
- CHE 504 Advanced Reactor Design
- CHE 513 Advanced Thermodynamics
- MA 336 Boundary Value Problems
- MA 371 Linear Algebra I or MA 373 Applied Linear Algebra for Engineers
- MA 438 or MA 538 Advanced Engineering Mathematics

Energy Production and Utilization

Students need to take 4 courses from the list below. Other courses may be substituted only with approval of the Department Head.

- CHE 465 Energy and the Environment*
- CHE 430/530 Petrochemical Processes*
- ECE 204 AC Circuits**
- ECE 371 Sustainable Energy Systems***
- ME 407 Power Plants
- ME 408 Renewable Energy
- ME 411 Propulsion Systems
- ME 450 Combustion

- PH 265 Fundamentals of Nuclear Physics & Radiation

* At least one of these courses is required in order to earn the concentration.
** PH113 is a prerequisite.
*** PH113 and ECE204 are prerequisites.

Industrial and Process Engineering

Students need to take CHE 470 (Safety, Health, and Loss Prevention), either CHE 540 (Advanced Process Control) or CHE 525 (Process Analytics), 2 courses from the Statistics and Modeling list below, and 1 course from the Engineering Management Electives list below. Other courses may be substituted only with approval of the Department Head.

Statistics and Modeling

- EMGT 445 Quality Methods
- EMGT 446 Statistical Methods in Six Sigma
- MA 487 Design of Experiments
- MA 444 Deterministic Models in Operations Research

Engineering Management Electives

- EMGT524 Production/Operations Management
- EMGT527 Project Management
- EMGT562 Risk Analysis and Management
- EMGT581 Multi-objective Optimization
- EMGT586 Supply Chain Management
- EMGT587 Systems Engineering
- EMGT588 Quality Management I
- EMGT589 Manufacturing Systems

Plan of Study

Freshman (A1 Schedule)

Fall

Course	Credit
CHEM 111 General Chemistry I	4
RHIT 100 Foundations for Rose-Hulman Success	1
MA 111 Calculus I	5
HUM H190 First-Year Writing Seminar	4
	Total Credits: 14

Winter

Course	Credit
CHEM 113 General Chemistry II	4
MA 112 Calculus II	5

PH 111 Physics I	4	
HSSA Elective	4	
		Total Credits: 17

Spring

Course	Credit	
CHE 110 Programming & Computation for Chemical Engineers	2	
CHEM 115 General Chemistry III	4	
EM 103 Introduction to Design	2	
MA 113 Calculus III	5	
PH 112 Physics II	4	
		Total Credits: 17

Sophomore (A1 Schedule)

Fall

Course	Credit	
CHE 200 Career Preparation I	0	
CHE 201 Conservation Principles & Balances	4	
CHEM 251 Organic Chemistry I	3	
CHEM 251L Organic Chemistry I Lab	1	
MA 221 Matrix Algebra & Differential Equations I	4	
HSSA Elective	4	
		Total Credits: 16

Winter

Course	Credit	
CHE 202 Basic Chemical Process Calculations	4	
CHEM 252 Organic Chemistry II	3	
CHEM 252L Organic Chemistry II Lab	1	
MA 222 Matrix Algebra & Differential Equations II	4	
HSSA Elective	4	
		Total Credits: 16

Spring

Course	Credit	
CHE 301 Fluid Mechanics	4	

CHE 303 Chemical Engineering Thermodynamics	4
MA 223 Engineering Statistics I	4
HSSA Elective	4
	Total Credits: 16

Junior (A1 Schedule)

Fall

Course	Credit
CHE 304 Multi-Component Thermodynamics	4
CHE 320 Fundamentals of Heat and Mass Transfer	4
CHE 315 Materials Science	4
CHEM 225 Analytical Chemistry I	4
	Total Credits: 16

Winter

Course	Credit
CHE 321 Applications of Heat & Mass Transfer	4
CHEM 360 Intro Physical Chemistry	4
CHE 340 Process Control	4
ENGL H290 Technical and Professional Communication	4
	Total Credits: 16

Spring

Course	Credit
CHE 404 Kinetics & Reactor Design	4
CHE 411 Chemical Engineering Lab I	3
ES 213 Electrical Systems	3
ES 213L Electrical Systems Lab	1
Elective (Free)	4
	Total Credits: 15

Senior (A1 Schedule)

Fall

Course	Credit
CHE 409 Professional Practice	1

CHE 412 Chemical Engineering Lab II	4	
CHE 416 Design I	4	
Elective (Free)	4	
Elective (CHE)	4	
		Total Credits: 17

Winter

Course	Credit	
CHE 413 Chemical Eng. Lab III	4	
CHE 417 Design II	4	
Elective (Approved)	4	
HSSA Elective	4	
		Total Credits: 16

Spring

Course	Credit	
CHE 418 Design III	2	
HSSA Elective	4	
HSSA Elective	4	
Elective(Approved)	4	
Elective(CHE)	4	
		Total Credits: 18

Freshman (A2 Schedule)

Fall

Course	Credit	
CHEM 111 General Chemistry I*	4	
RHIT 100 Foundations for Rose-Hulman Success	1	
MA 111 Calculus I	5	
HUM H190 First-Year Writing Seminar	4	
		Total Credits: 14

Winter

Course	Credit	
CHEM 113 General Chemistry II*	4	
MA 112 Calculus II	5	
PH 111 Physics I	4	
HSSA Elective	4	
		Total Credits: 17

Spring

Course	Credit
CHE 110 Programming & Computation for Chemical Engineers	2
CHEM 115 General Chemistry III	4
EM 103 Introduction to Design	2
MA 113 Calculus III	5
PH 112 Physics II	4
	Total Credits: 17

Sophomore (A2 Schedule)

Fall

Course	Credit
CHE 200 Career Preparation I	0
CHE 201 Conservation Principles and Balances	4
CHEM 251 Organic Chemistry I	3
CHEM 251L Organic Chemistry I Lab	1
MA 221 Matrix Algebra & Differential Equations I	4
HSSA Elective	4
	Total Credits: 16

Winter

Course	Credit
CHE 202 Basic Chemical Process Calculations	4
CHEM 252 Organic Chemistry II	3
CHEM 252L Organic Chemistry II Lab	1
MA 222 Matrix Algebra & Differential Equations II	4
HSSA Elective	4
	Total Credits: 16

Spring

Course	Credit
MA 223 Engineering Statistics I	4
CHEM 225 Analytical Chemistry I	4
HSSA Elective	4
CHE 315 Materials Science	4

	Total Credits: 16

Junior (A2 Schedule)

Fall

Course	Credit
CHE 301 Fluid Mechanics	4
CHE 303 Chemical Engineering Thermodynamics	4
CHE 340 Process Control	4
ENGL H290 Technical & Professional Communication	4
	Total Credits: 16

Winter

Course	Credit
CHE 304 Multi-Component Thermodynamics	4
CHE 320 Fundamentals of Heat & Mass Transfer	4
ES 213 Electrical Systems	3
ES 213L Electrical Systems Lab	1
HSSA Elective	4
	Total Credits: 16

Spring

Course	Credit
CHE 321 Applications of Heat & Mass Transfer	4
CHE 411 Chemical Engineering Lab I	3
CHEM 360 Intro Physical Chemistry	4
Elective (Free)	4
	Total Credits: 15

Senior (A2 Schedule)

Fall

Course	Credit
CHE 404 Kinetics & Reactor Design	4
CHE 409 Professional Practice	1
CHE 412 Chemical Engineering Lab II	4
CHE 416 Design I	4

Elective (Free)	4
	Total Credits: 17

Winter

Course	Credit
CHE 413 Chemical Eng. Lab III	4
CHE 417 Design II	4
Elective (Approved)	4
HSSA Elective	4
	Total Credits: 16

Spring

Course	Credit
CHE 418 Design III	2
HSSA Elective	4
Elective(CHE)	4
Elective(CHE)	4
Elective(Approved)	4
	Total Credits: 18

Chemical Engineering - Course Descriptions

CHE 110 Programming & Computation for Chemical Engineers 2R-0L-2C S

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
An introduction to problem solving and structured programming concepts using spreadsheets and computational software. Spreadsheet applications include graphical analysis, curve-fitting, parameter estimation, numerical differentiation and integration, solution of systems of algebraic (linear and nonlinear) equations and ordinary differential equations.

CHE 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

CHE 200 Career Preparation I 1R-0L-0C F

Prerequisites: There are no prerequisites for this course.
Corequisites: CHE 201 4R-0L-4C F
Career choices in chemical engineering. Internships and co-ops. Resume preparation. Interview skills.

CHE 201 Conservation Principles and Balances 4R-0L-4C F

Prerequisites: MA 113F,W,S, PH 111F,W, and either CHEM 113W,S or concurrent registration in CHEM 112
Corequisites: There are no corequisites for this course.
An introduction to engineering calculations, the use of common process variables, and conservation and accounting of extensive properties as a common framework for engineering analysis and modeling. Applications of conservation of mass and energy in the analysis of non-reactive chemical engineering processes will be addressed. There will be an introduction to equipment, flowcharts, techniques and methodologies used by practicing chemical engineers.

CHE 202 Basic Chemical Process Calculations 4R-0L-4C W
Prerequisites: CHE 201F, and MA 221F,W,S
Corequisites: There are no corequisites for this course.
The course continues to develop concepts from CHE 201 and provides a more extensive treatment of energy balances. Applications of the principles of conservation of mass and energy to reactive and transient systems will also be addressed.

CHE 290 Special Topics in Chemical Engineering Variable See Dept
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Topics of current interest in chemical engineering.

CHE 301 Fluid Mechanics 4R-0L-4C F,S
Prerequisites: CHE 201F, and MA 221F,W,S
Corequisites: There are no corequisites for this course.
Physical properties of fluids, fluid statics, laminar and turbulent flow. Design of pipe networks and pumps. Fluid flow as momentum transport. Flow through porous media. Non-Newtonian fluid flow. Flow past objects and boundary layer concept. Emphasis is placed on general methods of analysis applicable to any fluid.

CHE 303 Chemical Engineering Thermodynamics 4R-0L-4C F,S
Prerequisites: CHE 202W, and MA 221F,W,S
Corequisites: CHE 110 2R-0L-2C S
First and second laws of thermodynamics and their application including thermodynamic cycles, closed and open systems. Thermodynamic properties of pure components. Phase equilibria of pure components. Equations of state, state diagrams. Thermodynamic analysis of processes.

CHE 304 Multi-Component Thermodynamics 4R-0L-4C F,W
Prerequisites: CHE 303F,S, and MA 222F,W,S
Corequisites: There are no corequisites for this course.
Properties of mixtures. Phase equilibria for mixtures. Equations of state and activity coefficient models. Chemical reaction thermodynamics. Thermodynamic analysis of processes. Study of phase equilibria involving the use of a process simulator.

CHE 310 Numerical Methods for Chemical Engineers 4R-0L-4C See Department
Prerequisites: CHE 110S, and MA 222F,W,S or concurrent enrollment
Corequisites: There are no corequisites for this course.
The objective of this course is to learn the fundamentals of several important numerical methods and how to apply them to solve chemical engineering problems. This will include the study of algorithms to solve systems of algebraic and differential equations, toperform numerical integration, to apply linear and nonlinear regression techniques, and to perform stochastic Monte Carlo simulations. Matlab and Excel will be used as the programming and computing software.

CHE 315 Materials Science and Engineering 4R-0L-4C F,S

Prerequisites: CHEM 115W, S or consent of instructor
Corequisites: There are no corequisites for this course.
Introduction to the properties and processing of metals, ceramics, polymers, and semiconductors. The influences of crystal structure, interatomic bonding, and electronic structure on physical, mechanical, and electrical properties are emphasized. Causes and mitigation of various types of corrosion are explored. Properties and design of composite materials are introduced.

CHE 320 Fundamentals of Heat & Mass Transfer 4R-0L-4C F,W

Prerequisites: CHE 202W, and CHE 301F,S, and MA 222F,W,S
Corequisites: CHE 304 4R-0L-4C F,W
Discussion of fundamental heat and mass transfer principles: conduction, forced and free convection, radiation, and diffusion. Mathematical analysis and computation of heat transfer, mass transfer, temperature, and concentration profiles in systems with simple geometries. Finite difference equations. Estimation of local and overall heat and mass transfer coefficients.

CHE 321 Applications of Heat & Mass Transfer 4R-0L-4C W,S

Prerequisites: CHE 320F,W, and CHE 304F,W
Corequisites: There are no corequisites for this course.
Use, design, and selection of heat exchangers and heat exchange systems for various applications in the chemical process industries. Study of gas-liquid and liquid-liquid mass transfer operations including gas absorption, extraction, and distillation in equilibrium staged tray columns and packed columns. Quantitative treatment of mass transfer based on material and energy balances, phase equilibrium, and rates of heat and mass transfer. Applications of radiation heat transfer, boiling, and condensation.

CHE 340 Process Control 4R-0L-4C F, W

Prerequisites: CHE 202W, and MA 222F,W,S
Corequisites: There are no corequisites for this course.
The mathematics of process dynamics, control system design, Laplace transforms, feedback control theory, characteristics of sensors, transmitters and control elements, stability criteria, and frequency response. Use of control design software is emphasized.

CHE 404 Reaction Engineering 4R-0L-4C F,S

Prerequisites: CHEM 360W,S, and CHE 304F,W
Corequisites: There are no corequisites for this course.
The course covers the analysis of various reactors including batch and continuous types for homogenous and heterogeneous reactions, single reactions, multiple reactions, reactor cascades, and temperature effects. Computer methods and software for chemical reaction engineering are used.

CHE 405 Introduction to MEMS: Fabrication & Applications 3R-3L-4C S

Prerequisites: and Junior or Senior standing
Corequisites: There are no corequisites for this course.
Properties of silicon wafers, wafer-level processes, surface and bulk micromachining, thin-film deposition, dry and wet etching, photolithography, process integration, simple actuators. Introduction to microfluidic systems. MEMS applications: capacitive accelerometer, cantilever and pressure sensor. Cross-listed with ECE 416, EP 410, and ME 416.

CHE 409 Professional Practice 1R-0L-1C F

Prerequisites: Senior standing in Chemical Engineering

Corequisites: There are no corequisites for this course.
Topics on professional practice, ethics, and contemporary and global issues in the profession are discussed.

CHE 411 Chemical Engineering Laboratory I 2R-3L-3C S

Prerequisites: CHEM 225F,S, and CHEM 252W,S, and CHE 321W,S*, and MA 223F,W,S, and ENGL H290F, W, S
Corequisites: There are no corequisites for this course.
Principles underlying momentum, mass and energy transfer and the applications of equipment used to accomplish such transfer, introduction to laboratory concepts in data collection, record keeping, interpretation and analysis, and instrumentation including experimental error analysis, regression, model formulation, experimental design, and instrumentation. Written and oral reports are required. Formal instruction on written and oral communication will be provided.

CHE 412 Chemical Engineering Laboratory II 2R- 6L-4C F

Prerequisites: CHE 321W,S, and CHE 411S or consent of instructor
Corequisites: CHE 404 4R-0L-4C F,S
Continuation of principles underlying momentum, mass and energy transfer with some emphasis on kinetics, applications of equipment used to accomplish such transfer.

CHE 413 Chemical Engineering Laboratory III 2R- 6L-4C W

Prerequisites: CHE 412F
Corequisites: There are no corequisites for this course.
Continuation of CHE 412 with further development of hands-on laboratory skills.

CHE 416 Chemical Engineering Design I 4R-0L-4C F

Prerequisites: CHE 321W,S
Corequisites: There are no corequisites for this course.
Introduction to the design process; gross profit analysis; simulation to assist in process creation; synthesis of separation trains; design of separation equipment.

CHE 417 Chemical Engineering Design II 4R-0L-4C W

Prerequisites: CHE 416F, and CHE 404F,S
Corequisites: There are no corequisites for this course.
Design of reactor-separator-recycle networks; heat and power integration; batch process scheduling; annual costs, earnings and profitability; preliminary work on a capstone design project.

CHE 418 Chemical Engineering Design III: Capstone Design Project 0R-6L-2C S

Prerequisites: CHE 417W or consent of instructor
Corequisites: There are no corequisites for this course.
Completion of an open-ended design project that will include written and oral communication of intermediate results and a final written report.

CHE 419 Advanced MEMS: Modeling & Packaging 3R-3L-4C F

Prerequisites: EP 410S or equivalent (See EP 411/511.)
Corequisites: There are no corequisites for this course.
Design process, modeling; analytical and numerical. Actuators; dynamics and thermal issues. Use of software for layout and simulation. Characterization and reliability of MEMS devices. Electrical interfacing and packaging of MEMS. Microsensors, microfluidic systems, applications in engineering, biology, and physics. Students enrolled in CHE 419/519, must do project work on a topic selected by the instructor. Cross-listed with EP 411, and ECE 419.

CHE 430 Petrochemical Processes 4R-0L-4C See Department

Prerequisites: CHE 321W,S or consent of instructor

Corequisites: There are no corequisites for this course.

Multicomponent separation of petroleum by flash vaporization. Processes for production of lighter petroleum products from heavier derivatives. Production of petrochemicals from natural gas or other fossil fuels. Projects and presentations on refinery and petrochemical processes. Material balances and economic evaluations of refinery processes. Cross listed with CHE 530. Students cannot earn credit for both CHE 430 and CHE 530.

CHE 441 Polymer Engineering 4R-0L-4C SeeDept

Prerequisites: CHE 404F,S*, and CHEM 251F,W or consent of instructor

Corequisites: There are no corequisites for this course.

Interrelation of polymer structure, properties and processing. Polymerization kinetics. Methods for molecular weight determination. Fabrication and processing of thermoplastic and thermosetting materials. Student projects.

CHE 460 Particle Technology 4R-0L-4C See Department

Prerequisites: CHE 202W, and CHE 301F,S

Corequisites: There are no corequisites for this course.

Introduction to the fundamentals of particle technology including particle characterization, transport, sampling, and processing. Students will learn about the basic design and scale-up of some industrial particulate systems (including fluidized beds, mixers, pneumatic conveying systems, cyclone separators, and hoppers) as well as environmental and safety issues related to particulate handling.

CHE 462 Membrane Separations 4R-0L-4C See Dept

Prerequisites: CHE 320F,W or CE 460S

Corequisites: There are no corequisites for this course.

Introduction to transport mechanisms underlying membrane separations and associated industrial processes. Basic design parameters, applications, and limitations will be discussed for several membrane separation methods including reverse osmosis, ultrafiltration, microfiltration, and gas separations. Particular focus on current topics such as membrane fabrication, module design, and challenges to commercial implementation. This course will contain hands-on demonstrations and projects.

CHE 465 Energy and the Environment 4R-0L-4C See Department

Prerequisites: CHE 303F,S or CHEM 361F or CE 205F or ME 301F,W or consent of instructor

Corequisites: There are no corequisites for this course.

This is a survey course in which the energy needs of the world, the ways in which those needs are currently being met, the development and current usage of renewable energy, and the impact of these on the environment, specifically the impact on climate change, are examined. Life cycle analysis is also considered.

CHE 470 Safety, Health, and Loss Prevention 4R-0L-4C See Department

Prerequisites: CHE 320F,W

Corequisites: There are no corequisites for this course.

Fundamentals of chemical process safety including toxicology, industrial hygiene, toxic release and dispersion models, fires and explosions, designs and procedures to prevent fires and explosions. Overview of federal regulations governing the chemical process industries.

CHE 490 Special Topics in Chemical Engineering Variable See Dept

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Topics of current interest in chemical engineering.

CHE 499 Directed Research Variable Credit F,W,S

Prerequisites: consent of instructor
Corequisites: There are no corequisites for this course.
A special project is assigned to or selected by the student. The publication of research is encouraged. Variable credit. May be repeated up to a maximum of eight credits.

CHE 502 Transport Phenomena 4R-0L-4C S

Prerequisites: CHE 320F,W
Corequisites: There are no corequisites for this course.
Most of the course focuses on the derivation, simplification, and solution of the equations of change for momentum, energy, and mass transport. Mathematical determination of velocity profiles and momentum flux for isothermal, laminar flows in both steady and unsteady systems will be covered. Mathematical determination of temperature profiles and heat flux, and concentration profiles and mass flux both in solids and in laminar flows will also be covered. Boundary layer theory will be discussed. Turbulent flow theories may also be addressed.

CHE 504 Advanced Reaction Engineering 4R-0L-4C W

Prerequisites: CHE 404F,S
Corequisites: There are no corequisites for this course.
The course covers strategies for modeling non-ideal reactors and more complex reaction systems. Advanced topics in chemical reactions are analyzed with computer methods and software for reaction engineering.

CHE 505 Introduction to MEMS: Fabrication & Applications 3R-3L-4C S

Prerequisites: Junior or Senior class standing
Corequisites: There are no corequisites for this course.
Properties of silicon wafers; wafer-level processes, surface and bulk micromachining, thin-film deposition, dry and wet etching, photolithography, process integration, simple actuators. Introduction to microfluidic systems. MEMS applications: capacitive accelerometer, cantilever and pressure sensor. Cross-listed with BE 516, ECE 516, EP 510, and ME 516.

CHE 513 Advanced Chemical Engineering Thermodynamics 4R-0L-4C F

Prerequisites: CHE 304F,W
Corequisites: There are no corequisites for this course.
Review of thermodynamic principles including fundamental equations and the laws of thermodynamics. Thermodynamics of mixtures, phase equilibria, and thermodynamic analysis of processes. Project based in-depth study of phase equilibria, equations of state, and activity coefficient models. Use of process simulator for phase equilibria calculations. Introduction to statistical thermodynamics.

CHE 515 Nanomaterials Science & Engineering 4R-0L-4C See Department

Prerequisites: CHE 315F,S or ME 328W or BE 233W or EP 280W Junior Standing
Corequisites: There are no corequisites for this course.
Current research trends and industrial activity in the field of nanotechnology. Contains an overview of nanoscale characterization and production methods and emphasizes the roles that chemical functionality, thermodynamics, and physics play in determining the unique properties of nanoscale materials systems. Independent student reviews of current research literature form an integral part of the course.

CHE 519 Advanced MEMS: Modeling & Packaging 3R-3L-4C F

Prerequisites: EP 410S or equivalent course
Corequisites: There are no corequisites for this course.
Design process, modeling; analytical and numerical. Actuators; dynamics and thermal issues. Use of software for layout and simulation. Characterization and reliability of MEMS devices. Electrical interfacing and packaging of MEMS. Microsensors, microfluidic systems, applications in engineering, biology, chemistry, and physics. Cross-listed with EP 511, ME 519, and ECE 519.

CHE 525 Process Analytics 4R-0L-4C See Department

Prerequisites: There are no prerequisites for this course.
Corequisites: CHE 411 2R-3L-3C S
Introduction to methodologies used to collect, process, and store data from highly connected systems for applications in making informed engineering decisions. Students will learn about modern industrial control system architecture, data storage and time series databases, asset management, processing of streaming data, and decision making over various time scales.

CHE 530 Petrochemical Processes 4R-0L-4C See Department

Prerequisites: CHE 321W,S or consent of instructor
Corequisites: There are no corequisites for this course.
Multicomponent separation of petroleum by flash vaporization. Processes for production of light petroleum products from heavier derivatives. Production of petrochemicals from natural gas or other fossil fuels. Projects, presentations on refinery and petrochemical processes. Material balances and economic evaluations of the refinery processes. Projects and other assignment requirements will be adjusted to the course level. Students must do additional independent work. Cross listed with CHE 430. Students cannot earn credit for both CHE 430 and CHE 530.

CHE 540 Advanced Process Control 4R-0L-4C Not Offered

Prerequisites: CHE 340F, W and consent of instructor
Corequisites: There are no corequisites for this course.
Control topics beyond those covered in CHE 440. Topics will be selected from among the following: advanced control using cascade, feed forward, nonlinear, and adaptive control; multivariable systems including RGA analysis and decoupling; a major control system design and implementation project using a modern distributed control system.

CHE 545 Introduction to Biochemical Engineering 4R-0L-4C W

Prerequisites: BIO 110 F,W, and CHEM 330F,S, and CHE 404F,S or ES 201F,W or BE 132S or consent of instructor
Corequisites: There are no corequisites for this course.
Survey course introducing biochemical terminology and processes. Enzyme kinetics, cellular genetics, biochemical transport phenomena, and design and operation of biochemical reactors. Emphasis on applying engineering principles to biochemical situations.

CHE 546 Bioseparations 4R-0L-4C S

Prerequisites: BIO 110 F,W, and CHE 321W,S or ES 201F,W or consent of instructor
Corequisites: There are no corequisites for this course.
An analysis of bioseparation processes. Filtration, centrifugation, adsorption, electrophoresis, and chromatography are the primary topics of the course. Applications are emphasized.

CHE 562 Advanced Wastewater Treatment 4R-0L-4C See Dept

Prerequisites: CE 460S
Corequisites: There are no corequisites for this course.
Covers the theory, design and analysis of biological processes for the treatment of wastewater. Treatment processes include suspended and attached growth processes, aerobic and anaerobic processes, biological nutrient removal, aeration and gas transfer, and biosolids processing. Cross-listed with CE 562.

CHE 563 Advanced Water Treatment 4R-0L-4C See Dept

Prerequisites: CE 460S
Corequisites: There are no corequisites for this course.
Covers the theory, design and analysis of physical and chemical processes for the treatment of drinking water. Treatment processes include coagulation and flocculation, gravity separation, granular and membrane filtration, disinfection, air stripping, adsorption, ion exchange, and disinfection. Cross listed with CE 563.

CHE 590 Special Topics in Chemical Engineering 4R-0L-4C F,W,S

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Topics of current interest in chemical engineering. May be repeated.

CHE 597 Special Projects in Chemical Engineering Variable Credit F,W,S

Prerequisites: consent of instructor
Corequisites: There are no corequisites for this course.
A special project, or series of problems, or research problem is assigned to or selected by the student. A comprehensive report must be submitted at the conclusion of the project. Not to be used as a substitute for CHE 599, Thesis Research. Variable credit. May be repeated up to a maximum of eight credits.

CHE 598 Graduate Seminar 1R-0L-0C F,W,S

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Selected topics in chemical engineering are discussed by graduate students, faculty, and guest speakers.

CHE 599 Thesis Research As assigned F,W,S

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Graduate students only. Credits as assigned; however, not more than 12 credits will be applied toward the requirements of the M.S. degree.

CHE 699 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The work experiences should be informative or integral to the advancement or completion of the student's program requirements. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

Chemistry

Graduates with a degree in chemistry will be well prepared for employment, graduate study in a chemistry-related field, or professional school. Chemists are employed in research, quality control, design, sales and management. Many graduates pursue masters and doctoral degrees in chemistry, biochemistry, medicinal chemistry, materials science, or environmental science, among others. A chemistry degree is excellent preparation for medical school and related fields, and also for careers in business, law or education.

The curriculum at Rose-Hulman Institute of Technology provides a rigorous introduction to all subdisciplines of chemistry. Students have access to modern instrumentation, a new biochemistry lab, and a new environmental chemistry lab. Rose-Hulman students are introduced to modern computational methods beginning in the sophomore year. There are many opportunities for research or other individual projects, and students are encouraged to present their results at regional and national chemistry conferences. Close interaction with engineering departments provides students with a point of view not available at most other undergraduate institutions.

Students may broaden their education by choosing a minor or second major. Many students, including chemistry majors, may be interested in a second major or minor in biochemistry and molecular biology. Other common choices include biology, chemical engineering and mathematics.

Student Outcomes

Student Outcomes are statements that describe what students are expected to have by the time of graduation.

1. An ability to design and conduct experiments as well as to analyze and interpret data.
2. An ability to recognize the professional and ethical responsibilities of a chemist.
3. An ability to communicate effectively in presentations and reports.
4. An ability to recognize chemistry practices outside of the academic environment.
5. An ability to operate safely and effecitvely in a chemistry laboratory.

List of Required Chemistry Courses

Course	Numbers	Credits
General Chemistry	111, 113, 115	12
Organic Chemistry	251, 252, 253	12
Analytical Chemistry	225, 326, 327	12
Physical Chemistry	361, 362, 463	12
Inorganic Chemistry	441, 442	8
Biochemistry	330	4
Research	291, 395, 490, 491, 496, 497	11
Career Preparation	200	1
Electives		11
Total		**83**

Summary of minimum graduation requirements:

Course or areas	Required	Elective	Total
Chemistry	72	11	83
Physics	12	0	12
Mathematics	19	0	19
Biology	4	0	4
Humanities, Social Sciences, and the Arts	8	28	36
Math/Science Elective	0	4	4
Electives	0	32	32
Foundations for Rose-Hulman Success	1	0	1
Total	**116**	**75**	**191**

Minor in Chemistry

Students not taking a first or second major in chemistry may earn a Minor in Chemistry by successfully completing the sequence of courses listed below. The student desiring this minor must request the approval of the Department Head and file the appropriate form with the registrar. This form is available on the Department of Chemistry webpage.

The requirements for an minor in chemistry for students with a first or second major in biology or chemical engineering are different from those majoring in other disciplines.

Minor in Chemistry for Most Students

Course Number	Course Title	Credits
CHEM 113	General Chemistry II	4
CHEM 115	General Chemistry III	4
CHEM 225	Analytical Chemistry	4
CHEM 251	Organic Chemistry I	4
CHEM 252	Organic Chemistry II	4
	*Approved List of Chemistry Electives	4
Total		**24**

*Approved list of chemistry electives include CHEM 253, CHEM 290 (up to two credit hours), up to a total of 4 credit hours of CHEM270 and CHEM276, or any 300 or 400 level chemistry courses.

Minor in Chemistry for Chemical Engineering and Biology Majors

Course Number	Course Title	Credits
CHEM 225	Analytical Chemistry	4
CHEM 253	Organic Chemistry III	4

	Chemistry Electives*	12
Total		**20**

*The electives cannot count toward the student's major. Students who have taken CHE 303, 304 and CHEM 360 cannot count CHEM 361 or CHEM 362 toward the minor. No more than 2 credits of CHEM 290 can count toward the minor, and no more than 4 credit hours total of CHEM270 and CHEM276.

Plan of Study

Freshman

Fall

Course	Credit
CHEM 111 General Chemistry I	4
MA 111 Calculus I	5
HUM H190 First-Year Writing Seminar or HSSA Elective	4
RHIT 100 Foundations for Rose-Hulman Success	1
	Total Credits: 14

Winter

Course	Credit
CHEM 113 General Chemistry II	4
MA 112 Calculus II	5
PH 111 Physics I	4
BIO 110 Cell Structure and Function*	4
	Total Credits: 17

Spring

Course	Credit
CHEM 115 General Chemistry III	4
MA 113 Calculus III	5
HSSA Elective	4
PH 112 Physics II	4
	Total Credits: 17

Sophomore

Fall

Course	Credit
CHEM 251 Organic Chemistry I	3

CHEM 251L Organic Chemistry I Lab	1
PH 113 Physics III	4
MA 223 or MA 381 Eng. Stat. or Prob. Stat.	4
CHEM 225 Analytical Chemistry	4
	Total Credits: 16

Winter

Course	Credit
CHEM 200 Career Preparation	1
CHEM 252 Organic Chemistry II	3
CHEM 252L Organic Chemistry II Lab	1
CHEM 291 Intro to Undergraduate Research	3
Math/Science Elective***	4
HSSA Elective	4
	Total Credits: 16

Spring

Course	Credit
HSSA Elective	4
CHEM 253 Organic Chemistry III	3
CHEM 253L Organic Chemistry III Lab	1
Free Elective	4
ENGL H290 Technical and Professional Communication	4
	Total Credits: 16

Junior

Fall

Course	Credit
HSSA Elective	4
CHEM 361** Physical Chemistry I	4
CHEM 330 Biochemistry I	4
CHEM 395 Chemistry Seminar	0
CHEM 490 Research Rotation	2
	Total Credits: 14

Winter

Course	Credit
CHEM 326 Bioanalytical Chemistry	4
CHEM 362** Physical Chemistry II	4
CHEM 490 Research Rotation	2
HSSA Elective	4
Free Elective	4
	Total Credits: 18

Spring

Course	Credit
CHEM 463 Physical Chemistry 3	4
Advanced CHEM Elective	4
HSSA Elective	4
CHEM 490 Research Rotation	2
CHEM 327 Adv Analytical Chemistry	4
	Total Credits: 18

Senior

Fall

Course	Credit
CHEM 441 Inorganic Chemistry I	4
Free Elective	4
CHEM 495 Chemistry Seminar	0
Advanced CHEM Elective	4
HSSA Elective	4
	Total Credits: 16

Winter

Course	Credit
CHEM 442 Inorganic Chemistry II	4
Advanced CHEM Elective	3
CHEM 496 Chemistry Seminar	0
Free Elective	4
Free Elective	4
	Total Credits: 15

Spring

Course	Credit
CHEM 491 Chemistry Thesis	1
CHEM 497 Chemistry Seminar	1

Free Elective	4	
Free Elective	4	
Free Elective	4	
		Total Credits: 14

NOTES

Two degree or double major programs in biochemistry and either chemistry or biochemistry and molecular biology is not allowed.

*BIO 120 or BIO 130 may be substituted for BIO 110
**CHE 303, CHE 304 and CHEM 360 may be substituted for CHEM 361 and CHEM 362.

***Math/ScienceElective defined as 200 level or above coursework with any of the following prefixes: BIO, BMTH, CSSE, GEOL, ECONS, MA, or PH

Students must complete at least 3 credits of CHEM 490 prior to the Spring quarter of their senior year.

##Research and independent study do not meet this requirement.

Chemistry - Course Descriptions

CHEM 111 General Chemistry I 3R-0L-3C F,W,S
Prerequisites: There are no prerequisites for this course.
Corequisites: CHEM 111L 0R-3L-1C F,W,S
Topics include stoichiometry, nomenclature, phases, and writing balanced chemical equations. Quantum theory is introduced in relation to chemical applications. Atomic structure is introduced. Bonding principles and molecular structure are discussed in terms of Lewis Dot Structures, Valence Bond Theory, VSEPR Theory, Hybridization, and Molecular Orbital Theory.

CHEM 111L General Chemistry I Laboratory 0R-3L-1C F,W,S
Prerequisites: There are no prerequisites for this course.
Corequisites: CHEM 111 3R-0L-3C F,W,S
Fundamental chemistry laboratory skills are introduced along with data analysis in support of topics presented in CHEM111 recitation.

CHEM 112 Chemistry Honors 4R-3L-5C F
Prerequisites: Advanced placement
Corequisites: There are no corequisites for this course.
An accelerated course covering topics in CHEM 111 and CHEM 113. Upon successful completion of this course, an additional 3 credits will be awarded. Enrollment is limited to those students who complete the Rose-Hulman online Chemistry Advanced Placement Examination given prior to the freshman orientation period.

CHEM 113 General Chemistry II 3R-0L-3C W,S
Prerequisites: CHEM 111F,W,S, and CHEM 111LF,W,S
Corequisites: CHEM 113L 0R-3L-1C W,S
Topics in this course include the fundamentals of thermodynamics and kinetics. The fundamentals of chemical equilibrium are introduced. Definitions of acid and bases are discussed utilizing the Bronsted-Lowry and Lewis models. Nuclear chemistry is also included.

CHEM 113L General Chemistry II Laboratory 0R-3L-1C W,S

Prerequisites: CHEM 111F,W,S, and CHEM 111LF,W,S
Corequisites: CHEM 113 3R-0L-3C W,S
Fundamental chemistry laboratory skills are introduced along with data analysis in support of topics presented in CHEM113 recitation.

CHEM 115 General Chemistry III 3R-0L-3C W, S

Prerequisites: CHEM 113W,S, and CHEM 113LW,S or CHEM 112F
Corequisites: CHEM 115L 0R-3L-1C W,S
Topics in this course include acid-base reactions, electrochemistry, and coordination chemistry.

CHEM 115L General Chemistry III Laboratory 0R-3L-1C W,S

Prerequisites: CHEM 113W,S, and CHEM 113LW,S or CHEM 112F
Corequisites: CHEM 115 3R-0L-3C W, S
Fundamental chemistry laboratory skills are introduced along with data analysis in support of topics presented in CHEM113 recitation.

CHEM 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

CHEM 200 Career Preparation 1R-0L-1C W

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
This course is for chemistry and biochemistry majors to be taken in the second year. The course addresses career choices, summer opportunities, employment and graduate school preparation, and curriculum vitae and resumes preparation. Cross-listed with MA200, and SV200.

CHEM 210 Chemistry of Poisons and Potions 2R-0L-2C SeeDept

Prerequisites: CHEM 111F,W,S, and CHEM 111LF,W,S
Corequisites: There are no corequisites for this course.
This course examines chemical agents found in medicinal plants and their use in different contexts. Specifically, we will investigate the chemical characteristics of these agents commonly used by humans through cultural practices.

CHEM 211 Chemistry of Food and Cooking 2R-0L-2C See Dept.

Prerequisites: CHEM 111F,W,S, and CHEM 111LF,W,S
Corequisites: There are no corequisites for this course.
The course presents students with the basic structural elements of four categories of food molecules and many of the physical and chemical transformations that occur in food preparation. Among anticipated outcomes will be the ability to assess the role of ingredients and processes in specific recipes thereby allowing participants to make informed decisions about recipe modifications.

CHEM 212 Chemistry of Sport 2R-0L-2C SeeDept

Prerequisites: CHEM 111F,W,S, and CHEM 111LF,W,S
Corequisites: There are no corequisites for this course.

This course will take a molecule-focused look at the overlap of chemistry and sports. The course will look at types of performance-enhancing drugs and their history, mechanisms of action, claims of efficacy, and detection using case studies

CHEM 213 Chemistry of Art 2R-0L-2 SeeDept

Prerequisites: CHEM 111F,W,S, and CHEM 111LF,W,S
Corequisites: There are no corequisites for this course.
This course will highlight the intersection of the chemical sciences and visual arts. Focus will be given to understanding the chemical nature and behaviors of dyes, pigments, and paints, pottery and glazes, textiles, and materials used for sculpture. Historical developments of artistic media will be discussed and related to chemical conservation efforts and forgery detection.

CHEM 225 Analytical Chemistry 3R-0L-3C F,S

Prerequisites: CHEM 115W, S, and CHEM 115LW,S
Corequisites: CHEM 225L 0R-3L-1C F,S
This laboratory-driven course is an introduction to classical and modern quantitative analysis with emphasis on calculations, separations, and precise and accurate measurements. Theoretical and practical perspectives of chemical analysis are considered. Chemical instrumentation includes recording pH/mV meters, constant rate burets, colorimeters, spectrophotometers, high performance liquid chromatographs and gas-liquid chromatographs.

CHEM 225L Analytical Chemistry Laboratory 0R-3L-1C F,S

Prerequisites: CHEM 115W, S, and CHEM 115LW,S
Corequisites: CHEM 225 3R-0L-3C F,S
This course represents the laboratory component of analytical chemistry. Practicums are part of the grade along with reports.

CHEM 251 Organic Chemistry I 3R-0L-3C F,W

Prerequisites: CHEM 113W,S, and CHEM 113LW,S or CHEM 112F
Corequisites: CHEM 251L 0R-3L-1C F,W
An introduction to the classification of organic compounds, their structural features, including stereochemistry, and concepts related to reaction mechanisms and synthetic methods as it relates to compounds with biochemical relevance.

CHEM 251L Organic Chemistry I Laboratory 0R-3L-1C F,W

Prerequisites: CHEM 113W,S, and CHEM 113LW,S or CHEM 112F
Corequisites: CHEM 251 3R-0L-3C F,W
Organic Laboratory techniques in running chemical reactions and isolating compounds are developed. Assessment is in part via practicums. Computational chemistry methods and green chemistry approaches are also introduced. Lab will meet 5 times in the term.

CHEM 252 Organic Chemistry II 3R-0L-3C W,S

Prerequisites: CHEM 251F,W, and CHEM 251LF,W
Corequisites: CHEM 252L 0R-3L-1C W,S
Continuation of Organic Chemistry I with greater emphasis on reaction mechanisms and an introduction to the methods used to determine structure, including IR and NMR spectroscopy and mass spectrometry.

CHEM 252L Organic Chemistry II Laboratory 0R-3L-1C W,S

Prerequisites: CHEM 251F,W, and CHEM 251LF,W
Corequisites: CHEM 252 3R-0L-3C W,S

A continuation of Organic Chemistry I Lab where additional, more complicated synthetic techniques and methods along with additional spectroscopic techniques are introduced.

CHEM 253 Organic Chemistry III 3R-0L-3C S

Prerequisites: CHEM 252W,S, and CHEM 252LW,S

Corequisites: CHEM 253L 0R-4L-1C S

Continuation of Organic Chemistry II with a focus on carbon-carbon bond-forming reactions, heterocycles, and polyfunctional molecules.

CHEM 253L Organic Chemistry III Laboratory 0R-4L-1C S

Prerequisites: CHEM 252W,S, CHEM 252LW,S

Corequisites: CHEM 253 3R-0L-3C S

Project based laboratory where techniques and skills developed in the previous organic laboratories are applied to more open-ended problems.

CHEM 270 Special Topics in Chemistry (1-4)R-0L-(1-4)C See Dept

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

Studies in topics of current chemical interest not addressed in other named courses. A maximum of 4 total credit hours of CHEM270 and CHEM276 can be counted towards a chemistry major.

CHEM 276 Special Topics in Chemistry with Laboratory (0-3)R-(3-6)L-(1-4)C

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

Studies in topics of current chemical interest not addressed in other named courses. This course will have a laboratory component. A maximum of 4 total credit hours of CHEM270 and CHEM276 can be counted towards a chemistry major.

CHEM 290 Chemical Research 0R-(4-8)L-(1-2)C F, W, S

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

Research performed under the direction of a faculty member selected by mutual agreement. This course is designed for research performed before taking CHEM291. Students may register for 1 to 2 credit hours per quarter.

CHEM 291 Introduction to Chemical Research 2R-4L-3C W

Prerequisites: CHEM 113W,S, and CHEM 113LW,S or CHEM 112F declared chemistry or biochemistry major.

Corequisites: There are no corequisites for this course.

Students will be introduced to skills necessary for conducting chemical research. Students will gain proficiency in: (1) literature searching of primary, secondary, and tertiary sources emphasizing the use of online databases; (2) laboratory skills involving synthesis, characterization, analysis, and keeping a notebook; (3) safety practice including MSDS interpretation; and (4) ethical conduct in collecting and reporting data and results. Students will be required to attend all seminars during the quarter. Enrollment is reserved for students who are declared as chemistry or biochemistry majors.

CHEM 326 Bioanalytical Chemistry 3R-4L-4-C W

Prerequisites: CHEM 225F,S, and CHEM 225LF,S

Corequisites: There are no corequisites for this course.

Addresses instrumental methods of analysis applicable to biochemistry including instrument design, operating principles, theory and application. Topics include molecular spectroscopic techniques in the infrared, visible and ultraviolet regions, including luminescence and Raman spectroscopy. Separation techniques including liquid chromatography and capillary electrophoresis are also addressed.

CHEM 327 Advanced Analytical Chemistry 3R-4L-4C S

Prerequisites: CHEM 326W

Corequisites: There are no corequisites for this course.

Addresses theory, operating principles, and application of instrumental methods for chemical analysis in the areas of atomic spectroscopy, x-ray techniques, gas chromatography and electroanalytical methods.

CHEM 330 Biochemistry I 4R-0L-4C F,S

Prerequisites: CHEM 251F,W

Corequisites: There are no corequisites for this course.

Includes the structure and function of biological molecules, enzyme kinetics and mechanisms, and the reactions, strategy, and regulation of carbohydrate metabolism.

CHEM 331 Biochemistry II 4R-0L-4C W

Prerequisites: CHEM 330F,S, and BIO 210F

Corequisites: There are no corequisites for this course.

Includes the reactions, strategy, and regulation of the major metabolic pathways in humans and of selected pathways in plants, and the storage, repair, and transmission of genetic information.

CHEM 360 Introduction to Physical Chemistry for Engineers 4R-0L-4C W,S

Prerequisites: CHE 303F,S, CHE 304F,W, and CHEM 115W, S

Corequisites: There are no corequisites for this course.

Introduction to quantum chemistry, statistical thermodynamics, electrochemistry, chemical kinetics, surface chemistry and colloid science.

CHEM 361 Physical Chemistry I 4R-2L-4C F

Prerequisites: CHEM 115W, S, and CHEM 115LW,S, and MA 113F,W,S, and MA 223F,W,S or MA 381F,W,S* See notes below

Corequisites: There are no corequisites for this course.

Covers the laws of thermodynamics, free energy, gases, phase equilibria and solutions. Emphasizes the applications of differential and integral calculus and includes an introduction to statistical thermodynamics and surface chemistry. The laboratory will meet for 4 hours on alternate weeks and will investigate topics associated with thermodynamics and phase equilibrium.

CHEM 362 Physical Chemistry II 3R-2L-4C W

Prerequisites: CHEM 361F

Corequisites: There are no corequisites for this course.

Covers chemical equilibria, statistical mechanics, kinetics and electrochemistry. The laboratory will meet for 4 hours on alternate weeks.

CHEM 391 Research Proposal 1R-0L-1C F, W, S

Prerequisites: CHEM 291W

Corequisites: There are no corequisites for this course.

Students will take online lessons related to the generation and communication of research ideas culminating in the production of a research proposal. The research proposal will be written under the direction of a faculty member of record for the student's CHEM490 or by other faculty member selected by mutual agreement.

CHEM 395 Chemistry Seminar 0R-0L-0C F

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Students will be required to attend and/or present research seminars, the number to be determined by the department. The students will register for the course in the fall of the third year and if all the requirements are met, the students will receive a grade of Satisfactory. Failure to meet the requirements during the fall quarter will result in No Grade and the student must complete the requirements by the end of the third year. If the requirements are not completed by the end of the third year, a grade of Unsatisfactory is assigned and must be rectified to meet graduation requirements.

CHEM 420 Electronics for Scientists 3R-4L-4C See Dept
Prerequisites: CHEM 326W or CHEM 327S or consent of instructor
Corequisites: There are no corequisites for this course.
A fundamental course on understanding important electronic systems as they pertain to chemical signals and instrumentation. Topics include analog systems (RC circuits, diodes, transistors, and operational amplifiers), digital systems (logic gates, shift registers, and lock-in amplifiers), and signal enhancement and noise reduction modules. The laboratory component will showcase basic circuit design and construction, and will culminate with a student-built chemical instrument.

CHEM 421 Biochemical Mass Spectrometry 1R-0L-1C See Dept
Prerequisites: CHEM 330F,S
Corequisites: There are no corequisites for this course.
This course will explore the theoretical basis and practical aspects of mass spectrometry, with an emphasis on their use for analysis of biological molecules. Topics include ionization mechanisms and methods for sample preparation and mass spectral analysis, and the course will include a project.

CHEM 422 Fluorescence Spectroscopy 1R-0L-1C See Dept
Prerequisites: CHEM 330F,S
Corequisites: There are no corequisites for this course.
This course will explore the theoretical basis and practical aspects of fluorescence spectroscopy, with an emphasis on their use for analysis of biological molecules. Topics include mechanisms of fluorescence excitation and emission, quenching processes, anisotropy, and time-resolved fluorescence, and the course will include a project.

CHEM 423 NMR Spectroscopy 1R-0L-1C See Dept
Prerequisites: CHEM 252W,S
Corequisites: There are no corequisites for this course.
This course is designed to provide the basic training and tools necessary to operate the 300MHz Bruker NMR and the associated ICON software. Additionally, the focus will be on sample preparation, acquisition, analysis, and processing of 1H NMR, 13C NMR, COSY and HETCOR (2D NMR), DEPT-90, DEPT-135, heteronuclear NMR, and applications of NMR to related fields. The course will consist primarily of basic and practical NMR instruction.

CHEM 424 Absorption Spectroscopy 2R-0L-2C See Dept
Prerequisites: CHEM 326W or CHEM 327S
Corequisites: There are no corequisites for this course.
This course looks at absorption spectroscopy from the microwave to x-ray relating spectra to the molecular and/or atomic processes. The course will consist of both instruction and a project of student choice involving absorption process.

CHEM 425 Raman Spectroscopy 1R-0L-1C SeeDept

Prerequisites: CHEM 225F,S
Corequisites: There are no corequisites for this course.
This course explores various theoretical and practical aspects of Raman spectroscopy including fundamental vibrational modes of molecules and selection rules, the physicochemical origin of Raman scattering, Raman spectrometers, lasers, resonance Raman spectroscopy, surface-enhanced Raman spectroscopy (SERS), and applications of Raman spectroscopy. The course includes an independent project in which a Raman spectrum is acquired for a sample of interest.

CHEM 426 Microfluidics 1R-0L-1C SeeDept
Prerequisites: CHEM 225F,S
Corequisites: There are no corequisites for this course.
This course explores various theoretical and practical aspects of microfluidics. The course addresses the benefits and challenges of microfluidics in chemistry and chemical analysis and the materials and processes available for fabricating microfluidic devices. General characteristics of microfluidic devices including fluid flow regimes, heat transfer and diffusion are addressed as well as practical applications of microfluidic devices and how various functions like valving and detection are performed. The course includes an independent project involving the design and fabrication of a microfluidic device.

CHEM 427 HPLC 1R-0L-1C SeeDept
Prerequisites: CHEM 225F,S
Corequisites: There are no corequisites for this course.
This course will explore various theoretical and practical aspects of HPLC including a review of separation parameters, equilibrium types, retention mechanisms, stationary phases and their performance, mobile phases and their properties and choosing an appropriate separation type.

CHEM 428 Trace Metal Detection 1R-0L-1C SeeDept
Prerequisites: CHEM 225F,S
Corequisites: There are no corequisites for this course.
This course aims at providing students with fundamental skills and knowledge in trace metal analysis, for environmental and biological samples. The course will enable students to understand, develop and execute analytical protocols involving recent trace metal analysis methodologies and instrumentation using voltammetry. Students will learn by lectures, class activities, and homework assignments and how to optimize conditions to obtain sufficient analytical performance parameters in terms of selectivity, detection limit, cost, and analysis time.

CHEM 429 Capillary Electrophoresis 1R-0L-1C SeeDept
Prerequisites: CHEM 225F,S
Corequisites: There are no corequisites for this course.
This course will explore various theoretical principles and chemical/biochemical applications of capillary electrophoresis. Main emphasis will focus on the choice of CE as an alternative form for separations for biochemical samples. Students will learn by lectures, class activities, homework assignments and how to optimize experimental conditions to achieve a good separation.

CHEM 430 Advanced Biochemistry 4R-0L-4C S
Prerequisites: CHEM 330F,S
Corequisites: There are no corequisites for this course.

An in-depth exploration of selected topics from the current biochemistry scientific literature, including molecular mechanisms of infectious diseases and genetic disorders, methods for rational drug design, and relationships between structure and function for biological molecules.

CHEM 433 Biochemistry Laboratory 0R-3L-1C S

Prerequisites: CHEM 330F,S
Corequisites: There are no corequisites for this course.
Fundamental techniques employed in isolation, characterization and study of biomolecules, and enzyme kinetics. Techniques used may include homogenization, solvent extraction, centrifugation, salt fractionation, chromatography, and electrophoresis.

CHEM 441 Inorganic Chemistry I 4R-0L-4C F

Prerequisites: CHEM 252W,S, CHEM 362W, CHEM 360W,S
Corequisites: There are no corequisites for this course.
The chemistry of non-metals. This course consists of a systematic study of the properties and reactions of the elements and their compounds based upon modern theories of the chemical bond, as well as from the viewpoint of atomic structure and the periodic law.

CHEM 442 Inorganic Chemistry II 3R-4L-4C W

Prerequisites: CHEM 441F
Corequisites: There are no corequisites for this course.
The chemistry of metals. Modern theories such as valence bond, molecular orbital, electrostatic and ligand field are used to explain the properties of complex ions. Synthesis and characterization of complexes are done in the lab.

CHEM 451 Organic Structure Determination 2R-8L-4C See Dept

Prerequisites: CHEM 253S or instructor consent
Corequisites: There are no corequisites for this course.
Chemical and spectroscopic identification of organic compounds. Study of nuclear magnetic resonance and mass spectrometry, infrared spectroscopy and other techniques applied to structure elucidation and stereochemistry.

CHEM 463 Quantum Chemistry & Molecular Spectroscopy 4R-0L-4C S

Prerequisites: CHEM 111F,W,S, CHEM 111LF,W,S, PH 112W,S,F, and MA 221F,W,S
Corequisites: There are no corequisites for this course.
Covers elementary quantum mechanics with emphasis on applications in molecular structure.

CHEM 470 Special Topics in Chemistry (1-4)R-0L-(1-4)C See Dept

Prerequisites: or instructor consent
Corequisites: There are no corequisites for this course.
Studies in advanced topics of current chemical interest not addressed in other named courses.

CHEM 476 Special Topics in Chemistry with Laboratory (0-3)R-(3-6)L-(1-4)C See Dept

Prerequisites: To be taken concurrently with the appropriate elective not accompanied by an identified laboratory component.
Corequisites: There are no corequisites for this course.
Studies in advanced topics of current chemical interest not addressed in other named courses. This course will have a laboratory component.

CHEM 477 Directed Study in Chemistry (1-4)R-0L-(1-4)C F, W, S

Prerequisites: or instructor consent

Corequisites: There are no corequisites for this course.

Allows individual study in a topic not usually offered. A student may take 1 to 4 credits. A maximum of 4 credits is permitted.

CHEM 490 Chemical Research Rotation 1R-4L-2C F, W, S

Prerequisites: CHEM 291W

Corequisites: There are no corequisites for this course.

Open-ended research projects performed as part of a research group. The students will gain proficiency in advanced lab techniques, the scientific method, data management and communication.

CHEM 491 Senior Thesis 1R-0L-1C F, W, S

Prerequisites: CHEM 490F, W, S

Corequisites: There are no corequisites for this course.

Students will publish a thesis on their undergraduate research or a literature review of an advanced topic mutually agreed upon with the instructor.

CHEM 495 Chemistry Seminar 0R-0L-0C F

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

Students will be required to attend research seminars. If the requirement is not completed by the end of the quarter, a grade of Unsatisfactory is assigned and must be rectified to meet graduation requirements.

CHEM 496 Chemistry Seminar 0R-0L-0C W

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

Students will be required to attend research seminars. If the requirement is not completed by the end of the quarter, a grade of Unsatisfactory is assigned and must be rectified to meet graduation requirements.

CHEM 497 Senior Presentation 1R-0L-1C F, W, S

Prerequisites: CHEM 490F, W, S

Corequisites: There are no corequisites for this course.

Students will deliver a professional seminar on their undergraduate research or a review of an advanced topic mutually agreed upon with the instructor.

CHEM 499 Independent Chemical Research 0R-(4-8)L-(1-2)C F, W, S

Prerequisites: CHEM 291W

Corequisites: There are no corequisites for this course.

Research performed under the direction of a faculty member selected by mutual agreement. Students may register for 1 or 2 credit hours per quarter.

CHEM 520 Electronics for Scientists 3R-4L-4C See Dept

Prerequisites: CHEM 326W or CHEM 327S or consent of instructor

Corequisites: There are no corequisites for this course.

A fundamental course on understanding important electronic systems as they pertain to chemical signals and instrumentation. Topics include analog systems (RC circuits, diodes, transistors, and operational amplifiers), digital systems (logic gates, shift registers, and lock-in amplifiers), and signal enhancement and noise reduction modules. The laboratory component will showcase basic circuit design and construction, and will culminate with a student-built chemical instrument. For graduate credit there will be an additional project beyond the requirements for CHEM420. A student may not take both CHEM420 and CHEM520 for credit.

CHEM 530 Advanced Biochemistry 4R-0L-4C S
Prerequisites: CHEM 330F,S
Corequisites: There are no corequisites for this course.
An in-depth exploration of selected topics from the current biochemistry scientific literature, including molecular mechanisms of infectious diseases and genetic disorders, methods for rational drug design, and relationships between structure and function for biological molecules. Students enrolled in CHEM 530 must complete a project not covered in CHEM 430. A student may not receive credit for both CHEM 430 and CHEM 530.

CHEM 531 Biochemical Instrumentation 3R-4L-4C See Dept
Prerequisites: BIO 210F, and CHEM 330F,S
Corequisites: There are no corequisites for this course.
This project-based course includes approaches for the analysis of biochemical experimental problems, experimental design for molecular biology and biochemistry, and the theoretical basis and practical aspects of operating instruments used in biochemical research.

CHEM 532 Biochemical Pharmacology 4R-0L-4C See Dept
Prerequisites: CHEM 330F,S
Corequisites: There are no corequisites for this course.
Topics include medicinal chemistry and molecular pharmacology. The topics will also include a survey of potential drug targets, the molecular interactions between drugs and their targets, the drug discovery and development process and case studies of drugs treating diseases such as cancer, bacterial and viral infection, and neurological disorders.

CHEM 534 Biochemical Physiology 4R-0L-4C SeeDept
Prerequisites: CHEM 330F,S
Corequisites: There are no corequisites for this course.
An application of the principles of biochemistry to understanding the chemical aspects of the functioning of living organisms. This course covers topics related to the molecular mechanisms involved in the maintenance of physiological homeostasis, and when appropriate examines current research in the relevant systems. These mechanisms will be organized by the chemical signaling systems responsible for integrating and communicating the response to internal changes and external stimuli.

CHEM 535 Toxicology for Chemists 4R-0L-4C SeeDept
Prerequisites: CHEM 251F,W
Corequisites: There are no corequisites for this course.
A fundamental course on the interaction of chemical agents with the human body. Topics include toxic thresholds and dose-response relationships, toxicological mechanisms of action, and models for physical and aquatic toxicities. Students engage in quantitative structure-activity relationship (QSAR) modeling and hazard assessment.

CHEM 545 Organometallic Chemistry 4R-0L-4C See Dept
Prerequisites: CHEM 115W, S, and CHEM 252W,S
Corequisites: There are no corequisites for this course.
A survey of the chemistry of main group organometallic compounds and organo-transition metal complexes. Reaction mechanisms and uses in organic synthesis and catalysis are studied.

CHEM 552 Synthetic Organic Chemistry 4R-0L-4C See Dept
Prerequisites: CHEM 253S
Corequisites: There are no corequisites for this course.
A survey of contemporary methodology in organic synthesis. Retrosynthetic analysis, functional group transformations, condensation chemistry, and organometallic reagents will be stressed. Includes computer assisted synthesis.

CHEM 554 Theoretical Organic Chemistry 4R-0L-4C See Dept
Prerequisites: CHEM 253S, and CHEM 361F or CHEM 360W,S or permission of instructor
Corequisites: There are no corequisites for this course.
Study of physical and chemical methods used to investigate organic reaction mechanisms; the chemistry of carbenes; organic photochemistry.

CHEM 556 Green Chemistry 4R-0L-4C SeeDept
Prerequisites: CHEM 252W,S
Corequisites: There are no corequisites for this course.
Advanced topics in green chemistry including industrial applications, atom economy, safer solvent substitutions, alternatives assessment, green metrics (PMI, E-factor), and a brief introduction to chemical toxicology.

CHEM 561 Advanced Physical Chemistry 4R-0L-4C SeeDept
Prerequisites: CHEM 463S, and CHEM 360W,S or CHEM 362W
Corequisites: There are no corequisites for this course.
The course covers advanced topics in quantum mechanics, statistical thermodynamics, and kinetics.

CHEM 570 Special Topics in Chemistry (1-4)R-0L-(1-4)C See Dept
Prerequisites: permission of instructor
Corequisites: There are no corequisites for this course.
Studies in advanced topics of current chemical interest not addressed in other named courses. If cross-listed with CHEM470, students in CHEM570 will need to complete an additional project.

CHEM 581 Polymer Chemistry 3R-4L-4C See Dept
Prerequisites: CHEM 252W,S Junior class standing
Corequisites: There are no corequisites for this course.
Polymer synthesis, reactions, and characterization techniques. Structure/property relationships and morphology will be discussed, both for industrially relevant polymers as current topics of from the recent literature. Laboratory sequence consists of polymer synthesis and characterization.

CHEM 582 Physical Properties of Polymeric Materials 4R-0L-4C See Dept
Prerequisites: CHEM 361F or CHEM 360W,S
Corequisites: There are no corequisites for this course.
In this course the physical properties of polymeric systems will be defined in terms of the models that have been used to characterize them. The behavior of isolated polymers and polymers in solution will be mapped to macroscopic properties of bulk polymeric systems using theories such as Rotational Isomeric State and Flory's Lattice model. Methods of molecular weight determination will be fully developed. Phase transitions will be characterized and related to polymeric and monomeric structural features. Theories of elasticity and viscoelastic behavior will be used to explain macroscopic behaviors of polymeric materials.

CHEM 595 Chemistry Seminar 0R-0L-0C F
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Chemistry graduate students will be required to attend research seminars. If the requirement is not completed by the end of the quarter, a grade of Unsatisfactory is assigned and must be rectified to meet graduation requirements.

CHEM 596 Chemistry Seminar 0R-0L-0C W
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Chemistry graduate students will be required to attend research seminars. If the requirement is not completed by the end of the quarter, a grade of Unsatisfactory is assigned and must be rectified to meet graduation requirements.

CHEM 597 Chemistry Seminar 0R-0L-0C S
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Chemistry graduate students will be required to attend research seminars. If the requirement is not completed by the end of the quarter, a grade of Unsatisfactory is assigned and must be rectified to meet graduation requirements.

CHEM 599 Thesis Research As assigned F, W, S
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Graduate students only. Credits as assigned; however, not more than 12 credits will be applied toward the requirements of the M.S. degree.

CHEM 699 Professional Experience 1R-0L-1C See Dept
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The work experiences should be informative or integral to the advancement or completion of the student's program requirements. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

Civil Engineering

Civil engineering is a people-oriented profession that has long been in existence to serve the needs of mankind. It evolved as a formal discipline at the start of the 19th century with the advent of society's need for increased mobility and convenience. The role of the civil engineer has always been one that deals primarily with public works: the planning, design, and construction of airports, bridges, buildings, and transportation, irrigation, flood control, water supply and waste disposal systems. These civil engineering works not only manage our environment, but are part of the environment itself and, by their very nature, have important social and economic impacts.

The civil engineering curriculum is designed to give the student a sound education in preparation for this role. The first two years include courses that deal with the principles of mathematics, physical and engineering sciences on which engineering concepts are based, as well as courses in humanities and social sciences and introductory courses in engineering and design. The last two years are devoted to developing the necessary technical competence, as well as the ability to apply the knowledge that the student has acquired to the design and synthesis of complex civil engineering projects. Project-based learning is an essential ingredient, and a year-long, client-based capstone design project highlights the senior year.

The entire curriculum is oriented to develop a student's ability to think critically and logically. Upon graduation the student will be able to adapt this ability to the engineering environment of his or her choice. The curriculum in civil engineering will provide the student with the capacity for professional growth, either by advanced study or as a practicing professional engineer. A student may also use this academic background as a stepping stone to a position in management, administration, law, or some other non-engineering field.

Civil Engineering Department's Mission Statement

To provide an excellent civil engineering education that prepares graduates to develop into professionals who will exceed the needs of their employers, clients, and community in a continually changing world.

Civil Engineering Department's Program Educational Objectives and Student Learning Outcomes*

Program Educational Objectives

I. Graduates will demonstrate the ability to perform **essential engineering functions** in the design, management, or construction industry.

II. Graduates will demonstrate the ability to **design/construct complex engineering systems** in the broad-based engineering industry.

III. Graduates will demonstrate their potential for **technical leadership and management.**

Student Learning Outcomes

1. Mathematics: Apply mathematics, including differential equations and numerical methods, to solve engineering problems.
2. Science: Apply principles of natural science to solve engineering problems.
3. Social Sciences and Humanities: Apply concepts and principles developed from humanities and social sciences to inform engineering design.
4. Materials Science: Apply concepts and principles of materials science to solve civil engineering problems.
5. Engineering Mechanics: Apply concepts and principles of solid and fluid mechanics to solve engineering problems.
6. Experimental Methods and Data Analysis: Develop and conduct civil engineering experiments in at least two technical areas, analyze and interpret experimental data, and use engineering judgement to draw conclusions.
7. Critical Thinking and Problem Solving: Use critical thinking to formulate an effective solution to a civil engineering problem.
8. Project Management: Apply concepts and principles of project management in the practice of civil engineering.
9. Engineering Economics: Apply engineering economics concepts and principles to make engineering decisions.

10. Risk and Uncertainty: Apply concepts and principles of probability and statistics to address uncertainty and risk relevant to civil engineering.
11. Breadth in Civil Engineering Areas: Apply concepts and principles to solve problems in at least four technical areas appropriate to civil engineering.
12. Design: Apply an engineering design process to complex engineering problems in more than one civil engineering technical area.
13. Technical Depth: Apply advanced concepts and principles to solve engineering problems.
14. Sustainability: Apply principles of sustainability in the solution of civil engineering problems.
15. Communication: Prepare and present technical content to both specialized and general audiences in an effective manner within verbal, written, and graphical formats.
16. Leadership: Apply leadership concepts and principles to direct the efforts of a small group. (Affective)
17. Teamwork: Function effectively as a member of a team. (Affective)
18. Lifelong Learning: Acquire and apply new knowledge as needed, using appropriate learning strategies.
19. Professional Attitudes: Practice professional attitudes relevant to the practice of engineering. (Affective)
20. Professional Responsibilities: Explain professional expectations relevant to the practice of civil engineering.
21. Ethical Responsibilities: Analyze ethical dilemmas involving conflicting ethical interests to recommend and justify a course of action.
22. Service: Demonstrate a commitment to service to the community as a civil engineer.

** The civil engineering program uses the term "educational objective" to describe the expected accomplishments of our students in three to five years following graduation. The term "student learning outcome" is used to describe knowledge and skills at the time of graduation.*

The civil engineering program is accredited by the Engineering Accreditation Commission of ABET, https://www.abet.org, under the commission's General Criteria and Program Criteria for Civil and Similarly Named Engineering Programs.

Environmental Engineering Minor

The Environmental Engineering minor includes five (5) required courses and 8 elective credit hours. The required courses provide an introduction to the overall field of environmental engineering. The elective courses allow the student to tailor the minor to their interests.

The five (5) required courses are as follows:

CE 460	Introduction to Environmental Engineering
BIO 107	Introduction to Environmental Science
CE 562/CHE 562	Advanced Wastewater Treatment

CE 563/CHE 563	Advanced Water Treatment
CE 564	Aqatic Environmental Chemistry

And eight (8) credit hours from the following courses:

CE 565	Solid and Hazardous Waste Regulation and Treatment
CE 567	Applied Hydrologic Modeling
CE 568	Surface Water Quality Modeling
CE 570	Modeling Open Channel Hydraulics
CE 571	Environmental River Mechanics
CE 573	Groundwater Analysis
CE 590	Special Problems
CHE 462	Membrane Separations
CHE 465	Energy and the Environment
CHE 470	Safety, Health, and Loss Prevention
CHEM 535	Toxicology for Chemists
BIO 320	Ecology

CONSULTING ENGINEERING PROGRAM

If interested in the Consulting Engineering Program, refer to these requirements.

Plan of Study

Freshman

Fall

Course	Credit
MA 111 Calculus I	5
PH 111 Physics I	4
HUM H190 First-Year Writing Seminar or HSSA Elective	4
RHIT 100 Foundations for Rose-Hulman Success	1

CE 101 Engineering Surveying	2	
		Total Credits: 16

Winter

Course	Credit	
MA 112 Calculus II	5	
PH 112 Physics II	4	
HUM H190 First-Year Writing Seminar or HSSA Elective	4	
CE 111 Geographic Info Systems	2	
EM 102 Graphical Communications for CE	2	
		Total Credits: 17

Spring

Course	Credit	
MA 113 Calculus III	5	
EM 103 Introduction to Design	2	
EM 120 Engineering Statics	4	
HSSA Elective	4	
		Total Credits: 15

Sophomore

Fall

Course	Credit	
MA 221 Matrix Algebra & Differential Equations I	4	
CHEM 111 General Chemistry I	4	
EM 202 Dynamics	4	
HSSA Elective	4	
		Total Credits: 16

Winter

Course	Credit	
MA 222 Matrix Algebra & Differential Equations II	4	
EM 203 Mechanics of Materials	4	
CHEM 113 General Chemistry II	4	
CE 250 Sustainable CE Design	2	
Elective (Science)***	4	
		Total Credits: 18

Spring

Course	Credit
MA223 Engineering Statistics	4
EM 301 Fluid Mechanics	4
CE 310 Comp Apps in CE	2
CE 320 C.E. Materials	4
CE 380 Transportation Engineering	4
	Total Credits: 18

Junior

Fall

Course	Credit
CE 321 Structural Mechanics I	4
CE 336 Soil Mechanics	4
CE 205 Thermodynamics or CHE 201 Conservation Principles & Balances	4
CE 371 Hydraulic Engineering	4
	Total Credits: 16

Winter

Course	Credit
ES213 and ES213L Electrical Circuits or CHE202 Basic Chemical Process Calculations	4
CE 441 Construction Engineering	2
CE 432 Concrete Design I	3
CE 471 Water Resources Engineering	4
Elective (Science)***	4
	Total Credits: 17

Spring

Course	Credit
HSSA Elective	4
CE 431 Steel Design I	3
CE 460 Environmental Engineering	4
ENGL H290 Technical & Professional Communication	4
CE 461 Environmental Engineering Lab	2
	Total Credits: 17

Senior

Fall

Course	Credit
CE 486 C.E. Design & Synthesis I	2
CE **C.E. Elective	4
CE 450 C.E. Codes & Regulations	4
HSSA Elective	4
	Total Credits: 14

Winter

Course	Credit
CE 487 Technical System Design & Synthesis	2
CE 488 C.E. Design & Synthesis II	2
CE **C.E. Elective	4
*Elective (Technical)	4
CE 303 Engineering Economy	4
	Total Credits: 16

Spring

Course	Credit
CE 489 C.E. Design & Synthesis III	2
****Free Elective	4
HSSA Elective	4
HSSA Elective	4
CE 400 Career Preparation Seminar	0
	Total Credits: 14

NOTES

*Students shall choose, in consultation with their advisor, any four (4) credit course at the 200 level or higher in natural science, computer science, mathematics, biomathematics, engineering, engineering management, or multi-disciplinary studies as the Technical Elective.
**Student shall choose any 400 or 500 level CE elective course, designated with the"CE" prefix, as a CE Elective, in consultation with their advisor.
***At least 4 hours of science elective must be in a natural science outside Chemistry or Physics.
****Free elective is a total of four credits which can be from a combination of courses.

Civil Engineering - Course Descriptions

CE 101 Engineering Surveying 0R-6L-2C F
Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.
Covers basic principles and practices of surveying. Measurement through the application of surveying techniques; theory of errors and their analysis; concepts of horizontal, vertical, and angular measurement; coordinate systems; basic surveying operations and computations; reading and interpretation of building, highway, and/or bridge plans; traverse computations; applications to construction and design.

CE 111 Geographical Information Systems 2R-0L-2C W

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The course covers introductory concepts of geographical information systems and related technologies. Topics covered will relate to the use, collection, creation, and analysis of spatial data in applying GIS and related technologies to civil engineering projects.

CE 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

CE 205 Thermodynamics 4R-0L-4C F

Prerequisites: MA 112F,W,S
Corequisites: There are no corequisites for this course.
Covers first law of thermodynamics, second law of thermodynamics, concept of entropy, simple process analysis, properties of pure substances, equations of state, and state diagrams. Stresses use of property tables and charts and application of the first and the second laws to open and closed systems undergoing changes.

CE 250 Sustainable Civil Engineering Design 2R-0L-2C W

Prerequisites: EM 103S
Corequisites: There are no corequisites for this course.
An introduction to sustainable design of civil engineering systems. Includes treatment of current issues as they relate to design and construction for economic, environmental and social aspects of civil engineering.

CE 303 Engineering Economy 4R-0L-4C W

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Emphasizes time value of money and factors related thereto. Familiarizes students with concepts of annual cost, present worth, and minimum rate of return as tools for consideration of economic factors pertinent to the selection of alternate solutions to engineering problems.

CE 310 Computer Applications in Civil Engineering 2R-0L-2C S

Prerequisites: EM 202F, and EM 203W
Corequisites: There are no corequisites for this course.
Students develop solutions to a variety of civil engineering problems using application programs such as Mathcad and Excel. Emphasis is made on problem solving approach and structured programming with software tools useful to civil engineering computation and design.

CE 320 Civil Engineering Materials 3R-3L-4C S
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
A study of the origin, nature, performance and selection criteria of various basic materials used in the practice of civil engineering. These include aggregates, portland cement, concrete, and bituminous materials. Emphasis will be placed on standard methods of testing and characterization as related to the mechanical behavior of materials.

CE 321 Structural Mechanics I 4R-0L-4C F
Prerequisites: EM 203W
Corequisites: There are no corequisites for this course.
Classical structural analysis. Idealizations, stability, reactions and internal forces, influence lines, approximate analysis, and displacements.

CE 336 Soil Mechanics 3R-3L-4C F
Prerequisites: EM 203W, and EM 301S
Corequisites: There are no corequisites for this course.
Introduces the student to the fundamental concepts of soil mechanics. Covers types and properties of soils, lateral and vertical pressures, settlement and consolidation, strength and seepage studies. Includes laboratory investigation of soil properties.

CE 371 Hydraulic Engineering 3R-3L-4C F
Prerequisites: EM 301S or CHE 301F,S or ES 212W,S
Corequisites: There are no corequisites for this course.
Application of basic fluid mechanics principles to the fields of hydraulics and water resources. Topics covered include: open channel flow, closed conduit flow, flow measurement, and turbomachinery. Stresses practical applications in the laboratory.

CE 380 Introduction to Transportation Engineering 4R-0L-4C S
Prerequisites: CE 101F
Corequisites: There are no corequisites for this course.
Study of transportation functions and transportation systems; measuring and estimating demand; characteristics of transportation modes, interactions between modes, and mode interfaces; social, environmental, technological, economic, and public policy impacts; techniques of transportation system planning, design, and operation, with an emphasis on highway geometric design.

CE 400 Career Preparation Seminar 1R-0L-0C S
Prerequisites: CE 488W
Corequisites: There are no corequisites for this course.
Preparation for the student to become a practicing engineer. Topics include Civil Engineering job expectations, continuing education, legal considerations, professionalism, consumer topics, and financial considerations.

CE 421 Structural Mechanics II 4R-0L-4C W
Prerequisites: CE 321F
Corequisites: There are no corequisites for this course.
Hand methods for structural analysis of indeterminate structures: approximating drift of frames and solid walls, force method, moment distribution method, distribution of shear when there is a rigid diaphragm, and in-plane diaphragm forces.

CE 431 Structural Design in Steel I 3R-0L-3C S
Prerequisites: CE 321F

Corequisites: There are no corequisites for this course.
Covers the analysis and design of the basic elements of a steel structure using Load and Resistance Factor Design specifications. Includes tension and compression members, beams, beam-columns and connections.

CE 432 Structural Design in Concrete I 3R-0L-3C W

Prerequisites: CE 321F
Corequisites: There are no corequisites for this course.
Deals with the analysis and design of reinforced concrete beams, floor slabs, and columns using the Ultimate Strength Design procedure.

CE 436 Foundation Engineering 4R-0L-4C F

Prerequisites: CE 336F, and CE 432W
Corequisites: There are no corequisites for this course.
Covers the application of soil mechanics principles to foundation problems. Includes design of building foundations and retaining walls, stability analysis of open cuts and slopes, dewatering methods, and a study of the influence of local geology.

CE 441 Construction Engineering 2R-0L-2C W

Prerequisites: Junior class standing or consent of instructor
Corequisites: There are no corequisites for this course.
Covers planning and scheduling techniques for construction engineering: Gantt charts, critical path method, precedence diagramming method, activity on arrow and PERT methods, resource allocation, and time-cost tradeoffs.

CE 442 Cost Engineering 4R-0L-4C W

Prerequisites: Senior class standing
Corequisites: There are no corequisites for this course.
An investigation of some of the cost accounting, cost management and estimating techniques which are used in the construction industry. Various types of estimates will be considered, as will their multiple applications for project management. Special attention will be given to the preparation of detailed estimates based on quantity take-offs and to analyses of production productivity.

CE 445 Construction Methods & Equipment 4R-0L-4C F

Prerequisites: Senior class standing or consent of instructor
Corequisites: There are no corequisites for this course.
A study of economics, fundamental concepts and functional applications of major categories of construction equipment. Operational characteristics, capability and applicability of equipment to heavy, highway and major building construction projects.

CE 450 Civil Engineering Codes & Regulations 4R-0L-4C F

Prerequisites: There are no prerequisites for this course.
Corequisites: CE 486 1R-3L-2C F
Codes and regulations provide a baseline of expectation for civil engineering practice, and in turn, engineers influence the codes and regulations to create new best practices. This course examines how civil engineers interact with public policy and the legal system to work within CE codes and regulations. This course also includes discussion around the ASCE Code of Ethics and how it relates to the need for community engagement, professional norms, and professional best practices that impact engineering practice.

CE 460 Introduction to Environmental Engineering 4R-0L-4C S

Prerequisites: EM 301S or CHE 301F,S or ES 212W,S

Corequisites: There are no corequisites for this course.
Introduction to water pollution control, air pollution control, and solid and hazardous waste management. Topics include water treatment, wastewater treatment, impacts of pollutants on lakes and streams, and stream and air quality modeling.

CE 461 Environmental Engineering laboratory 1R-3L-2C S

Prerequisites: There are no prerequisites for this course.
Corequisites: CE 460 4R-0L-4C S
Emphasizes laboratory methods and interpretation of laboratory results for chemical analysis of water and wastewater.

CE 471 Water Resources Engineering 4R-0L-4C W

Prerequisites: EM 301S or CHE 301F,S or ES 212W,S
Corequisites: There are no corequisites for this course.
Presents an overview of the engineering, planning, design, and operation of various water resources projects. Topics include surface and groundwater hydrology, sanitary and storm sewer design, dams and reservoirs, water law, wetlands, and nonpoint source pollution.

CE 480 Geometric Design of Highways and Streets 4R-0L-4C W

Prerequisites: CE 380S
Corequisites: There are no corequisites for this course.
Highway planning and design with evaluation of multiple alignment alternatives; geometric design of highways: horizontal and vertical alignment, cross-sectional design; intersection design; earthwork measurements and quantities; reverse curve design; legal aspects of transportation engineering; proper use of the American Association of State Highway and Transportation Officials (AASHTO) design guidelines.

CE 481 Traffic Analysis & Design 4R-0L-4C F

Prerequisites: CE 380S
Corequisites: There are no corequisites for this course.
Study of fundamentals of traffic engineering; components of the traffic system; intersection types and design elements; basic variables of the traffic system (flow, capacity, level of service, delay); design and analysis of traffic signals and intersections; traffic control and traffic impact analysis; safety performance and traffic crash analysis; use of the Highway Capacity Manual and traffic analysis software.

CE 483 Railroad Engineering 4R-0L-4C S

Prerequisites: Junior standing or consent of instructor
Corequisites: There are no corequisites for this course.
Provides an overview of rail transportation: history, organizations, economics, safety, freight operations, track-train dynamics, signals and communications, motive power and equipment, track components, construction and maintenance. The basic objective of the course is to gain an understanding of railroads as a transportation industry that merges a number of engineering fields as well as other disciplines that contribute to the success of a complex, growth- oriented industry.

CE 486 Civil Engineering Design & Synthesis I 1R-3L-2C F

Prerequisites: ENGL H290F, W, S at least six from the following nine courses: CE 321, CE 336, CE 371, CE 380, CE 431, CE 432, CE 441, CE 460, CE 471
Corequisites: CE 450 4R-0L-4C F
Civil engineering projects submitted by corporate and governmental sponsors will be initiated by small teams of students to implement principles used in planning, design,

and synthesis. Learning objectives include contracting, concept development, concept feasibility, planning and scheduling design work, data collection for subsequent design.

CE 487 Technical System Design & Synthesis 2R-2L-2C W

Prerequisites: CE 486F

Corequisites: CE 488 1R-2L- 2C W

Technical system design of subdisciplinary elements of civil engineering projects submitted by corporate and governmental sponsors will be completed by individual team members to fulfill the needs of a team project initiated with CE486 and continuing in CE488. The “x” will be used to identify subdiscipline designation (c = general civil design, e= environmental, g = geotechnical, s = structural, t = transportation, w = water resources).

CE 488 Civil Engineering Design & Synthesis II 1R-2L- 2C W

Prerequisites: CE 486F

Corequisites: CE 487 2R-2L-2C W

Project management by small teams for civil engineering projects submitted by corporate and governmental sponsors will continue. Learning objectives include coordinate of major design work in subdisciplines, progress reporting to the client, critical path model management to keep the project on schedule to fulfill the needs of a team project initiated with CE486 and continuing in CE487.

CE 489 Civil Engineering Design & Synthesis III 1R-3L-2C S

Prerequisites: CE 487W, and CE 488W

Corequisites: There are no corequisites for this course.

Civil engineering projects submitted by corporate and governmental sponsors will be completed. Final recommendations and engineering designs will be presented to the sponsors with due attention to the social, economic, and environmental constraints of the project. Learning objectives include construction planning and cost, final reporting, and public presentation of findings.

CE 490 Directed Studies CE 490 Directed Studies 1-4C Arranged F,W,S

Prerequisites: Approval of department head, adviser, and course instructor

Corequisites: There are no corequisites for this course.

Provides the opportunity for the civil engineering students to do a selected project of mutual interest to them and a faculty member or make up for deficiencies in transfer credit hours and topics. Credit is assigned up to 4 credits per term with a maximum of 8 credits toward graduation.

CE 510 Environmental Engineering Externship 0R-12L-4C See Dept

Prerequisites: Grad or consent of instructor

Corequisites: There are no corequisites for this course.

Environmental engineering externship approved by the department.

CE 520 Structural Engineering Externship 0R-12L-4C

Prerequisites: Grad or consent of instructor

Corequisites: There are no corequisites for this course.

Structural engineering externship approved by the department.

CE 521 Matrix Methods for Structural Analysis 4R-0L-4C F

Prerequisites: CE 321F

Corequisites: There are no corequisites for this course.

Derivation of the direct stiffness method for truss and frame elements. Derivation of the finite element method for 2D plate elements. Requires development of computer programs to implement the direct stiffness method.

CE 522 Structural Dynamics 4R-0L-4C W

Prerequisites: Grad or consent of instructor

Corequisites: CE 521 4R-0L-4C F

Analysis and behavior of structural members and systems subject to dynamic loads including basic theory for single-degree-of-freedom and multi-degree-of-freedom analytical models of civil engineering structures; seismic hazard analysis and methods of analysis for seismic loads; response spectra; time history; and linear and nonlinear methods.

CE 523 Advanced Solid Mechanics 4R-0L-4C W

Prerequisites: Grad or consent of instructor

Corequisites: There are no corequisites for this course.

The fundamentals of elasticity are introduced and related to various problems such as beams on elastic foundations, unsymmetrical bending, torsion of thin walled members, and curved beams. Introduction to the analysis and modeling techniques for existing and repaired structures. Design of retrofit measures for a variety of structures using advanced composite materials.

CE 524 Building Design 4R-0L-4C S

Prerequisites: CE 421W* *Graduate standing, or consent of instructor and CE 421

Corequisites: There are no corequisites for this course.

Advanced structural analysis and design concepts for buildings: material nonlinearity, plastic design, pushover analysis, bracing, floor vibrations. Course culminates in a design project.

CE 525 Bridge Engineering 4R-0L-4C S

Prerequisites: CE 421W, and CE 431S, and CE 432W

Corequisites: There are no corequisites for this course.

Deals with the various types of bridge structures, the materials of which they are constructed and the manner in which loads are transmitted to the foundation. Introduces concepts of bridge engineering by providing the students with the necessary knowledge and skills to apply the AASHTO LRFD specifications for the analysis and design of highway and bridge superstructure components.

CE 532 Structural Design in Concrete II 3R-3L-4C F

Prerequisites: CE 432W

Corequisites: There are no corequisites for this course.

Advanced topics in reinforced concrete analysis and design such as serviceability. slender columns, two-way slabs, and strut-and-tie modeling.

CE 533 Connections & Detailing 4R-0L-4C S

Prerequisites: CE 431S, and CE 432W

Corequisites: There are no corequisites for this course.

Analysis and design of structural systems with emphasis on detailing requirements; behavior of bolted and welded connections, including gusset plates, moment-resistant connections, and simple connections; design and analysis of base plate and anchoring systems; and an introduction to seismic detailing requirements.

CE 535 Structural Design in Prestressed Concrete 4R-0L-4C F

Prerequisites: CE 432W

Corequisites: There are no corequisites for this course.
Analysis and design of prestressed concrete stru ctures. Beams, slabs, loss of prestress, deflections, precast construction.

CE 537 Retaining Structure Design 4R-0L-4C W

Prerequisites: CE 336F, and CE 432W
Corequisites: There are no corequisites for this course.
Covers the determination of earth pressures, selection of appropriate retaining wall types, and design of commonly used retaining structures. Includes both external (geotechnical) and internal (structural) analysis.

CE 562 Advanced Wastewater Treatment 4R-0L-4C

Prerequisites: CE 460S
Corequisites: There are no corequisites for this course.
Covers the theory, design and analysis of biological processes for the treatment of wastewater. Treatment processes include suspended and attached growth processes, aerobic and anaerobic processes, biological nutrient removal, aeration and gas transfer, and biosolids processing.

CE 563 Advanced Water Treatment 4R-0L-4C

Prerequisites: CE 460S
Corequisites: There are no corequisites for this course.
Covers the theory, design and analysis of physical and chemical processes for the treatment of drinking water. Treatment processes include coagulation and flocculation, gravity separation, granular and membrane filtration, disinfection, air stripping, adsorption, ion exchange, and disinfection.

CE 564 Aquatic Environmental Chemistry 4R-0L-4C F

Prerequisites: Senior or Graduate student standing
Corequisites: There are no corequisites for this course.
Emphasis equilibrium relationships of importance in understanding both natural waters and wastewaters. The carbonate system and the concept of pH as a master variable are stressed.

CE 565 Solid & Hazardous Waste Regulation & Treatment 4R-0L-4C On Demand

Prerequisites: CE 460S
Corequisites: There are no corequisites for this course.
Covers solid and hazardous waste management, including characterization, collection system design, waste minimization, design of landfills and incinerators, and remediation principles.

CE 567 Applied Hydrologic Modeling 4R-0L-4C

Prerequisites: CE 471W
Corequisites: There are no corequisites for this course.
Watershed planning and stormwater management strategies are examined using computer simulation models. With an emphasis on conceptual foundation, students will be introduced to some of the most widely used models in the fields of hydrology and stormwater quantity management. Topics examined include watershed loss, transform, and routing methods, as well as model configuration, calibration, and evaluation.

CE 568 Surface Water Quality Modeling 4R-0L-4C S

Prerequisites: CE 460S or consent of instructor
Corequisites: There are no corequisites for this course.

Covers the mathematical analysis of transport and fate of pollutants in natural surface waters and their impact on water quality using analytical and numerical models. Includes one- and two-dimensional steady-state and transient models. Pollutants examined include oxygen-demanding organics, nutrients and toxic compounds.

CE 570 Modeling Open Channel Hydraulics 4R-0L-4C W

Prerequisites: CE 371F

Corequisites: There are no corequisites for this course.

Presents steady and unsteady flow problems in open channels and pipes, dealing with mechanics of flow over rigid and mobile boundaries. Covers analysis of river dynamics and hydraulic principles in stormwater conveyance through numerical and computer modeling.

CE 571 Environmental River Mechanics 3R-3L-4C S

Prerequisites: CE 371F

Corequisites: There are no corequisites for this course.

Concepts of fluvial geomorphology and fluvial hydraulics are examined, including natural stream flow, sediment transport, and ecological processes in alluvial rivers. Students will apply these principles to solve common design problems of channel instability and rehabilitation of impaired streams. Students will visit local streams to perform field data collection of channel geometry, bed and bank material, and water quality.

CE 573 Groundwater Analysis 4R-0L-4C

Prerequisites: CE 471W

Corequisites: There are no corequisites for this course.

Covers hydrodynamics of flow through porous media. The primary emphasis is on the analysis of steady and unsteady flow in confined and unconfined aquifers. Groundwater modeling is introduced.

CE 589 Environmental Engineering Design & Synthesis 4R-12L-8C F,W,S

Prerequisites: Graduate Standing

Corequisites: There are no corequisites for this course.

Environmental engineering projects submitted by external sponsors are undertaken by small teams of students to develop advanced principles used in planning, design, and synthesis. Final recommendations and engineering designs are presented to the sponsors with due attention to the social, economic, and ethical constraints of the project. Each student team also prepares a manuscript of the completed project that is suitable for publication n a peer-reviewed professional journal. The final report to the sponsor and the manuscript prepared by the team must be approved by the team's graduate committee comprised of at a minimum, the course instructor, a faculty mentor from the CE department, and a faculty external to the CE department.

CE 590 Special Problems 2/4R-0L-2/4C F,W,S

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

Special problems or reading by special arrangement with the faculty.

CE 597 Special Projects in Civil Engineering Variable Credit F,W,S

Prerequisites: Permission of instructor

Corequisites: There are no corequisites for this course.

A special project, or series of problems, or research problem is assigned to or selected by the student. A comprehensive report must be submitted at the conclusion of the project. Not to be used as a substitute for CE 599, Thesis Research. Variable credit. May be repeated up to a maximum of eight credits.

CE 598 Special Topics in Civil Engineering Variable Credit
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Studies in advanced topics of current interest.

CE 599 Thesis Research As assigned F,W,S
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Graduate students only. Credits as assigned; however, not more than 12 credits will be applied toward the requirements of the M.S. degree.

CE 699 Professional Experience 1R-0L-1C
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The work experiences should be informative or integral to the advancement or completion of the student's program requirements. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

Computer Engineering

Computer Engineers (CPE) are electrical engineers that have additional training in the areas of software design and hardware-software integration. Common CPE tasks include writing embedded software for real-time microcontrollers, designing VLSI chips, working with analog sensors, designing mixed signal circuit boards, and designing operating systems. Computer engineers are also well-suited for research in the field of robotics, which relies on using computers together with other electrical systems. Below is a recommended plan of study for CPE.

CPE program educational objectives

Computer Engineering graduates shall:

1. Practice excellence in their profession using a systems approach encompassing technological, economic, ethical, environmental, social, and human issues within a changing global environment;
2. Function independently and in leadership positions within multidisciplinary teams;
3. Continue life-long learning by acquiring new knowledge, mastering emerging technologies, and using appropriate tools and methods;
4. Adapt and independently extend their learning to excel in fields about which they are passionate;
5. Strengthen teams and communities through collaboration, effective communication, public service, and leadership.

CPE Student Learning Outcomes

At the time of graduation, students will have demonstrated:

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.

The computer engineering program is accredited by the Engineering Accreditation Commission of ABET, https://www.abet.org, under the commission's General Criteria and Program Criteria for Electrical, Computer, Communications, Telecommunication(s), and Similarly Named Engineering Programs.

COMPUTER ENGINEERING CORE COURSES

Course Number	Course Title	Credits
ECE160	Engineering Practice	2
ECE180	Introduction to Signal Processing	4
ECE203	DC Circuits	4
ECE204	AC Circuits	4
ECE205	Circuits and Systems	4
ECE230	Introduction to Embedded Systems	4
ECE233	Introduction to Digital Systems	4
ECE250	Electronic Device Modeling	4
ECE300	Continuous-Time Signals Systems	4
ECE312	Communication Networks	4
ECE332	Computer Architecture II	4
ECE343	High Speed Digital Design	4
ECE362	Principles of Design	3
ECE380 or ECE320*	Discrete-Time Signals and Systems or	4

	Linear Control Systems	
ECE460	Engineering Design I	3
ECE461	Engineering Design II	4
ECE462	Engineering Design III	2
CSSE120	Intro to Software Development	4
CSSE220	Object-Oriented Software Dev	4
CSSE230	Data Structure & Algorithm Analysis	4
CSSE232	Computer Architecture I	4
CSSE332	Operating Systems	4
PH111	Physics I	4
PH112	Physics II	4
PH113	Physics III	4
MA111	Calculus I	5
MA112	Calculus II	5
MA113	Calculus III	5
MA221	Matrix Algebra & Differential Equations I	4
MA222	Matrix Algebra & Differential Equations II	4
MA381	Intro to Probability	4
MA374	Combinatorics	4
HUMH190	First-Year Writing Seminar	4
ENGLH290	Technical & Professional Communication	4
RHIT100	Foundations of RHIT Success	1
	ECE Area Electives	12
	HSSA Electives	28
	Math/Sci Elective	4
	Restricted Science Elective	4
	Technical Elective	4
	Free Electives	8

*CPE students who are also earning the robotics minor MUST take ECE320.

SECOND MAJOR IN COMPUTER ENGINEERING

The ECE Department will not allow the following second major combinations:

1. Degree in Electrical Engineering and a Second Major in Computer Engineering.
2. Degree in Computer Engineering and a Second Major in Electrical Engineering.

MINOR IN ELECTRICAL AND COMPUTER ENGINEERING (ECE)

The Minor in ECE is designed to allow students to add another dimension to their Rose-Hulman degree.

Advisor: ECE Department Head

Requirements for Minor in ECE

- ECE203, or ES203, or both ES213 and ES213L
- Plus five additional ECE courses, except ECE160, ECE362, ECE460, ECE461, ECE462, ECE466, and ECE206

AREAS OF CONCENTRATION

ENHANCED STUDY IN COMMUNICATION SYSTEMS

Communications Certificate
Certificate Advisor: Dr. Yong Jin Kim

Information about Available Certificates

Plan of Study

Freshman

Fall

Course	Credit
PH 111 Physics I	4
MA 111 Calculus I	5
RHIT 100 Foundations for Rose-Hulman Success	1
HUM H190 First-Year Writing Seminar or HSSA Elective	4
ECE 160 Engineering Practice	2
	Total Credits: 16

Winter

Course	Credit
PH 112 Physics II	4
MA 112 Calculus II	5
CSSE 120 Intro to Software Development	4
HUM H190 First-Year Writing Seminar or HSSA Elective	4

	Total Credits: 17

Spring

Course	Credit
PH 113 Physics III	4
MA 113 Calculus III	5
ECE 203 DC Circuits	4
ECE 180 Introduction to Signal Processing	4
	Total Credits: 17

Sophomore

Fall

Course	Credit
MA 221 Matrix Algebra & Differential Equations I	4
CSSE 220 Object Oriented Software Development	4
ECE 204 AC Circuits	4
ECE 233 Introduction to Digital Systems	4
	Total Credits: 16

Winter

Course	Credit
MA 222 Matrix Algebra & Differential Equations II	4
ECE 230 Introduction to Embedded Systems	4
ECE 205 Circuits & Systems	4
CSSE 230 Data Structures & Algorithm Analysis	4
	Total Credits: 16

Spring

Course	Credit
MA 381 Introduction to Probability with Applications to Statistics	4
ECE 250 Electronic Device Modeling	4
ECE 300 Continuous-Time Signals & Systems	4
HSSA Elective	4

	Total Credits: 16

Junior

Fall

Course	Credit
MA 374 Combinatorics	4
CSSE 232 Computer Architecture I	4
ECE 380 Discrete-Time Signals & Sys or ECE 320* Linear Control Systems	4
ENGL H290 Technical & Professional Communication	4
	Total Credits: 16

Winter

Course	Credit
ECE 312 Communication Networks	4
CSSE 332 Operating Systems	4
HSSA Elective	4
Math/Science Elective	4
	Total Credits: 16

Spring

Course	Credit
ECE 332 Computer Architecture II	4
ECE 343 High Speed Digital Design	4
ECE 362 Principles of Design	3
HSSA Elective	4
	Total Credits: 15

Senior

Fall

Course	Credit
ECE 460 Engineering Design I	3
ECE Area Elective	4
Restricted Science Elective	4
HSSA Elective	4
	Total Credits: 15

Winter

Course	Credit
ECE 461 Engineering Design II	4
ECE Area Elective	4
Technical Elective	4
HSSA Elective	4
	Total Credits: 16

Spring

Course	Credit
ECE 462 Engineering Design III	2
ECE Area Elective	4
HSSA Elective	4
Free Elective	4
Free Elective	4
	Total Credits: 18

*** CPE students who are also earning the robotics minor MUST take ECE320.**

AREA ELECTIVES - A total of 12 credit hours are required in this category. Eight of these credit hours must bear an ECE prefix; the other four can bear either ECE or CSSE prefix. At least eight of these credit hours must be at the 400 level or above; the other four can be at the 300 level or above. No more than 4 credit hours of ECE498 can be counted towards Area Electives and ECE398 cannot be counted as Area Elective credit. Exceptions can be made to these requirements with ECE Department Head and Advisor approval.

TECHNICAL ELECTIVE - CHEM and BIO 100 level courses or other courses at the 200 level or above NOT bearing an HSSA prefix. Exceptions can be made for the 200 level requirement with Department Head and Advisor approval.

FREE ELECTIVE - Free electives may be selected from any RHIT courses other than ECE206, ES213, or ES213L.

RESTRICTED SCIENCE ELECTIVE - (4 credit hours required) Must take one of the following electives including the lab: CHEM111, PH255, PH405, BIO110, BIO120, BIO130.

MATH/SCIENCE ELECTIVE - MA100-Level and PH100-Level credits cannot be used to satisfy this elective. MA 351-356 Problem Solving Seminar may not be used for these electives. Courses that are cross-listed with any engineering courses will not satisfy these electives.

Computer Engineering Course Descriptions

ECE 160 Engineering Practice 0R-4L-2C F,W
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
An introduction to electrical and computer engineering, systems engineering design, programming, microcontrollers, soldering and circuit building. Students will work individually and on teams to complete projects and create a system for an end of term

competition. Students will also learn about technical documentation and communication. Topics include functions, arrays, conditionals, loops, Boolean algebra, wireless communication, resistors, transistors, diodes motors, sensor, analog and digital inputs and outputs.

ECE 180 Introduction to Signal Processing 3R-3L-4C F,W,S

Prerequisites: MA 112, and ECE 160 or CSSE 120 or ENGD 120 or ME 123 or prior programming experience

Corequisites: There are no corequisites for this course.

An introduction to discrete-time signal processing applied to audio, images, and video. Topics include phasor representation of sinusoidal signals, complex arithmetic, sampling, signal spectra, linear time-invariant systems, frequency response, convolution, filter implementation, and MATLAB programming. Integral laboratory.

ECE 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

ECE 203 DC Circuits 3R-3L-4C S, F

Prerequisites: MA 111, and PH 112

Corequisites: There are no corequisites for this course.

A review of the definition of voltage, current, energy and power. An introduction to Ohm's Law, ideal DC independent and dependent voltage and current sources, resistors, inductors, capacitors, and operational amplifiers. Circuit analysis and simplification by using series, parallel, and Wye-Delta reduction, Kirchhoff's laws, mesh and nodal analysis, Thevenin, Norton and Maximum Power Theorems, superposition, and source transformations. An integral laboratory to build electric circuits and measure voltage, current, resistance and power.

ECE 204 AC Circuits 3R-3L-4C F,W

Prerequisites: PH 113*, and either ECE 203** or ENGD 120** or BE 131**, or both ES 213**, and ES 213L** *Prerequisite or concurrent registration **with a grade of C or better

Corequisites: There are no corequisites for this course.

Capacitance, Self and Mutual Inductance. Root-mean-square values of waveforms. Application of phasors to sinusoidal steady-state. Impedance of circuit elements. Mesh and Nodal Analysis applied to ac circuits. Thevenin and Norton theorems applied to ac circuits. Single-phase ac power. Power factor correction. Voltage regulation and efficiency of feeders. Balanced three-phase systems. Ideal and non-ideal transformer models. Integral laboratory.

ECE 205 Circuits & Systems 3R-3L-4C W,S

Prerequisites: ECE 180 or BE 321, and HUM H190, and MA 222, and either ECE 203* or ENGD 120*, or both ES 213*, and ES 213L* *with a grade of C or better; ** or concurrent registration

Corequisites: There are no corequisites for this course.

Introduction to 1st and 2nd order circuits and review of differential equations. Bode plots. System classification, impulse and step response, convolution. Laplace and inverse Laplace transforms, block and signal flow diagrams. Benefits of feedback. Modeling and simulating electrical systems. Matlab and Simulink. Integral laboratory.

ECE 206 Elements of Electrical Engineering 4R-0L-4C W,S

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

A course designed for engineers (other than electrical or computer) covering analysis of passive circuits, introduction to op-amps, instrumentation, sinusoidal steady-state, a-c power, and induction motors. EE and CPE majors may not take this course.

ECE 230 Introduction to Embedded Systems 3R-3L-4C W,S

Prerequisites: ECE 233, CSSE 120, and ECE 160

Corequisites: There are no corequisites for this course.

Sensors and actuators. Input and output devices. Microcontroller architecture. Standard communications protocols. Interrupt generation and processing. Data representation and storage. Memory management. The C programming language and programming styles. Integral laboratory and a term project.

ECE 233 Introduction to Digital Systems 3R-3L-4C F, W, S

Prerequisites: CSSE 120 or ECE 160 or ENGD 120

Corequisites: There are no corequisites for this course.

Number systems, Binary arithmetic, logic gates, forming logic circuits. Boolean algebra, Karnaugh maps. Propagation delay, hazards, common Combinational logic circuits, structures, and design. Contraction, latches, flip-flops, finite state machines, counters, Sequential circuit timing, and designing Sequential circuits. Register design, control and datapath design. Basic computer architecture, including memory. Integral laboratory.

ECE 250 Electronic Device Modeling 3R-3L-4C S,F

Prerequisites: ECE 204 or ECE 205, ES 203* or ES 213*, and ES 213L* * with grade of B or better

Corequisites: There are no corequisites for this course.

Modeling, analysis, and simulation of electronic circuits that contain two-terminal and threeterminal semiconductor devices. Large-signal, biasing, and small-signal analysis models. Introduction to wave shaping circuits, switching circuits, and amplifiers. Integral laboratory.

ECE 300 Continuous-Time Signals & Systems 3R-3L-4C F, S

Prerequisites: ECE 205, and MA 222, and MA 381* *Prerequisite or concurrent registration

Corequisites: There are no corequisites for this course.

Signal modeling. Fourier series and Fourier transforms. Response of systems to periodic and aperiodic signals. Filter characterization and design. Ideal and practical sampling. Use of numerical analysis software. Integral laboratory

ECE 310 Communication Systems 3R-3L-4C W, S

Prerequisites: ECE 380

Corequisites: There are no corequisites for this course.

Transmission of information over bandlimited, noisy communication channels. Line codes, probability of error, intersymbol interference. Modulation techniques, synchronization and frequency conversion. Integral laboratory.

ECE 312 Communication Networks 4R-0L-4C F, W

Prerequisites: MA 381, and CSSE 120

Corequisites: There are no corequisites for this course.

Layered architectures. Circuit and packet switching. The ISO Reference Model. Point-to-point protocols, error control, framing. Accessing shared media, local area networks. Virtual circuits, datagrams, routing, congestion control. Queuing theory. Reliable message transport, internetworking.

ECE 320 Linear Control Systems 3R-3L-4C W,S

Prerequisites: ECE 300*, and ECE 230* or ME 430*
Corequisites: There are no corequisites for this course.
Analysis of linear control systems using classical and modern control theories in both continuous and discrete time. Plant representation, closed loop system representation, time response, frequency response, concept of stability. Root locus, Bode, and Nyquist methods. Computer modeling and simulation of feedback systems, implementation of discrete-time algorithims on microcontrollers.

Prerequisite Notes:
ECE300 and either ECE230 or ME430

ECE 332 Computer Architecture II 4R-0L-4C W, S
Prerequisites: CSSE 232
Corequisites: There are no corequisites for this course.
Instruction-Level Parallelism. Pipelining. Data Hazards. Exceptions. Branch Prediction. Multilength Instructions. Loop Unrolling. TI C6000 Digital Signal Processor. Cache. Memory. MSP430 Microcontroller. PIC Microcontroller. Intel Itanium. Multiprocessors. Hardware Multithreading. Graphics Processors. Supercomputers.

ECE 340 Electromagnetic Fields 4R-0L-4C F,W
Prerequisites: ECE 204 , and MA 222
Corequisites: There are no corequisites for this course.
Static and dynamic fields. Electric and magnetic properties of materials. Energy, force and power. Resistors, capacitors, and inductors. Application in sensing and actuation. Maxwell's equations. Introduction to electromagnetic waves. Use of vector calculus and numeric approximation. Technical reports and/or term papers.

ECE 341 Electromagnetic Waves 4R-0L-4C W,S
Prerequisites: ECE 340
Corequisites: There are no corequisites for this course.
Wave propagation and reflection. Power and lossy materials. Quasistatic analysis. Steady-state and transient analysis of transmission lines. Application in high-speed systems. Introduction to antennas. Technical reports and/or term papers.

ECE 342 Introduction to Electromagnetic Compatibility 3R-3L-4C F,S
Prerequisites: ECE 300 and Computer Engineering Major
Corequisites: There are no corequisites for this course.
Electromagnetic compatibility (EMC) regulations and measurement. Frequency behavior of passive components. Electromagnetic fields and waves. Transient behavior of transmission lines. Dipole and monopole antennas. Four coupling mechanisms: electrical and magnetic fields, common impedance, and electromagnetic wave. Conducted emissions. Radiated emissions. Electromagnetic shielding and grounding.

ECE 343 High-Speed Digital Design 3R-3L-4C W,S
Prerequisites: ECE 300 and Computer Engineering Major
Corequisites: There are no corequisites for this course.
Signal path modeling through connecting lengths of transmission lines with lumped element models of discontinuities. Circuit parameters from geometries and material properties for resistance, capacitance, inductance and transmission line segments. Lossless and lossy transmission line circuit modeling. High-frequency and high-speed behavior of passive components. Frequency spectrum of digital signals. Digital device driver and receiver modeling. Transmission line impedance discontinuity and termination techniques. Electric and magnetic field coupling mechanisms for capacitive and inductive crosstalk. Ground noise, power plane noise and resonance. Signal and

power integrity issues in high-speed digital systems at both the printed-circuit board and chip levels.

ECE 351 Analog Electronics 3R-3L-4C F,W

Prerequisites: ECE 205, and ECE 250

Corequisites: There are no corequisites for this course.

Amplifier design and analysis including discrete and integrated circuit topologies. Cascaded amplifier, input and output stages, frequency response. Linear and non-linear op-amp circuits. Introduction to the non-ideal properties of op-amps. Integral laboratory.

ECE 362 Principles of Design 3R-0L-3C W,S

Prerequisites: ECE 204 , and ECE 205, ECE 230, and ECE 233, and ECE 250, and ECE 300

Corequisites: There are no corequisites for this course.

A formal design course that emphasizes the design process. Project management, project reporting and decision-making are learned by student teams as they carry a project through several stages of a formal design process.

ECE 370 Electric Machinery 3R-3L-4C W,S

Prerequisites: ECE 204

Corequisites: There are no corequisites for this course.

An introduction to electric machinery fundamentals. Operating principles and detailed analysis of single-phase and three-phase transformers, power electronics in the context of generators and motors, synchronous generators and motors, induction motors and generators, and dc motors and generators. Integral laboratory.

ECE 371 Conventional & Renewable Energy Systems 3R-3L-4C W

Prerequisites: ECE 204

Corequisites: There are no corequisites for this course.

Conventional and modern sources of energy for power generation in electric power industry with the imposed economic, regulatory, and environmental constraints. Wind, solar-photovoltaic, micro-hydropower, biomass, and fuel cell systems. Integral laboratory.

ECE 380 Discrete-Time Signals and Systems 4R-0L-4C F,W

Prerequisites: ECE 300, and MA 381

Corequisites: There are no corequisites for this course.

System properties: linearity and time-invariance. Sampling and reconstruction. Convolution in discrete-time systems. Z-transform, FIR and IIR filters. Discrete-time filter design. Discrete Fourier transform. Random Variables and Random Processes.

ECE 398 Undergraduate Projects 1-4C

Prerequisites: Arranged Prereq: Consent of instructor

Corequisites: There are no corequisites for this course.

Special design or research projects.

ECE 412 Software Defined Radio 4R-0L-4C See Dept Advising Site

Prerequisites: ECE 380

Corequisites: There are no corequisites for this course.

Essential concepts of wireless communications. Software defined radio (SDR) architecture. Analog and digital modulation formats. Transmitter and receiver system design and implementation methods. Synchronization techniques. Term project.

ECE 414 Wireless Systems 4R-0L-4C W

Prerequisites: ECE 310

Corequisites: There are no corequisites for this course.

Introduction to wireless communications and networks. Wireless channel models, vector space, modulation and demodulation, optimal receiver design, equalization, channel capacity, multipleaccess techniques, spread spectrum, and multiple-antenna systems. Additional recommended prerequisite: MA371 or MA373 with a grade of B or higher.

ECE 415 Wireless Electronics 2R-6L-4C

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

Design, fabrication, and testing of a high frequency transmitter-receiver system including but not limited to oscillators, mixers, filters, amplifiers, and matching networks. Integral laboratory.

ECE 416 Introduction to MEMS: Fabrication & Applications 3R-3L-4C S

Prerequisites: Junior or Senior standing

Corequisites: There are no corequisites for this course.

Properties of silicon wafers; wafer-level processes, surface and bulk micromachining, thin-film deposition, dry and wet etching, photolithography, process integration, simple actuators. Introduction to microfluidic systems. MEMS applications: capacitive accelerometer, cantilever and pressure sensor. Cross-listed with CHE 405, EP 410, and ME 416.

ECE 418 Fiber Optic Systems 4R-0L-4C S

Prerequisites: ECE 310 Consent of instructor

Corequisites: There are no corequisites for this course.

Analysis and design of common photonic systems such as fiber optic communication links, optical sensing systems, and optical networks. Topics include basic architectures, component overview, system design, and expected degradations along with mitigation techniques. An oral presentation of a technical paper is required.

ECE 419 Advanced MEMS: Modeling and Packaging 3R-3L-4C F

Prerequisites: EP 410 or equivalent course

Corequisites: There are no corequisites for this course.

Design process, modeling; analytical and numerical. Actuators; dynamics and thermal issues. Use of software for layout and simulation. Characterization and reliability of MEMS devices. Electrical interfacing and packaging of MEMS. Microsensors, microfluidic systems, applications in engineering, biology, chemistry, and physics. Cross-listed with EP 411, and CHE 419.

ECE 420 Discrete-Time Control Systems 4R-0L-4C See Dept Advising Site

Prerequisites: ECE 320

Corequisites: There are no corequisites for this course.

Sampled systems and z-transforms. Transfer function and state-variable models of systems. Discrete-time control of systems including state variable feedback and observer construction.

ECE 425 Introduction to Mobile Robotics 3R-3L-4C W

Prerequisites: CSSE 120, and ECE 320 or ME 406 or BE 350 or CHE 340

Corequisites: There are no corequisites for this course.

This course will introduce the basic principles of mobile robotics history, theory, hardware and control. Topics will include robot components, effectors and actuators, locomotion, sensors, feedback control, control architectures, representation, localization and navigation. This is a project-oriented course and the student will have hands-on experience with a real mobile robot. The student will be required to complete several laboratory assignments and a multidisciplinary team design project.

ECE 430 Microcontroller-Based Systems 3R-3L-4C F

Prerequisites: ECE 250* *For ECE students, consent of instructor for other students.

Corequisites: There are no corequisites for this course.

Microcontroller register set, addressing modes and instruction set. Microcontroller peripheral support modules. Assembly language and C programming. Fundamental data structures. Interrupts. Real time programming. Data communications. Microcontroller interface to displays, digital and analog devices, sensors, and actuators. Embedded system design, implementation and applications. Integrated development environment. Formal final report and oral presentation. Integral laboratory. Credit cannot be obtained for both ECE 331 and ECE 430.

ECE 433 Advanced Digital System Design with Verilog 3R-3L-4C F

Prerequisites: ECE 233

Corequisites: There are no corequisites for this course.

Concepts and designs of combinational and sequential digital systems; Modern design methodology; ASM and ASMD charts for behavioral modeling; Synthesizable Verilog descriptions and synthesis techniques; Design verification and functional simulations; FPGA implementations of digital systems; Timing analysis and constraints; Storage devices; Implementation options; I/O clocking techniques; Synchronous and asynchronous designs; Complex digital systems; IP core applications. Integrated Development Environment. Integral laboratory.

ECE 434 Embedded Linux 3R-3L-4C W

Prerequisites: CSSE 332 or ECE 230 with a grade of B or better; or graduate standing, Operating Systems and Linux experience.

Corequisites: There are no corequisites for this course.

Brief introduction to Linux on an embedded processor. Software development in various languages (C, shell scripts, Python, JavaScript, etc.). Hardware interfacing. Kernel development. Software tools (IDE, gcc, make, node.js, etc.)

ECE 436 Internet of Things 4R-0L-4C S

Prerequisites: ECE 230 or CSSE 132, and ECE 312 or CSSE 432 or consent of instructor

Corequisites: There are no corequisites for this course.

Introduction to the design and development of an Internet of Things (IoT) solution. Provides breadth of knowledge on a broad range of topics, such as sensors, communication, power, cloud storage, data analysis, automation, privacy and security. Focuses on a team design project to provide a complete IoT solution for a real-world application. This is a required course for the minor in Internet of Things for students earning a primary or secondary major in EE, CPE, CS, or SE. Students cannot earn credit for both MDS210 and ECE436.

ECE 452 Power Electronics 3R-3L-4C F

Prerequisites: ECE 250

Corequisites: There are no corequisites for this course.

Analysis and design of networks that use electronic devices as power switches. Silicon-controlled rectifiers, power transistors, power MOSFETS, and IGBTs are used to form phase-controlled rectifiers, AC voltage controllers, choppers, and inverters. Integral laboratory.

ECE 454 System Level Analog Electronics 3R-3L-4C W

Prerequisites: ECE 351

Corequisites: There are no corequisites for this course.

Analysis and design of Op-Amp circuits: wave shaping circuits, Schmitt triggers, power amplifiers, high power buffers, controlled current sources, peak detectors, sample and hold circuits. Precision Op-Amp Circuits. Non-ideal properties of Op-Amps. Integral laboratory.

ECE 460 Engineering Design I 1R-6L-3C F

Prerequisites: ECE 362, and either ECE 230*, and ECE 310*, and ECE 320*, and ECE 341*, and ECE 351*, and ECE 370* or ECE 371*, and ECE 380* or CSSE 332**, and CSSE 230**, and ECE 250**, and ECE 230**, and ECE 312**, and ECE 332**, and ECE 343**, and either ECE 380** or ECE 320** *For EE: Prereq or concurrent registration in the remainder of course. **For CPE: Prereq or concurrent registration in the remainder of course.
Corequisites: There are no corequisites for this course.
A continuation of a sequence of formal design courses that emphasizes completion of a client-driven project using a formal design process. Student teams carry a project from inception to completion to satisfy the need of a client. Integral laboratory.

ECE 461 Engineering Design II 1R-9L-4C W

Prerequisites: ECE 460
Corequisites: There are no corequisites for this course.
Continuation of the design project from ECE460. Integral laboratory.

ECE 462 Engineering Design III 1R-3L-2C W,S

Prerequisites: ECE 461
Corequisites: There are no corequisites for this course.
Completion of the design project from ECE 460 and ECE 461. Integral laboratory.

ECE 470 Power Systems Analysis I 3R-3L-4C F

Prerequisites: ECE 370
Corequisites: There are no corequisites for this course.
Modeling of power system components that encompass transmission lines, power transformers, synchronous generators, and loads for power system representation and per unit analysis. Formulation of power system representation in the context of power flow analysis. The industry standard Siemens-PTI PSS/E software package will be used for solutions of the large-scale power flow. Economic dispatch by optimum allocation of generation, control of system voltage profile, and real and reactive power flow control by tap-changing transformers. Integral laboratory.

ECE 471 Power Systems Analysis II 4R-0L-4C W

Prerequisites: ECE 470
Corequisites: There are no corequisites for this course.
Modeling of power system components that encompass transmission lines, power transformers, synchronous generators for analysis of power systems during balanced and unbalanced faults/short-circuits with symmetrical components. The industry standard ASPEN One-Liner software package will be used for simulation of large-scale faulted systems. Power system grounding and its impact on fault levels. Power system stability and generator rotor dynamics phenomenon with use of equal-area criterion. Modern approaches to power system stability analysis are introduced. Integral laboratory.

ECE 472 Power Systems Protection 3R-3L-4C S

Prerequisites: ECE 470, and ECE 471
Corequisites: There are no corequisites for this course.
Design and application of relaying schemes for protection of transformers, buses, distribution lines, transmission lines, generators, motors, capacitors, and reactors. Integral laboratory.

ECE 473 Control of Power Systems 3R-3L-4C W

Prerequisites: Senior standing or consent of instructor
Corequisites: There are no corequisites for this course.
Principles of interconnected operation of power systems. Optimum scheduling of generation using economic dispatch and unit commitment. Primary and secondary

load-frequency control. Voltage and reactive-power flow control. Principles of state estimation. Integral laboratory.

ECE 480 Introduction to Image Processing 3R-3L-4C W

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

Basic techniques of image processing. Discrete and continuous two dimensional transforms such as Fourier and Hotelling. Image enhancement through filtering and histogram modification. Image restoration through inverse filtering. Image segmentation including edge detection and thresholding. Introduction to image encoding. Relevant laboratory experiments.

ECE 481 Electronic Music Synthesis 4R-0L-4C S

Prerequisites: ECE 380

Corequisites: There are no corequisites for this course.

Analog synthesis techniques. Instrument control using MIDI. FM, additive and subtractive synthesis. Physical modeling and sound spatialization. Course project.

ECE 483 DSP System Design 3R-3L-4C F

Prerequisites: ECE 380, and MA 381

Corequisites: There are no corequisites for this course.

Study of finite word length effects in DSP systems. Cascaded filter structures. Coefficient quantization, roundoff noise, scaling for overflow prevention. Discrete-time noise, filtering noise, power spectral density. Polyphase filtering, interpolation and decimation. Implementation and system design and test issues for a SSB communication system. Integral laboratory based on a fixed point programming project.

ECE 497 Special Topics in Electrical Engineering 1-4C

Prerequisites: Arranged prerequisite consent of instructor and department head

Corequisites: There are no corequisites for this course.

Topics of current interest to undergraduate students.

ECE 498 Undergraduate Projects 1-4C

Prerequisites: Arranged prerequisite consent of instructor

Corequisites: There are no corequisites for this course.

Special design or research projects.

ECE 510 Error Correcting Codes 4R-0L-4C F (odd years)

Prerequisites: ECE 310* *Graduate standing or with a grade of B or better, or consent of instructor

Corequisites: There are no corequisites for this course.

Coding for reliable digital communication. Topics to be chosen from: Hamming and BCH codes, Reed-Solomon codes, convolutional codes, Viterbi decoding, turbo codes, and recent developments, depending on interests of class and instructor. Mathematical background will be developed as needed.

ECE 511 Data Communications 4R-0L-4C F (even years)

Prerequisites: ECE 310*, and MA 381* or ECE 310**, and MA 381** *Graduate standing **with a grade of B or better in both courses, or consent of instructor

Corequisites: There are no corequisites for this course.

Design of digital communication systems. Autocorrelation function and power spectrum, vector space models of signals and noise, optimal receiver structures and performance, bandlimited channels and equalization, convolutional coding.

ECE 512 Probability, Random Processes, and Estimation 4R-0L-4C W

Prerequisites: MA 381, and ECE 380

Corequisites: There are no corequisites for this course.

Review of probability and random variables, random vectors, topics in estimation and detection theory, linear and nonlinear estimation, orthogonality principle, hypothesis testing, random processes, stationarity, correlation functions, and spectra. Additional topics chosen from Wiener and Kalman filtering, and Markov chains.

ECE 516 Introduction to MEMS: Fabrication & Applications 3R-3L-4C S

Prerequisites: Junior or Senior class standing

Corequisites: There are no corequisites for this course.

Properties of silicon wafers; wafer-level processes, surface and bulk micromachining, thin-film deposition, dry and wet etching, photolithography, process integration, simple actuators. Introduction to microfluidic systems. MEMS applications: capacitive accelerometer, cantilever and pressure sensor. Cross-listed with BE 516, CHE 505, EP 510, and ME 516.

ECE 519 Advanced MEMS: Modeling & Packaging 3R-3L-4C F

Prerequisites: EP 410 or equivalent course

Corequisites: There are no corequisites for this course.

Design process, modeling; analytical and numerical. Actuators; dynamics and thermal issues. Use of software for layout and simulation. Characterization and reliability of MEMS devices. Electrical interfacing and packaging of MEMS. Microsensors, microfluidic systems, applications in engineering, biology, chemistry, and physics. Cross-listed with ME 519, EP 511, and CHE 519.

ECE 530 Advanced Microcomputers 3R-3L-4C S

Prerequisites: *Graduate standing; or with a grade of B or better; or consent of instructor ECE 230* *Graduate standing; or with a grade of B or better; or consent of instructor

Corequisites: There are no corequisites for this course.

32-bit microcontroller architecture. Software development in both assembly language and C language. Hardware interfacing. Use of a real-time-operating system (RTOS). System-on-a-chip (SOC) hardware/software design using a field programmable gate array (FPGA) chip containing an embedded microcontroller cores. Software debugging tools. Integral laboratory.

ECE 531 Digital Test & Product Engineering 3R-3L-4C S

Prerequisites: ECE 230*, and ECE 233*, and ECE 250* *Graduate standing; or with grades of B or better in all three courses; or consent of instructor.

Corequisites: There are no corequisites for this course.

Industrial testing techniques for microcontrollers and other digital integrated circuits. Includes common digital system fault modeling, test generation, and design for testability in addition to memory testing strategies. Integral labs using an industrial grade automatic test environment (ATE).

ECE 532 Advanced Topics in Computer Architecture 4R-0L-4C W

Prerequisites: ECE 332 with a B or better.

Corequisites: There are no corequisites for this course.

Superscalar processors. Out-of-Order Execution. Register Renaming. Dynamic Random Access Memory (DRAM). Prefetching. Trace Cache. Victim Cache. 3D DRAM. Multithreading. Multicore. Cache Coherence. Transactional Memory. Performance Modeling. Power Modeling. Intel Pentium Pro Architecture. Transmeta Crusoe Architecture. Code Morphing. ARMv7 Architecture. Nvidia G80 Architecture.

ECE 534 Advanced Signal & Power Integrity 4R-0L-4C W

Prerequisites: ECE 341*, and ECE 342* or ECE 343* *Graduate standing; or all courses with a grade of B or better; or ECE342 with a grade of B or better, or consent of instructor

Corequisites: There are no corequisites for this course.
Signal and power integrity modeling and measurement in high-speed digital systems at IC, PCB, and chassis levels. High-frequency behavior of passive components and packages. Behavior and SPICE models of drivers and receivers. Lossy transmission lines and discontinuity characterization. Mixedmode s-parameters and other network parameters. Frequency and time-domain modeling of capacitive and inductive crosstalk. Differential signaling techniques; timing conventions. Synchronization. Signal equalization. Power plane noise and resonance. High-speed PCB design guidelines. Measurement techniques including time-domain reflectometry, vector network analyzer and impedance analyzer. PCB simulation. Full-wave simulations.

ECE 540 Antenna Engineering 3R-3L-4C W

Prerequisites: ECE 341* Graduate standing (course not required); *or with a grade of B or better; or consent of instructor.

Corequisites: There are no corequisites for this course.
Electromagnetic radiation, antenna terminology and characteristics, dipole antennas, arrays, aperture antennas, measurements, computer-aided analysis, design projects and reports.

ECE 541 Microwave/Millimeter-Wave Engineering 4R-0L-4C S

Prerequisites: ECE 341 Graduate standing; or with grade of B or better, or consent of instructor

Corequisites: There are no corequisites for this course.
Wave-guiding structures, microwave network analysis, scattering parameters, Z, Y and ABCD parameters, passive devices and components, design, fabrication, simulation and measurement of microwave devices and components, matching strategies, multi-conductor transmission lines and crosstalk.

ECE 542 Advanced Electromagnetics 4R-0L-4C F

Prerequisites: ECE 341 and Graduate standing; or with grade of B or better, or consent of instructor

Corequisites: There are no corequisites for this course.
Maxwell’s equations, EM field theorems, potential functions, power and energy, material properties, wave propagation, reflection and transmission, radiation, scattering, Green's functions, metamaterials and metamaterial-inspired structures, modeling & simulation, measurement technique.

ECE 543 Electromagnetic Metamaterials 4R-0L-4C

Prerequisites: ECE 341* Graduate standing (course not required) *or with grade of B or better; or consent of instructor

Corequisites: There are no corequisites for this course.
Electromagnetic fundamentals, control of permittivity and permeability, dispersion, causality, double-negative materials, epsilon near-zero materials, transmission line-based metamaterials, composite right/left handed wave-guiding structures, even/odd mode analysis, differential signaling, electromagnetic bandgap structures, phase control, dual band devices, enhanced bandwidth devices, zeroth-order resonators, full wave simulation, device fabrication and laboratory measurement.

ECE 551 Digital Integrated Circuit Design 3R-3L-4C F

Prerequisites: ECE 250, and ECE 233 both with a grade of B or better; or graduate standing.

Corequisites: There are no corequisites for this course.
Design, performance analysis, and physical layout of CMOS logic. Custom and standard cell methodologies. Use of commercial CAD tools. Design issues such as interconnect, timing, and testing methods. Integral laboratory and project.

ECE 552 Analog Integrated Circuit Design 3R-3L-4C W
Prerequisites: ECE 351, and ECE 380 Graduate standing; or with a grade of B or better in both courses; or consent of instructor
Corequisites: There are no corequisites for this course.
Design, performance analysis, and physical layout of analog integrated circuits. Focus on operational amplifier design and op-amp circuits. Introduction to mixed-signal circuit design such as switch-capacitors, A/D, or D/A systems. Integral laboratory and design project.
ECE 553 Radio-Frequency Integrated Circuit Design 3R-3L-4C S
Prerequisites: ECE 310, and ECE 351 Graduate standing (courses not required); or with a grade of B or better; or consent of instructor
Corequisites: There are no corequisites for this course.
Design, analysis, and physical layout of high-frequency analog integrated-circuits for modern RF transceivers. Circuit design for each primary transceiver component. General issues such as impedance matching and design of inductors on integrated circuits. Integral laboratory and design project.
ECE 554 Instrumentation 4R-0L-4C S
Prerequisites: ECE 351 Graduate standing; or with grade of B or better; or consent of instructor
Corequisites: There are no corequisites for this course.
Transducers and their applications. Analog signal processing techniques using operational amplifiers. A/D and D/A converters. Protection from electric shock. Measurement of biological potential waveforms (ECG, EMG, EEG, ENG, EOG, ERG). Ultrasound techniques and instrumentation. X-ray CAT techniques. No laboratory, but many in-class demonstrations and emphasis on circuit simulation.
ECE 556 Power Electronics: DC Power Supplies 3R-3L-4C S
Prerequisites: ECE 351 Graduate standing; or with grade of B or better; or consent of instructor
Corequisites: There are no corequisites for this course.
Analysis and design of AC-DC and DC-DC converters. Linear, basic switching, charge-pump, and fly-back topologies. Introduction to devices used in a power switching supplies. Thermal management. Integral laboratory.
ECE 557 Analog Test & Product Engineering 3R-3L-4C F
Prerequisites: ECE 300, and ECE 351 Graduate standing; or with a grade of B or better in both courses, or consent of instructor
Corequisites: There are no corequisites for this course.
Fundamental skills necessary to be an industrial integrated circuit test engineer or product engineer. Includes the economics associated with testing, impact of fabrication variation on devices, instrumentation associated with industrial testing, turning a data sheet into a test plan, industrial testing techniques for analog circuits, trade-offs between test time and test accuracy, statistical analysis of the data and statistical process control, the use of device interface boards necessary to control device loading for different tests. Integral labs with an industrial grade automatic tester (ATE).
ECE 558 Mixed-Signal Test & Product Engineering 3R-3L-4C W
Prerequisites: ECE 300, and ECE 233, and ECE 351 Graduate standing; or with grades of B or better in all three courses; or consent of instructor.
Corequisites: There are no corequisites for this course.
Industrial testing techniques for AC and DC tests of mixed-signal integrated circuits using an automatic test environment (ATE). Includes the structure and operation of comparators and standard data converters (DACs, ADCs), common data converter

datasheet specifications, impact of data converter design on testing strategies, and statistical analysis of accuracy-time trade-offs. Integral labs using an industrial grade ATE.

ECE 580 Digital Signal Processing 4R-0L-4C W

Prerequisites: ECE 380, and MA 381 *Graduate standing (courses not required); or with grade of B or better in both courses; or consent of instructor. MA367 with a grade of B or higher recommended.

Corequisites: There are no corequisites for this course.

Digital filters. Fundamental concepts of digital signal processing. Analysis of discrete-time systems. Sampling and reconstruction. Theory and application of z-transforms. Design of recursive and nonrecursive digital filters. Window functions. Discrete Fourier transforms and FFT algorithm.

ECE 581 Digital Signal Processing Projects 2R-2L-2 or 4C

Prerequisites: ECE 580 concurrent registration

Corequisites: There are no corequisites for this course.

Computer-aided design of digital filters and other DSP modules. Software and hardware realization using modern DSP chips. DSP chip architectures, C-language programming, and interfacing techniques. Optional advanced project may be done to earn four credit hours; otherwise two credit hours are given. Integral laboratory.

ECE 582 Advanced Image Processing 3R-3L-4C S

Prerequisites: CSSE 120 or Senior standing or Graduate standing

Corequisites: There are no corequisites for this course.

Introduction to image segmentation and recognition. Use of neural networks, fuzzy logic and morphological methods for feature extraction. Advanced segmentation, detection, recognition and interpretation. Relevant laboratory experiments and required project. Cross-listed with OE 537.

ECE 584 Medical Imaging Systems 4R-0L-4C

Prerequisites: ECE 300* or BE 321 or OE 392 *Graduate standing; or ECE300 with grade of B or better; or consent of instructor

Corequisites: There are no corequisites for this course.

Engineering principles of major imaging techniques/modalities for biomedical applications and health care including diagnostic x-ray, computed tomography, nuclear techniques, ultrasound, and magnetic resonance imaging. Topics include general characteristics of medical images; physical principles, signal processing to generate an image, and instrumentation of imaging modalities. Clinical applications of these technologies are also discussed. Cross-listed with BE541 and OE584.

Prerequisite Notes:

Prerequisites - Clarification:
ECE 300 - Continuous-Time Signals & Systems and Graduate standing;
or ECE 300 Continuous-Time Signals & Systems with a grade of B or better
or BE 340 – Biomedical Signal Processing
or OE 392 – Linear Optical Systems with a grade of B or better;
or consent of instructor

ECE 596 Independent Study in Electrical Engineering 1C-4C

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

Special research or project based work that is done in consultation with a faculty member. Participation in these projects should require a graduate level of involvement and expectations, otherwise ECE498 Undergraduate Projects should be used. No more than 8 credit hours of ECE596 can be counted towards a graduate degree in the ECE Department without ECE Department Head Approval.

ECE 597 Special Topics in Electrical Engineering 4C

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

Special topics of current interest to graduate students and senior undergraduates.

ECE 598 Thesis Research 1-4C

Prerequisites: Arranged

Corequisites: There are no corequisites for this course.

Thesis topic selected in consultation with adviser. Graduate students only.

ECE 699 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The work experiences should be informative or integral to the advancement or completion of the student's program requirements. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

Computer Science

The Computer Science curriculum prepares students for careers in all areas of the computer industry as well as for graduate studies in computer science and computer related fields. Students have also found a computer science major to be excellent preparation for careers in law, medicine, business administration, industrial engineering, biomedical engineering, and other technical and non-technical fields.

Computer science is a rapidly changing discipline. The lifetime of a particular computer system or software package can be very short. The computer science curriculum is designed to prepare students for multiple careers in a rapidly changing environment. The department's courses emphasize fundamental concepts and techniques that will last longer than present technology.

Computer science majors complete a core of basic computer science courses that includes the study of algorithms, data structures, database concepts, computer architecture, programming languages, operating systems, and software engineering. Majors also complete important courses in closely related fields, e.g., discrete mathematics, digital logic design, and probability and statistics. The major requires students to study all aspects of the science of computing, including hardware, software, and theory.

Courses in database systems, compilers, computer graphics, fractals and chaotic dynamical systems, artificial intelligence, theory of computation, analysis of algorithms, computer networks, computer vision, web-based information systems, and cryptography are available as advanced electives. A three-term senior project provides valuable practical experience in the specification, design, implementation, and documentation of large software systems. Qualified students can undertake independent study in advanced topics in computer science, participate in a research project with a faculty member, or complete a senior thesis.

Programming assignments and large projects are part of most computer science courses. These assignments familiarize students with the wide variety of tasks performed by software professionals. Programming assignments include system specification, system feasibility studies, system design, system maintenance studies, and user interface design in addition to system implementation (i.e., coding), testing (verification and validation), and documentation. Projects include both individual and team activities and require appropriate written and oral presentations.

Computer science majors have diverse interests and career goals. Five free elective courses allow students to tailor their undergraduate education to their specific goals. Students planning to undertake graduate study in computer science usually take additional advanced courses in computer science, electrical engineering, and mathematics.

The department has its own local area network. This network is connected to the campus-wide network and the Internet. Laboratory machines are mostly Sun Ultra workstations. Computer science majors have unlimited access to the department's laboratories. Computer science majors are frequently employed by the computing center as user consultants, and by the department as system managers and course assistants.

The student chapter of the Association for Computing Machinery provides seminars and other technical activities throughout the year and sponsors the school's programming teams which compete in local, regional, and national contests. The national computer science honor society, Upsilon Pi Epsilon, has chartered its Indiana Alpha Chapter at Rose-Hulman.

Computer Science Program Educational Objectives

Graduates from the computer science program will be prepared for many types of careers in the field of computing and be prepared for graduate study in computer science and in closely related disciplines. In the early phases of their careers, we expect

Rose-Hulman computer science graduates to be:

1. Computing professionals in a variety of organizations, including ones doing traditional software development, technological innovation, and cross-disciplinary work
2. Business and technological leaders within existing organizations
3. Entrepreneurial leaders
4. Recognized by their peers and superiors for their communication, teamwork, and leadership skills
5. Actively involved in social and professional service locally, nationally, and globally
6. Graduate students and researchers
7. Leaders in government and law as government employees, policy makers, governmental advisors, and legal professionals

Computer Science Student Outcomes

Graduates of the program will have an ability to:

1. Analyze a complex computing problem and to apply principles of computing and other relevant disciplines to identify solutions.
2. Design, implement, and evaluate a computing-based solution to meet a given set of computing requirements in the context of the program's discipline.

3. Communicate effectively in a variety of professional contexts.
4. Recognize professional responsibilities and make informed judgments in computing practice based on legal and ethical principles.
5. Function effectively as a member or leader of a team engaged in activities appropriate to the program's discipline.
6. Apply computer science theory and software development fundamentals to produce computing-based solutions.

The faculty strives to maintain an open atmosphere that encourages mutual respect and support as well as learning and sharing of knowledge.

The computer science program is accredited by the Computing Accreditation Commission of ABET, https://www.abet.org, under the commission's General Criteria and Program Criteria for Computer Science and Similarly Named Computing Programs.

CSSE electives cannot include any of CSSE 372, 373, 375, 376, and 477.
Science elective is any CHEM, PH, GEOL, or BIO courses totaling at least 4 credits.

HSSA electives must be distributed as required by HSSA.

Summary of graduation requirements for the computer science major

To complete the major in computer science a student must complete the following:

1. All required courses listed by number in the schedule of courses above: CSSE120, CSSE132, CSSE220, CSSE230, CSSE232, CSSE280, CSSE304, CSSE332, CSSE333, CSSE371, CSSE374, CSSE473 or MA473 and CSSE474 or MA474, and either CSSE487-9 or CSSE494-6 or CSSE497-9; MA111, MA112, MA113, MA221, MA276, MA374, MA381; ECE233, ECE332; PH111, PH112; CHEM111; HUMH190, ENGLH290; RHIT100.
2. Twelve credits of additional computer science courses numbered between 300 and 492 and designated as computer science electives. None of the credits may be from CSSE372, 373, 375, 376, and 477. The student's academic advisor must approve the courses to satisfy this requirement. Use of computer science courses numbered 490 through 492 to fulfill this requirement must be approved by the department head. Credits used to satisfy any requirements for a minor or secondary major pursued by a student cannot also be used to satisfy CS elective requirements for the student's primary or secondary major in Computer Science. Credits used by a student pursuing a secondary major in CS that are intended to satisfy the CS elective requirement can only be used to satisfy technical or free elective requirements within the student's primary major or not used towards any requirements within the primary major.
3. Four credits of science electives, which can be any CHEM, PH, BIO, or GEOL courses not already required for the computer science major.
4. Four additional credits of technical electives, consisting of any courses in biology, chemistry, engineering (except software engineering and engineering management), geology, mathematics, biomathematics, or physics.
5. Twenty-eight credits of additional courses offered by the Department of Humanities, Social Sciences, and the Arts. The distribution of these courses must meet the requirements of the Department of Humanities, Social Sciences, and the Arts.

6. Twenty credits of free elective courses. These courses must have the approval of the student's academic adviser. Free electives may be selected from any Rose-Hulman course.
7. A total of 192 credits.

DATA SCIENCE MAJOR (SECOND MAJOR ONLY)

Data Science is open to all students as a second major; this means that the student will have some other discipline as their primary major. Students whose primary major is in Computer Science, Software Engineering or Mathematics will find the Data Science program the easiest since there is considerable overlap between those programs and the Data Science requirements Students from other disciplines are also encouraged to participate, but will have to take more courses. All students are encouraged to take the individual courses in the program, regardless of whether they wish to fulfill the second major requirements. Learn more about Data Science requirements.

Area Minor in Computer Science

Advisor: CSSE Department Head

Students majoring in Software Engineering may not receive a Computer Science minor.

Required courses

- CSSE120 Introduction to Software Development
- CSSE220 Object-Oriented Software Development
- CSSE230 Data Structures and Algorithm Analysis
- 16 additional credits of computer science courses numbered above 200 that are either required by the CS major or are identified as CS electives
- None of the f ollowing courses may be used: CSSE371, CSSE374, CSSE487-489, CSSE494-496, CSSE497-499

Minor in Cybersecurity

Prerequisites (may already be required by degree program):

- (4cr) CSSE 220 (requires CSSE 120* or exempt)
  * Degrees requiring a programming class might allow the use of CSSE 120 as a substitute for the named course. Consult the major program's advisor for details.
- (4cr) MA276 Introduction to Proofs (requires MA112 + MA111 or exempt) ***only if*** selecting MA479 (see below)

- (4cr) ENG H290 Technical & Professional Communications

CATEGORY A – [4 cr] Ethics:

- (4cr) PHIL H202 - Business & Eng Ethics (or equivalent approved by the minor advisor)

CATEGORY B – [12 cr] Core (take all of these):

- (2cr) CSSE 140 and CSSE 141

- (2cr) either CSSE 142 Practical Security III or CSSE 145 Cybersecurity Seminar
- (4cr) CSSE 340 Foundations of Cybersecurity (CSSE majors) or CSSE 240 Principles of Cybersecurity (non-CSSE majors)
- (4cr) either CSSE 343 Cybercrime & Digital Forensics or MA 479 Cryptography

CATEGORY C – [choose 8 cr] additional Cyber Electives:

** A maximum 4cr may be from classes numbered below 300*

- (4cr) the other of either CSSE 343 -or- MA 479 (crypto)
- (4cr) CSSE 490 Advanced crypto
- (4cr) ECE 497 Malware Analysis & Reverse Engineering
- (4cr) CSSE 290 CTF Competition Class or similar elective
- (4cr) CSSE 490 Blockchain and Security
- (4cr) CSSE 490 Network Security
- (1-8cr) other cybersecurity-related classes or electives such as independent study, directed research, thesis, or capstone projects (approved by the minor advisor)

Expected cybersecurity content: 20cr (Category B and C)

Minimum separation from named degree or other minor requirements: 12cr*

* may be used as free elective credit in major degree programs

Note: At most 8 credits of the Core/Cyber Elective course work (categories B and C above) can be used to satisfy degree requirements for any major or any other minor sought by the student. The remaining credit hours can only be used to satisfy technical or free electives within the primary major.

Plan of Study

Freshman

Fall

Course	Credit
CSSE 120 Introduction to Software Development	4
MA 111 Calculus I	5
PH 111 Physics I	4
RHIT 100 Foundations for Rose-Hulman Success	1
HUM H190 First-Year Writing Seminar	4
	Total Credits: 18

Winter

Course	Credit
CSSE 220 Object-Oriented Software Development	4
MA 112 Calculus II	5

PH 112 Physics II	4	
HSSA Elective	4	
		Total Credits: 17

Spring

Course	Credit	
CSSE 132 Introduction to Computer Systems	4	
MA 113 Calculus III	5	
ECE 233 Introduction to Digital Systems	4	
Science Elective	4	
		Total Credits: 17

Sophomore

Fall

Course	Credit	
CSSE 232 Computer Architecture I	4	
CSSE 280 Intro to Web Programming	4	
MA 221 Matrix Algebra & Differential Equations I	4	
MA 276 Introduction to Proofs	4	
		Total Credits: 16

Winter

Course	Credit	
CSSE 230 Data Structures & Algorithm Analysis	4	
CSSE 332 Operating Systems	4	
MA 374 Combinatorics	4	
ENGL H290 Technical & Professional Communication	4	
		Total Credits: 16

Spring

Course	Credit	
CSSE 333 Database Systems	4	
ECE 332 Computer Architecture II	4	
MA 381 Introduction to Probability with Applications to Statistics	4	
HSSA Elective	4	

		Total Credits: 16

Junior

Fall

Course	Credit	
CSSE 371 Software Requirements Engineering	4	
CSSE 304 Programming Lang. Con.	4	
CHEM 111 General Chemistry I (Lecture and Lab)	4	
HSSA Elective	4	
		Total Credits: 16

Winter

Course	Credit	
CSSE/MA 473 Design & Analysis of Algorithms	4	
CSSE 374 Software Design	4	
CS Elective	4	
HSSA Elective	4	
		Total Credits: 16

Spring

Course	Credit	
CSSE/MA 474 Theory of Computation	4	
HSSA Elective	4	
Free Elective	4	
Free Elective	4	
		Total Credits: 16

Senior

Fall

Course	Credit	
CSSE 487 Senior Research Project I or CSSE 497 Senior Capstone Project I or CSSE 494 Senior Thesis I	4	
CS Elective	4	
HSSA Elective	4	
Free Elective	4	
		Total Credits: 16

Winter

Course	Credit
CSSE 488 Senior Research Project II or CSSE 498 Senior Capstone Project II or CSSE 495 Senior Thesis II	4
CS Elective	4
HSSA Elective	4
Technical Elective	4
	Total Credits: 16

Spring

Course	Credit
CSSE 489 Senior Research Project III or CSSE 499 Senior Capstone Project III or CSSE 496 Senior Thesis III	4
Free Elective	4
Free Elective	4
	Total Credits: 12

Computer Science - Course Descriptions

CSSE 120 Introduction to Software Development 3R-3L-4C F,W,S
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
An introduction to programming with an emphasis on problem solving. Problems may include visualizing data, interfacing with external hardware or solving problems from a variety of engineering disciplines. Programming concepts covered include data types, variables, control structures, arrays, and data I/O. Software development concepts covered include testing, debugging, incremental development, understanding requirements, and version control systems.

CSSE 132 Introduction to Systems Programming 3R-3L-4C F,S
Prerequisites: CSSE 120F,W,S
Corequisites: There are no corequisites for this course.
Provides students with understanding of computer system level issues and their impact on the design and use of computer systems. Students will study low-level programming (assembly) and memory operations, representation of various types of data and programs in memory, and resource/efficiency trade-offs. System requirements such as resource management, security, communication and synchronization are studied and basic systems tools for these tasks are implemented. Course topics will be explored using a variety of hands-on assignments and projects.

CSSE 140 Practical Security I 0R-1L-1C F
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
This is an entry-level introduction to exploiting and securing computer systems, networks, and web sites. This shallow introduction exposes students to various applied cybersecurity topics including Firewalls, SSH, passwords, web security, and basic unix

system administration. Through a series of hands-on exercises, students will relate these topics to practical ways to secure computers.

CSSE 141 Practical Security II 0R-1L-1C W

Prerequisites: CSSE 140F

Corequisites: There are no corequisites for this course.

A second-level introduction to exploiting and securing computer systems, networks, and web sites. This class continues the introduction to applied cybersecurity topics including basic Cryptography, network protocol analysis, reverse engineering, steganography, forensics, and more unix system administration. Students are also introduced to capture-the-flag exercises, which are widely practiced cybersecurity skill competitions.

CSSE 142 Practical Security III 2L-2C Term F

Prerequisites: CSSE 141W

Corequisites: There are no corequisites for this course.

A third-level class on exploiting and securing computer systems, networks, and web sites. This class continues the introduction to applied cybersecurity topics and focus on applying concepts learned in CSSE140/141 to security competitions such as capture-the-flag events. This class exposes students to strategy used in security competitions, teamwork skills for effective competition, and construction of set of exercises used for running a CTF event. Students will work in teams to solve security-oriented problems, apply their skills to create competition challenges/exercises for use in CSSE 141 and for competition training, practice for security competitions, and participate in or run a few security competitions.

CSSE 145 Cybersecurity Seminar 2R-0L-2C Varies

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

This course provides exposure to leading-edge industrial and academic experts in Cybersecurity and Digital Privacy. Topics including the societal, economic, scientific, and psychological impacts of modern areas of cybersecurity and privacy are examined from both practical and theoretical points of view. Students in this class will attend live and view remote or recorded talks from industry/academic experts, read emergent papers on Cybersecurity and Digital Privacy, participate in discussions or debate about the topics, and reflect on the impacts these topics have on their major area of study. May be repeated for credit with approval from the course instructor when topics are different.

CSSE 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as “S” satisfactory, or “U” unsatisfactory based on the written report of the professional experience.

CSSE 212 Hardware-oriented Programming 3R-3L-4C

Prerequisites: ICS major

Corequisites: There are no corequisites for this course.

Simple computer architecture. Special hardware-oriented programming. Introduction to the C programming language, especially the use of pointers. Interrupt programming.

This course is taught as part of the International Computer Science dual degree program at Hochschule Ulm, Germany.

CSSE 220 Object-Oriented Software Development 3R-3L-4C F,W,S

Prerequisites: CSSE 120F,W,S
Corequisites: There are no corequisites for this course.
Object-oriented programming concepts, including the use of inheritance, interfaces, polymorphism, abstract data types, and encapsulation to enable software reuse and assist in software maintenance. Recursion, GUIs and event handing. Use of common object-based data structures, including stacks, queues, lists, trees, sets, maps, and hash tables. Space/time efficiency analysis. Testing. Introduction to UML.

CSSE 221 Fundamentals of Software Development Honors 3R-3L-4C

Prerequisites: A score of 4 or 5 on the APCS A exam or permission of instructor
Corequisites: There are no corequisites for this course.
This course is intended for students who have sufficient programming experience to warrant placement in an accelerated course covering the topics from CSSE 120 and CSSE 220. This course will satisfy the prerequisite requirements for courses that have CSSE 220 as a prerequisite.

CSSE 225 Programming 3 3R-3L-4C

Prerequisites: ICS major
Corequisites: There are no corequisites for this course.
Differences between Java and C++. C++ concepts of object-oriented programming (classes, objects, inheritance, polymorphism). Storage management. Multiple inheritance, operator overloading, friend-concept, exception handling, I/O. Error analysis of programs. Generic programming and introduction to C++ - standard library. This course is taught as part of the International Computer Science dual degree program at Hochschule Ulm, Germany.

CSSE 230 Data Structures and Algorithm Analysis 3R-3L-4C F,W,S

Prerequisites: MA 112F,W,S, and CSSE 220F,W,S with a grade of C or better
Corequisites: There are no corequisites for this course.
This course reinforces and extends students' ability to independently design, develop, and debug object-oriented software that uses correct, clear, and efficient algorithms and data structures. Students study and implement classical data structures such as list, stack, queue, tree, priority queue, hash table, graph, set, and dictionary. Formal efficiency analysis is used to evaluate the complexity of algorithms for these data structures. Students gain proficiency in writing recursive methods. Students design and implement software individually.

CSSE 232 Computer Architecture I 3R-3L-4C F,W

Prerequisites: ECE 233F, W, S, and CSSE 120F,W,S
Corequisites: There are no corequisites for this course.
Computer instruction set architecture and implementation. Specific topics include historical perspectives, performance evaluation, computer organization, instruction formats, addressing modes, computer arithmetic, single-cycle and multi-cycle data paths, and processor control. Assembly language programming is used as a means of exploring instruction set architectures. The final project involves the complete design and implementation of a miniscule instruction set processor.

CSSE 240 Principles of Cybersecurity 4R-0L-4C W

Prerequisites: CSSE 120F,W,S, and HUM H190F, W
Corequisites: There are no corequisites for this course.

This course introduces ethical, theoretical, and practical issues of information security in interconnected systems of computers. Implications of relevant professional codes of ethics are a recurring theme of the course, as are societal and human impacts on computer system security. Foundational topics include access control matrices and standard system models, as well as policies for security, confidentiality, and integrity. Implementation issues include key management, cipher techniques, authentication, principles of secure design, representation of identity, access control mechanisms, information flow, life cycle issues, and formal evaluation and certification techniques. Additional topics include malicious logic, vulnerability analysis, and auditing. Computer system attack techniques are observed and evaluated in a closed environment to motivate and inform discussion and exploration of computer network defense techniques.

CSSE 241 Computing in a Global Society 2R-6L-4C

Prerequisites: CSSE 220F,W,S or CSSE 221F,W,S

Corequisites: There are no corequisites for this course.

The ability to work with colleagues from other cultures and to work on international projects are key assets in today's job market. The centerpiece of this course is a real-world computing project that students develop in cooperation with peers from an institution of higher education in a foreign country. Exposes students to the procedures and complexities of working on projects that span many time-zones and cultures. Additionally, students examine the use and impact of computing in a global community. International travel is required; students will be expected to incur additional expenses (will vary depending on the project, institution, and country). May be repeated once (for free elective credit only) if the country involved is different.

CSSE 242 Programming in the Community Variable Credit (1 or 2 credits) F, W, S

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

Programming in the Community is a unique course where Rose-Hulman students learn how to become teachers in Computer Science for younger students. As the name suggests, students will go teach CS material to K-12 students at their local school. Students will be assigned to a teaching team to take turns leading and helping follow along projects for the K-12 students. Students are expected to join a weekly instructor meeting on Teams, then take two teaching trips into the community per week (40 to 50 minute lessons). Transportation can be arranged for students unable to travel to the school. Students of any major are welcome to join. This class is a very real-world experience. It is a great way to learn leadership and teaching skills while doing great community service. May be repeated up to 12 credit hours.

CSSE 252 Computer Game Design 4R-OL-4C

Prerequisites: ENGL H290F, W, S

Corequisites: There are no corequisites for this course.

An introduction to computer game design. Topics include game concepts, game settings and worlds, storytelling and narrative, character development, creating the user experience, gameplay, game balancing, and game genres. Working in teams, students will design their own game and produce several design documents for that game.

CSSE 280 Introduction to Web Programming 3R-3L-4C F, W

Prerequisites: CSSE 220F,W,S or CSSE 221F,W,S

Corequisites: There are no corequisites for this course.

Introduction to the client-side and server-side mechanisms for creating dynamic web applications with persistent data storage. Browser-server interaction via HTTP. Static web page creation using current markup and styling languages. Client-side programming with modern scripting languages and the DOM. Server-side programming with emerging web programming languages and frameworks. Persistent data storage with a state-of-the-art database management system. Asynchronous client-server communication via HTTP requests. Development and consumption of REST APIs. Deployment of web applications to cloud platforms or platform as a service providers. Security considerations. This course provides breadth of knowledge of many tools/ technologies rather than deep knowledge of any particular tool/technology. No previous experience with Web development is required.

CSSE 286 Introduction to Machine Learning 4R-0L-4C

Prerequisites: Prior programming experience

Corequisites: There are no corequisites for this course.

An introduction to machine learning (ML) systems, with a focus especially on Artificial Intelligence-based systems, versus statistical ones. The course is designed to be useful to students with a basic knowledge of programming and software systems, whether or not they are computer science majors. During the course, students try different machine learning algorithms on data from problems in a domain of interest to them, comparing results with that of other students taking the class, as well as comparing the outcomes of the different algorithms on their own data. A goal of the course is learning how to gain real predictive value from “big data.”

CSSE 290 Special Topics in Computer Science 4C

Prerequisites: Arranged prerequiste - permission of instructor

Corequisites: There are no corequisites for this course.

Selected topics of current interest. May be repeated for credit if topic is different.

CSSE 304 Programming Language Concepts 4R-0L-4C F,W

Prerequisites: CSSE 230F,W,S, and CSSE 280F, W

Corequisites: There are no corequisites for this course.

Syntax and semantics of programming languages. Grammars, parsing, data types, control flow, parameter passing, run-time storage management, binding times, functional programming and procedural abstraction, syntactic extensions, continuations, language design and evaluation. Students will explore several language features by writing an interpreter that implements them.

CSSE 332 Operating Systems 4R-0L-4C W,S

Prerequisites: CSSE 220F,W,S or CSSE 221F,W,S, and CSSE 132F,S or CSSE 232F,W

Corequisites: There are no corequisites for this course.

Students learn fundamental concepts of modern operating systems by studying how and why operating systems have evolved. Topics include CPU scheduling, process synchronization, memory management, file systems, I/O systems, privacy and security, and performance evaluation. Students implement parts of an operating system as a means of exploring the details of some of these topics.

CSSE 333 Database Systems 3R-3L-4C W,S

Prerequisites: CSSE 230F,W,S

Corequisites: There are no corequisites for this course.

Relational database systems, with emphasis on entity relationship diagrams for data modeling. Properties and roles of transactions. SQL for data definition and data manipulation. Use of contemporary API's for access to the database. Enterprise examples provided from several application domains. The influence of design on the use of indexes, views, sequences, joins, and triggers. Physical level data structures: B+ trees and RAID. Survey of object databases.

CSSE 335 Introduction to Parallel Computing 4R-0L-4C S

Prerequisites: MA 221F,W,S and programming experience
Corequisites: There are no corequisites for this course.
Principles of scientific computation on parallel computers. Algorithms for the solution of linear systems and other scientific computing problems on parallel machines. Course includes a major project on RHIT's parallel cluster. Same as MA 335.

CSSE 340 Foundations of Cybersecurity 4R-0L-4C W

Prerequisites: CSSE 132F,S, and CSSE 280F, W
Corequisites: There are no corequisites for this course.
This course introduces ethical, theoretical, and practical issues of information security in interconnected systems of computers. Implications of relevant professional codes of ethics are a recurring theme of the course, as are societal and human impacts on computer system security. Foundational topics include access control matrices and standard system models, as well as policies for security, confidentiality, and integrity. Implementation issues include key management, cipher techniques, authentication, principles of secure design, representation of identity, access control mechanisms, information flow, life cycle issues, and formal evaluation and certification techniques. Additional topics include malicious logic, vulnerability analysis, and auditing. Computer system attack techniques are discussed and explored in a closed environment to motivate and inform discussion and exploration of computer network defense techniques.

CSSE 343 Cybercrime and Digital Forensics 2R-2L-4C

Prerequisites: ENGL H100F, W, and either CSSE 132F,S or Senior Class Standing
Corequisites: There are no corequisites for this course.
This course introduces students to “cybercrime,” how police investigate these crimes, and what forensics techs use to uncover digital evidence. Students will examine the laws, technologies, tools, and procedures used in the investigation and prosecution of computer crimes through case studies, discussions, ethical debates, and hands-on laboratory exercises that uncover and analyze digital evidence. This class covers topics including: basics of criminal law, collection and chain of evidence, search & seizure procedures, digital trail discovery, data recovery, and smartphone investigation.

CSSE 351 Computer Graphics 4R-0L-4C F

Prerequisites: MA 221F,W,S, and either CSSE 220F,W,S or CSSE 221F,W,S
Corequisites: There are no corequisites for this course.
Computer graphics algorithms, hardware and software. Line generators, affine transformations, line and polygon clipping, interactive techniques, perspective projection, solid modeling, hidden surface algorithms, lighting models, shading, and graphics standards. Programming assignments and a final project are required.

CSSE 352 Computer Game Development 4R-0L-4C

Prerequisites: CSSE 230F,W,S
Corequisites: There are no corequisites for this course.
An introduction to designing and developing computer games. Topics include game genres, game design, sprites, game physics, collisions, characters, scripting, graphics,

and sound. Students will design and implement their own game using an available game engine.

CSSE 371 Software Requirements Engineering 3R-3L-4C F

Prerequisites: CSSE 230F,W,S, and ENGL H290F, W, S, and CSSE 333W,S and Junior standing

Corequisites: There are no corequisites for this course.

Basic concepts and principles of software requirements engineering, its tools and techniques, and methods for modeling software systems. Topics include requirements elicitation, prototyping, functional and non-functional requirements, object-oriented techniques, and requirements tracking.

CSSE 372 Software Project Management 4R-0L-4C F

Prerequisites: There are no prerequisites for this course.

Corequisites: CSSE 230 3R-3L-4C F,W,S

Major issues and techniques of project management. Project evaluation and selection, scope management, team building, stakeholder management, risk assessment, scheduling, quality, rework, negotiation, and conflict management. Professional issues including career planning, lifelong learning, software engineering ethics, and the licensing and certification of software professionals.

CSSE 373 Formal Methods in Specification and Design 4R-0L-4C S

Prerequisites: CSSE 230F,W,S, and MA 276F, W

Corequisites: There are no corequisites for this course.

Introduction to the use of mathematical models of software systems for their specification and validation. Topics include finite state machine models, models of concurrent systems, verification of models, and limitations of these techniques.

CSSE 374 Software Design 3R-3L-4C W

Prerequisites: CSSE 230F,W,S and Junior standing

Corequisites: There are no corequisites for this course.

Introduction to the architecture and design of complete software systems, building on components and patterns. Topics include architectural principles and alternatives, design documentation, and relationships between levels of abstraction.

CSSE 375 Software Construction and Evolution 3R-3L-4C S

Prerequisites: CSSE 374W

Corequisites: There are no corequisites for this course.

Issues, methods and techniques associated with constructing software. Topics include detailed design methods and notations, implementation tools, coding standards and styles, peer review techniques, and maintenance issues.

CSSE 376 Software Quality Assurance 4R-0L-4C S

Prerequisites: CSSE 230F,W,S

Corequisites: There are no corequisites for this course.

Theory and practice of determining whether a product conforms to its specification and intended use. Topics include software quality assurance methods, test plans and strategies, unit level and system level testing, software reliability, peer review methods, and configuration control responsibilities in quality assurance.

CSSE 386 Data Mining with Programming 4R-0L-4C

Prerequisites: CSSE 220F,W,S, and CSSE 280F, W, and MA 221F,W,S, and either MA 223F,W,S or MA 381F,W,S

Corequisites: There are no corequisites for this course.

An introduction to data mining for large data sets, including data preparation, exploration, aggregation/reduction, and visualization. Elementary methods for classification, association, and cluster analysis are covered. Significant attention will be given to presenting and reporting data mining results. Students may not get credit for both this course and also the MA 384 Data Mining course.

CSSE 400 CSSE Seminar 4R-0L-4C

Prerequisites: ICS major

Corequisites: There are no corequisites for this course.

This course presents an overview of current application areas within computer science and software engineering through the use of practical case studies. Students will undertake their own preparation of one or more case studies and present their results. This course is taught as part of the International Computer Science dual degree program at Hochschule Ulm, Germany.

CSSE 402 Theory and Practice of Garbage Collection 4R-0L-4C

Prerequisites: CSSE 332W,S

Corequisites: There are no corequisites for this course.

Garbage collection (GC) is a method of automatically reclaiming dynamically allocated storage that an application no longer needs. In this course, students will explore the classical problems of garbage collection such as detecting unused objects and reclaiming the space allocated to them. Students will survey the GC literature to become familiar with the current state-of-the-art and future research directions. Students will explore techniques used to implement state-of-the-art garbage collection algorithms and will design and implement garbage collectors for a memory-managed language (e.g.,Java, C#, php, or Python).

CSSE 403 Programming Language Paradigms 4R-0L-4C F (even years)

Prerequisites: CSSE 304F,W

Corequisites: There are no corequisites for this course.

A survey of some current and emerging programming languages, focusing on unique language paradigms-ways of structuring solutions or manipulating data. Examples of paradigms include dynamic programming languages, object-oriented programming, highly parallelizable code, and functional programming. Emphasizes developing independent learning techniques that will allow students to acquire skills in new languages quickly. Students will develop basic skills in at least three different languages representing distinct paradigms. They will also be exposed to a selection of other languages. Includes a substantial team project.

CSSE 404 Compiler Construction 4R-0L-4C S (odd years)

Prerequisites: CSSE 232F,W, and CSSE 304F,W, and CSSE 474S

Corequisites: There are no corequisites for this course.

Theory and practice of programming language translation. Lexical analysis, syntax analysis, parser generators, abstract syntax, symbol tables, semantic analysis, intermediate languages, code generation, code optimization, run-time storage management, error handling. Students will construct a complete compiler for a small language.

CSSE 413 Artificial Intelligence 4R-0L-4C F

Prerequisites: CSSE 230F,W,S

Corequisites: There are no corequisites for this course.

Students investigate how to model and implement intelligent behavior using computers. Topics are chosen from how machines can: solve problems; reason and use knowledge; learn from experience; and perceive and act. Students explore these topics by implementing many of the ideas in software. Readings are drawn both from a textbook and from technical papers in recent conferences and journals.

CSSE 415 Machine Learning 4R-0L-4C S

Prerequisites: MA 221F,W,S, and either MA 223F,W,S or MA 381F,W,S, and either CHE 310See Department or CSSE 220F,W,S or ECE 230W,S or MA 332F,W or MA 386F,W or ME 323W,S

Corequisites: There are no corequisites for this course.

An introduction to machine learning. Topics include: error metrics, accuracy vs interpretability trade-off, feature selection, feature engineering, bias-variance trade-off, under-fitting vs. overfitting, regularization, cross-validation, the bootstrap method, the curse of dimensionality and dimensionality reduction using the singular value decomposition. Both parametric and nonparametric methods are covered including: k-nearest neighbors, linear and logistic regression, decision trees and random forests, and support vector machines. Same as MA415.

Prerequisites Notes:

Prerequisite Clarification for CSSE415:

Junior Standing and MA221,

and either MA223 or MA381,

and one of CHE310, CSSE220, ECE230, MA332, MA386 (or ME323 or ME327).

CSSE 416 DEEP LEARNING 4R-0L-4C See Dept

Prerequisites: See below

Corequisites: There are no corequisites for this course.

An introduction to deep learning using both fully-connected and convolutional neural networks. Topics include: least squares estimation and mean square error, maximum likelihood estimation and cross-entropy, convexity, gradient descent and stochastic gradient descent algorithms, multivariate chain rule and gradient computation using back propagation, linear vs nonlinear operations, convolution, over-fitting vs under-fitting and hyper-parameter optimization, L2, early stopping and dropout regularization, data augmentation and transfer learning. Same as MA416.

Prerequisites Notes:

MA 212 or MA 221, and either MA 223 or MA 381, and either CHE 310 or CSSE 220 or ECE 230 or MA 332 or MA 386 or ME 327

CSSE 432 Computer Networks 4R-0L-4C S

Prerequisites: CSSE 220F,W,S or CSSE 221F,W,S

Corequisites: There are no corequisites for this course.

Organization, design, and implementation of computer networks, especially the Internet. Network protocols, protocol layering, flow control, congestion control, error control, packet organization, routing, gateways, connection establishment and maintenance, machine and domain naming, security. Each of the top four layers of the Internet protocol stack: application (FTP, HTTP, SMTP), transport (TCP, UDP), network (IP), link (Ethernet).

CSSE 433 Advanced Database Systems 4R-0L-4C S

Prerequisites: CSSE 333W,S

Corequisites: There are no corequisites for this course.

This course covers advanced topics in the design and development of database management systems and their modern applications. Topics to be covered include query processing and, in relational databases, transaction management and concurrency control, eventual consistency, and distributed data models. This course introduces students to NoSQL databases and provides students with experience in determining the right database system for the right feature. Students are also exposed to polyglot persistence and developing modern applications that keep the data consistent across many distributed database systems.

CSSE 434 Introduction to the Hadoop Ecosystem 4R-0L-4C

Prerequisites: CSSE 230F,W,S *Some Experience with SQL recommended
Corequisites: There are no corequisites for this course.
This advanced course examines emergent Big Data techniques through hands-on introductions to the various technologies and tools that make up the Hadoop ecosystem. Topics covered include internals of MapReduce and the Hadoop Distributed File system (HDFS), internals of the YARN distributed operating system, MapReduce for data processing, transformation & analysis tools for data at scale (processing terabytes and petabytes of information quickly), scheduling jobs using workflow engines, data transfer tools & real time engines for data processing.

CSSE 435 Robotics Engineering 3R-3L-4C S

Prerequisites: ME 430F,W or ECE 230W,S
Corequisites: There are no corequisites for this course.
Interdisciplinary course in robotics focusing on communication, software development, kinematics, robot GUI design, sensing, control, and system integration. Labs in the course cover MATLAB GUI development with GUIDE, Denavit-Hartenberg parameters, Arduino programming, Arduino to Android communication, Android app development, and OpenCV4Android image recognition. Students in the course will program an Android + Arduino, 6-wheeled mobile robot with 5 DOF servo arm to participate in an outdoor GPS robotics challenge. Same as ME 435.

CSSE 443 Distributed Systems & IT Security 3R-3L-4C

Prerequisites: ICS major
Corequisites: There are no corequisites for this course.
Building complex distributed information systems requires a systematic approach. This course covers the analysis of existing distributed information systems and provides the ability to model simple new distributed applications with special attention to the trustworthiness, reliability and security of information systems. Topics covered include the main architectural models of distributed systems, describing simple distributed applications according to architecture and function, defining simple communication protocols, the benefits of using middleware, the risks of using distributed systems, and safety measures. This course is taught as part of the International Computer Science dual degree program at Hochschule Ulm, Germany.

CSSE 444 Real-time Systems 3R-3L-4C

Prerequisites: ICS major
Corequisites: There are no corequisites for this course.
Students will learn the features and specifications of real-time systems. Topics covered include real-time operating systems and programming languages, design patterns for real-time systems, scheduling, synchronization, hybrid task sets, and applications of real-time systems. This course is taught as part of the International Computer Science dual degree program at Hochschule Ulm, Germany.

CSSE 451 Advanced Computer Graphics 4R-0L-4C W (even years)
Prerequisites: CSSE 351F
Corequisites: There are no corequisites for this course.
Advanced topics in computer graphics. Topics will be drawn from current graphics research and will vary, but generally will include ray tracing, radiosity, physically-based modeling, animation, and stereoscopic viewing. Programming assignments and a research project are required.

CSSE 453 Topics in Artificial Intelligence 4R-0L-4C
Prerequisites: CSSE 413F
Corequisites: There are no corequisites for this course.
Advanced topics in artificial intelligence. Topics will vary. Past topics have included machine game playing and machine learning. May be repeated for credit if topic is different.

CSSE 461 Computer Vision 4R-0L-4C S (odd years)
Prerequisites: MA 221F,W,S, and either CSSE 220F,W,S or CSSE 221F,W,S *Also recommended (but not required) either MA371 or MA373.
Corequisites: There are no corequisites for this course.
An introduction to 3D computer vision techniques. Both theory and practical applications will be covered. Major topics include image features, camera calibration, stereopsis, motion, shape from x, and recognition.

CSSE 463 Image Recognition 4R-0L-4C W
Prerequisites: MA 221F,W,S Junior standing and programming experience
Corequisites: There are no corequisites for this course.
Introduces statistical pattern recognition of visual data; low-level visual feature extraction (color, shape, edges); clustering and classification techniques. Applies knowledge to various application domains through exercises, large programming projects in Matlab, and an independent research project. Familiarity with probability distributions will be helpful, but not required.

CSSE 473 Design and Analysis of Algorithms 4R-0L-4C W
Prerequisites: CSSE 230F,W,S, and MA 276F, W, and MA 374F, W, S
Corequisites: There are no corequisites for this course.
Students study techniques for designing algorithms and for analyzing the time and space efficiency of algorithms. The algorithm design techniques include divide-and-conquer, greedy algorithms, dynamic programming, randomized algorithms and parallel algorithms. The algorithm analysis includes computational models, best/average/worst case analysis, and computational complexity (including lower bounds and NP-completeness). Same as MA 473.

CSSE 474 Theory of Computation 4R-0L-4C S
Prerequisites: CSSE 230F,W,S, and MA 276F, W, and MA 374F, W, S
Corequisites: There are no corequisites for this course.
Students study mathematical models by which to answer three questions: What is a computer? What limits exist on what problems computers can solve? What does it mean for a problem to be hard? Topics include models of computation (including Turing machines), undecidability (including the Halting Problem) and computational complexity (including NP-completeness). Same as MA 474.

CSSE 477 Software Architecture 4R-0L-4C F
Prerequisites: CSSE 374W or consent of instructor
Corequisites: There are no corequisites for this course.

This is a second course in the architecture and design of complete software systems, building on components and patterns. Topics include architectural principles and alternatives, design documentation, relationships between levels of abstraction, theory and practice of human interface design, creating systems which can evolve, choosing software sources and strategies, prototyping and documenting designs, and employing patterns for reuse. How to design systems which a team of developers can implement, and which will be successful in the real world.

CSSE 479 Cryptography 4R-0L-4C S

Prerequisites: MA 276F, W, and either CSSE 220F,W,S or CSSE 221F,W,S
Corequisites: There are no corequisites for this course.
Introduction to basic ideas of modern cryptography with emphasis on mathematical background and practical implementation. Topics include: the history of cryptography and cryptanalysis, public and private key cryptography, digital signatures, and limitations of modern cryptography. Touches upon some of the societal issues of cryptography. Same as MA 479.

CSSE 480 Cross-Platform Development 3R-3L-4C F

Prerequisites: CSSE 230F,W,S
Corequisites: There are no corequisites for this course.
Programming cross-platform mobile applications that target Android, iOS, and web mobile devices using programmatic UIs, layouts, reusable components, and data persistence via cloud backends. Emphasis is on hands-on use of these components in application development. Includes a substantial team project including UI mockups, design, development, testing, and presentation.

CSSE 481 Web-Based Information Systems 4R-0L-4C F (odd years)

Prerequisites: CSSE 230F,W,S
Corequisites: There are no corequisites for this course.
In this course, students learn about several aspects of research: thinking creatively about interesting research problems, researching existing work in a chosen area, and keeping current in a field. Students are exposed to the process of research by writing a pre-proposal for a project that advances the web. Projects either develop new web-technologies or applications or investigate a topic of importance. Based on feedback received, groups of students write a research proposal which goes through a formal peer review process. Approved projects are pursued for the remainder of the quarter. Students present current research as well as give a final presentation of their group project. Selected web-technologies are introduced; in the past, these have included CGI programming and XML technologies.

CSSE 483 Android Application Development 4R-0L-4C

Prerequisites: CSSE 230F,W,S
Corequisites: There are no corequisites for this course.
An introduction to programming mobile applications using the Android stack. Topics include the activity lifecycle, resources, layouts, intents for multiple activities, menus, fragments and dialogs, adapters, data persistence via shared preferences, SQLite, and web backends. Emphasis is on hands-on use of these components in application development. Includes a substantial team project (UI mockups, user stories, UML design, development, testing, and presentation).

CSSE 484 iOS Application Development 3R-3L-4C W

Prerequisites: CSSE 230F,W,S
Corequisites: There are no corequisites for this course.

An introduction to programming mobile applications using the iOS stack. Topics include using X-Code for Swift and Objective-C app development, UI components, Storyboards, view controller actions and outlets, table views, navigation controllers, Core Data, and APIs for backend communication. Emphasis is on hands-on use of these components in application development. Includes a substantial team project (UI mockups, user stories, development, testing, and presentation).

CSSE 487 Senior Research Project I 4C

Prerequisites: ENGL H290F, W, S and senior standing
Corequisites: There are no corequisites for this course.
Individual or group research on an unsolved technical problem. The problem is expected to be at an advanced level and have an appropriate client. A prototype system, a technical report, and a public presentation are required.

CSSE 488 Senior Research Project II 4C

Prerequisites: CSSE 487F, W, S
Corequisites: There are no corequisites for this course.
Individual or group research on an unsolved technical problem. The problem is expected to be at an advanced level and have an appropriate client. A prototype system, a technical report, and a public presentation are required.

CSSE 489 Senior Research Project III 4C

Prerequisites: CSSE 488F, W, S
Corequisites: There are no corequisites for this course.
Individual or group research on an unsolved technical problem. The problem is expected to be at an advanced level and have an appropriate client. A prototype system, a technical report, and a public presentation are required.

CSSE 490 Special Topics in Computer Science 1-4C

Prerequisites: Instructor consent
Corequisites: There are no corequisites for this course.
Selected topics of current interest. May be repeated for credit if topic is different.

CSSE 491 Directed Independent Studies 1-4C

Prerequisites: Consent of instructor and department head
Corequisites: There are no corequisites for this course.
Independent study of an advanced subject not included in regularly offered courses. May be repeated for credit if topic or level is different.

CSSE 492 Undergraduate Research in Computer Science 1-4C

Prerequisites: Consent of instructor and department head
Corequisites: There are no corequisites for this course.
Research under direction of a faculty member. Presentation of preliminary and final results to departmental seminar. Presentation of work at professional meetings or by publication in professional journals is strongly encouraged. May be repeated for credit if topic or level is different.

CSSE 493 Undergraduate Research in Software Engineering 1-4C

Prerequisites: Consent of instructor and department head
Corequisites: There are no corequisites for this course.
The Computer Science curriculum prepares students for careers in all areas of the computer industry as well as for graduate studies in computer science and computer related fields. Students have also found a computer science major to be excellent

preparation for careers in law, medicine, business administration, industrial engineering, biomedical engineering, and other technical and non-technical fields.

CSSE 494 Senior Thesis I 4C

Prerequisites: ENGL H290F, W, S Consent of instructor and department head
Corequisites: There are no corequisites for this course.
Individual study and research of a topic in computer science or software engineering. Topic is expected to be at an advanced level. Research paper and presentation to department seminar are required.

CSSE 495 Senior Thesis II 4C

Prerequisites: CSSE 494F, W, S Consent of instructor and department head
Corequisites: There are no corequisites for this course.
Individual study and research of a topic in computer science or software engineering. Topic is expected to be at an advanced level. Research paper and presentation to department seminar are required.

CSSE 496 Senior Thesis III 4C

Prerequisites: CSSE 495F, W, S Consent of instructor and department head
Corequisites: There are no corequisites for this course.
Individual study and research of a topic in computer science or software engineering. Topic is expected to be at an advanced level. Research paper and presentation to department seminar are required.

CSSE 497 Senior Capstone Project I 4C F

Prerequisites: CSSE 371F, CSSE 374W* and senior standing
Corequisites: There are no corequisites for this course.
For a capstone experience, students work on a team to complete a three-term software engineering project for an approved client. Students choose from two approaches to complete their capstone: 1) Develop a substantive software product, using defensible software processes. The teams focus on delivering key software development, administrative, and user artifacts to the client. Tasks include project planning, risk analysis, use of standards, prototyping, configuration management, quality assurance, project reviews and reports, team management and organization, copyright, liability, and handling project failure. 2) Investigate a substantive software product or engineering process problem, using a defensible and documented research approach. Tasks include problem analysis, developing alternative solutions, evaluating the solutions via prototyping and iterative processes of investigation, comparing the potential solutions, recording the investigation experience in a research report, and delivering the research artifacts to the client.

CSSE 498 Senior Capstone Project II 4C W

Prerequisites: CSSE 371F, CSSE 374W, and CSSE 497F
Corequisites: There are no corequisites for this course.
For a capstone experience, students work on a team to complete a three-term software engineering project for an approved client. Students choose from two approaches to complete their capstone: 1) Develop a substantive software product, using defensible software processes. The teams focus on delivering key software development, administrative, and user artifacts to the client. Tasks include project planning, risk analysis, use of standards, prototyping, configuration management, quality assurance, project reviews and reports, team management and organization, copyright, liability, and handling project failure. 2) Investigate a substantive software product or engineering process problem, using a defensible and documented research approach. Tasks

include problem analysis, developing alternative solutions, evaluating the solutions via prototyping and iterative processes of investigation, comparing the potential solutions, recording the investigation experience in a research report, and delivering the research artifacts to the client.

CSSE 499 Senior Capstone Project III 4C S

Prerequisites: CSSE 371F, CSSE 374W, and CSSE 498W

Corequisites: There are no corequisites for this course.

For a capstone experience, students work on a team to complete a three-term software engineering project for an approved client. Students choose from two approaches to complete their capstone: 1) Develop a substantive software product, using defensible software processes. The teams focus on delivering key software development, administrative, and user artifacts to the client. Tasks include project planning, risk analysis, use of standards, prototyping, configuration management, quality assurance, project reviews and reports, team management and organization, copyright, liability, and handling project failure. 2) Investigate a substantive software product or engineering process problem, using a defensible and documented research approach. Tasks include problem analysis, developing alternative solutions, evaluating the solutions via prototyping and iterative processes of investigation, comparing the potential solutions, recording the investigation experience in a research report, and delivering the research artifacts to the client.

Electrical Engineering

Electrical Engineering (EE) is a professional engineering discipline that deals with the study and application of electricity, electronics, and electromagnetism. Common EE tasks include designing communication systems, energy conversion and power delivery, control systems applications, design of analog and digital systems, and others. Below is a recommended plan of study for EE.

EE Program Educational Objectives

Electrical Engineering graduates shall:

1. Practice excellence in their profession using a systems approach encompassing technological, economic, ethical, environmental, social, and human issues within a changing global environment;
2. Function independently and in leadership positions within multidisciplinary teams;
3. Continue life-long learning by acquiring new knowledge, mastering emerging technologies, and using appropriate tools and methods;
4. Adapt and independently extend their learning to excel in fields about which they are passionate;
5. Strengthen teams and communities through collaboration, effective communication, public service, and leadership.

EE Student Learning Outcomes

At the time of graduation, students will have demonstrated:

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, 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.

The electrical engineering program is accredited by the Engineering Accreditation Commission of ABET, https://www.abet.org, under the commission's General Criteria and Program Criteria for Electrical, Computer, Communications, Telecommunication(s), and Similarly Named Engineering Programs.

B.S. in Electrical Engineering Required Credits

Course Number	Course Title	Credits
ECE160	Engineering Practice	2
ECE180	Introduction to Signal Processing	4
ECE203	DC Circuits	4
ECE204	AC Circuits	4
ECE205	Circuits and Systems	4
ECE230	Introduction to Microcontrollers	4
ECE233	Introduction to Digital Systems	4
ECE250	Electronic Device Modeling	4
ECE300	Continuous-Time Signals Systems	4
ECE310	Communication Systems	4
ECE320	Linear Control Systems	4
ECE340	Electromagnetic Fields	4
ECE341	Electromagnetic Waves	4
ECE351	Analog Electronics	4
ECE362	Principles of Design	3
ECE370 or ECE 371	Power & Energy Systems or Sustainable Energy Systems	4

ECE380	Discrete-Time Signals and Systems	4
ECE460	Engineering Design I	3
ECE461	Engineering Design II	4
ECE462	Engineering Design III	2
CSSE120	Introduction to Software Development	4
CSSE220	Object Oriented Software Development	4
PH111	Physics I	4
PH112	Physics II	4
PH113	Physics III	4
MA111	Calculus I	5
MA112	Calculus II	5
MA113	Calculus III	5
MA221	Matrix Algebra & Differential Equations I	4
MA222	Matrix Algebra & Differential Equations II	4
MA381	Intro to Probability	4
HUMH190	First-Year Writing Seminar	4
ENGLH290	Technical & Professional Communication	4
RHIT100	Foundations for RHIT Success	1
	ECE Area Electives	12
	HSSA Electives	28
	Math/Sci Elective	4
	Math Elective	4
	Restricted Science Elective	4
	Tech Elective	4
	Free Electives	8

SECOND MAJOR IN ELECTRICAL ENGINEERING

The ECE Department will not allow the following second major combinations:

1. Degree in Electrical Engineering and a Second Major in Computer Engineering.
2. Degree in Computer Engineering and a Second Major in Electrical Engineering.

MINOR IN ELECTRICAL AND COMPUTER ENGINEERING (ECE)

The Minor in ECE is designed to allow students to add another dimension to their Rose-Hulman degree.

Advisor - ECE Department Head

Requirements for Minor in ECE

- One of ECE203 **,** or ES203 **,** or both ES213 and ES213L
- Plus five additional ECE courses, except ECE160, ECE203, ECE362, ECE460, ECE461, ECE462, ECE466, and ECE206

AREAS OF CONCENTRATION

Information about Available Certificates

For further information about the certificate program, please contact Tina Hudson (hudson@rose-hulman.edu).

Plan of Study

Freshman

Fall

Course	Credit
PH 111 Physics I	4
MA 111 Calculus I	5
RHIT 100 Foundations for Rose-Hulman Success	1
HUM H190 First-Year Writing Seminar or HSSA Elective	4
ECE 160 Engineering Practice	2
	Total Credits: 16

Winter

Course	Credit
PH 112 Physics II	4
MA 112 Calculus II	5
CSSE 120 Introduction to Software Development	4
HUM H190 First-Year Writing Seminar or HSSA Elective	4
	Total Credits: 17

Spring

Course	Credit
PH 113 Physics III	4
MA 113 Calculus III	5

ECE 203 DC Circuits	4
ECE 180 Introduction to Signal Processing	4
	Total Credits: 17

Sophomore

Fall

Course	Credit
MA 221 Matrix Algebra & Differential Equations I	4
CSSE 220 Object Oriented Software Development	4
ECE 204 AC Circuits	4
ECE 233 Introduction to Digital Systems	4
	Total Credits: 16

Winter

Course	Credit
MA 222 Matrix Algebra & Differential Equations II	4
ECE 205 Circuits & Systems	4
ECE 230 Introduction to Embedded Systems	4
ECE 370 Power & Energy Systems or ECE 371 Sustainable Energy Systems	4
	Total Credits: 16

Spring

Course	Credit
MA 381 Introduction to Probability with Applications to Statistics	4
ECE 250 Electronice Device Modeling	4
ECE 300 Continuous-Time Signals & Systems	4
HSSA Elective	4
	Total Credits: 16

Junior

Fall

Course	Credit
ECE 380 Discrete-Time Signals & Systems	4
ECE 351 Analog Electronics	4
ECE 340 Electromagnetic Fields	4
ENGL H290 Technical & Professional Communication	4
	Total Credits: 16

Winter

Course	Credit
ECE 320 Linear Control Systems	4
ECE 341 Electromagnetic Waves	4
Math/Science Elective	4
HSSA Elective	4
	Total Credits: 16

Spring

Course	Credit
ECE 310 Communications Systems	4
ECE 362 Principles of Design	4
Restricted Science Elective	4
HSSA Elective	3
	Total Credits: 15

Senior

Fall

Course	Credit
ECE 460 Engineering Design I	3
ECE Area Elective	4
Math Elective	4
HSSA Elective	4
	Total Credits: 15

Winter

Course	Credit
ECE 461 Engineering Design II	4
ECE Area Elective	4
Tech Elective	4
HSSA Elective	4

	Total Credits: 16

Spring

Course	Credit
ECE 462 Engineering Design III	2
ECE Area Elective	4
HSSA Elective	4
Free Elective	4
Free Elective	4
	Total Credits: 18

AREA ELECTIVES - A total of 12 credit hours are required in this category. Eight of these credit hours must bear an ECE prefix; the other four can bear either ECE or CSSE prefix. At least eight of these credit hours must be at the 400 level or above; the other four can be at the 300 level or above. No more than 4 credit hours of ECE498 can be counted towards Area Electives and ECE398 cannot be counted as Area Elective credit. Exceptions can be made to these requirements with ECE Department Head and Advisor approval.

TECHNICAL ELECTIVE - CHEM and BIO 100 level courses or other courses at the 200 level or above NOT bearing an HSSA prefix. Exceptions can be made for the 200 level requirement with Department Head and Advisor approval.

FREE ELECTIVE - Free electives may be selected from any RHIT courses other than ECE206, ES213, or ES213L.

RESTRICTED SCIENCE ELECTIVE - (4 credit hours required) Must take one of the following electives including the lab: CHEM111, PH255, PH405, BIO110, BIO120, BIO130.

MATH AND MATH/SCIENCE ELECTIVES - MA100-Lvl and PH100-Lvl credits cannot be used to satisfy these electives. EE Students are strongly encouraged to take MA 371 Linear Algebra I or MA 373 Applied Linear Algebra for Engineers. MA 351-356 Problem Solving Seminar may not be used for these electives. Courses that are cross-listed with any engineering courses will not satisfy these elective requirements.

Electrical Engineering - Course Descriptions

ECE 160 Engineering Practice 0R-4L-2C F,W
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
An introduction to electrical and computer engineering, systems engineering design, programming, microcontrollers, soldering and circuit building. Students will work individually and on teams to complete projects and create a system for an end of term competition. Students will also learn about technical documentation and communication. Topics include functions, arrays, conditionals, loops, Boolean algebra, wireless communication, resistors, transistors, diodes motors, sensor, analog and digital inputs and outputs.

ECE 180 Introduction to Signal Processing 3R-3L-4C F,W,S

Prerequisites: MA 112F,W,S, and ECE 160F,W or CSSE 120F,W,S or ENGD 120S or ME 123F,W,S or prior programming experience
Corequisites: There are no corequisites for this course.
An introduction to discrete-time signal processing applied to audio, images, and video. Topics include phasor representation of sinusoidal signals, complex arithmetic, sampling, signal spectra, linear time-invariant systems, frequency response, convolution, filter implementation, and MATLAB programming. Integral laboratory.

ECE 199 Professional Experience 1R-0L-1C
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

ECE 203 DC Circuits 3R-3L-4C S, F
Prerequisites: MA 111F,W, and PH 112W,S,F
Corequisites: There are no corequisites for this course.
A review of the definition of voltage, current, energy and power. An introduction to Ohm's Law, ideal DC independent and dependent voltage and current sources, resistors, inductors, capacitors, and operational amplifiers. Circuit analysis and simplification by using series, parallel, and Wye-Delta reduction, Kirchhoff's laws, mesh and nodal analysis, Thevenin, Norton and Maximum Power Theorems, superposition, and source transformations. An integral laboratory to build electric circuits and measure voltage, current, resistance and power.

ECE 204 AC Circuits 3R-3L-4C F,W
Prerequisites: PH 113S,F,W*, and either ECE 203S, F** or ENGD 120S** or BE 131S**, or both ES 213S**, and ES 213LS** *Prerequisite or concurrent registration **with a grade of C or better
Corequisites: There are no corequisites for this course.
Capacitance, Self and Mutual Inductance. Root-mean-square values of waveforms. Application of phasors to sinusoidal steady-state. Impedance of circuit elements. Mesh and Nodal Analysis applied to ac circuits. Thevenin and Norton theorems applied to ac circuits. Single-phase ac power. Power factor correction. Voltage regulation and efficiency of feeders. Balanced three-phase systems. Ideal and non-ideal transformer models. Integral laboratory.

ECE 205 Circuits & Systems 3R-3L-4C W,S
Prerequisites: ECE 180F,W,S or BE 321W, and HUM H190F, W, and MA 222F,W,S, and either ECE 203S, F* or ENGD 120S*, or both ES 213S*, and ES 213LS* *with a grade of C or better; ** or concurrent registration
Corequisites: There are no corequisites for this course.
Introduction to 1st and 2nd order circuits and review of differential equations. Bode plots. System classification, impulse and step response, convolution. Laplace and inverse Laplace transforms, block and signal flow diagrams. Benefits of feedback. Modeling and simulating electrical systems. Matlab and Simulink. Integral laboratory.

ECE 206 Elements of Electrical Engineering 4R-0L-4C W,S
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.

A course designed for engineers (other than electrical or computer) covering analysis of passive circuits, introduction to op-amps, instrumentation, sinusoidal steady-state, a-c power, and induction motors. EE and CPE majors may not take this course.

ECE 230 Introduction to Embedded Systems 3R-3L-4C W,S

Prerequisites: ECE 233F, W, S, CSSE 120F,W,S, and ECE 160F,W

Corequisites: There are no corequisites for this course.

Sensors and actuators. Input and output devices. Microcontroller architecture. Standard communications protocols. Interrupt generation and processing. Data representation and storage. Memory management. The C programming language and programming styles. Integral laboratory and a term project.

ECE 233 Introduction to Digital Systems 3R-3L-4C F, W, S

Prerequisites: CSSE 120F,W,S or ECE 160F,W or ENGD 120S

Corequisites: There are no corequisites for this course.

Number systems, Binary arithmetic, logic gates, forming logic circuits. Boolean algebra, Karnaugh maps. Propagation delay, hazards, common Combinational logic circuits, structures, and design. Contraction, latches, flip-flops, finite state machines, counters, Sequential circuit timing, and designing Sequential circuits. Register design, control and datapath design. Basic computer architecture, including memory. Integral laboratory.

ECE 250 Electronic Device Modeling 3R-3L-4C S,F

Prerequisites: ECE 204 F,W or ECE 205W,S, ES 203F,W,S* or ES 213F,W,S*, and ES 213LF,W,S* * with grade of B or better

Corequisites: There are no corequisites for this course.

Modeling, analysis, and simulation of electronic circuits that contain two-terminal and threeterminal semiconductor devices. Large-signal, biasing, and small-signal analysis models. Introduction to wave shaping circuits, switching circuits, and amplifiers. Integral laboratory.

ECE 300 Continuous-Time Signals & Systems 3R-3L-4C F, S

Prerequisites: ECE 205W,S, and MA 222F,W,S, and MA 381F,W,S* *Prerequisite or concurrent registration

Corequisites: There are no corequisites for this course.

Signal modeling. Fourier series and Fourier transforms. Response of systems to periodic and aperiodic signals. Filter characterization and design. Ideal and practical sampling. Use of numerical analysis software. Integral laboratory

ECE 310 Communication Systems 3R-3L-4C W, S

Prerequisites: ECE 380F,W

Corequisites: There are no corequisites for this course.

Transmission of information over bandlimited, noisy communication channels. Line codes, probability of error, intersymbol interference. Modulation techniques, synchronization and frequency conversion. Integral laboratory.

ECE 312 Communication Networks 4R-0L-4C F, W

Prerequisites: MA 381F,W,S, and CSSE 120F,W,S

Corequisites: There are no corequisites for this course.

Layered architectures. Circuit and packet switching. The ISO Reference Model. Point-to-point protocols, error control, framing. Accessing shared media, local area networks. Virtual circuits, datagrams, routing, congestion control. Queuing theory. Reliable message transport, internetworking.

ECE 320 Linear Control Systems 3R-3L-4C W,S

Prerequisites: ECE 300F, S*, and ECE 230W,S* or ME 430F,W*
Corequisites: There are no corequisites for this course.
Analysis of linear control systems using classical and modern control theories in both continuous and discrete time. Plant representation, closed loop system representation, time response, frequency response, concept of stability. Root locus, Bode, and Nyquist methods. Computer modeling and simulation of feedback systems, implementation of discrete-time algorithims on microcontrollers.

ECE 332 Computer Architecture II 4R-0L-4C W, S
Prerequisites: CSSE 232F,W
Corequisites: There are no corequisites for this course.
Instruction-Level Parallelism. Pipelining. Data Hazards. Exceptions. Branch Prediction. Multilength Instructions. Loop Unrolling. TI C6000 Digital Signal Processor. Cache. Memory. MSP430 Microcontroller. PIC Microcontroller. Intel Itanium. Multiprocessors. Hardware Multithreading. Graphics Processors. Supercomputers.

ECE 340 Electromagnetic Fields 4R-0L-4C F,W
Prerequisites: ECE 204 F,W, and MA 222F,W,S
Corequisites: There are no corequisites for this course.
Static and dynamic fields. Electric and magnetic properties of materials. Energy, force and power. Resistors, capacitors, and inductors. Application in sensing and actuation. Maxwell's equations. Introduction to electromagnetic waves. Use of vector calculus and numeric approximation. Technical reports and/or term papers.

ECE 341 Electromagnetic Waves 4R-0L-4C W,S
Prerequisites: ECE 340F,W
Corequisites: There are no corequisites for this course.
Wave propagation and reflection. Power and lossy materials. Quasistatic analysis. Steady-state and transient analysis of transmission lines. Application in high-speed systems. Introduction to antennas. Technical reports and/or term papers.

ECE 342 Introduction to Electromagnetic Compatibility 3R-3L-4C F,S
Prerequisites: ECE 300F, S and Computer Engineering Major
Corequisites: There are no corequisites for this course.
Electromagnetic compatibility (EMC) regulations and measurement. Frequency behavior of passive components. Electromagnetic fields and waves. Transient behavior of transmission lines. Dipole and monopole antennas. Four coupling mechanisms: electrical and magnetic fields, common impedance, and electromagnetic wave. Conducted emissions. Radiated emissions. Electromagnetic shielding and grounding.

ECE 343 High-Speed Digital Design 3R-3L-4C W,S
Prerequisites: ECE 300F, S and Computer Engineering Major
Corequisites: There are no corequisites for this course.
Signal path modeling through connecting lengths of transmission lines with lumped element models of discontinuities. Circuit parameters from geometries and material properties for resistance, capacitance, inductance and transmission line segments. Lossless and lossy transmission line circuit modeling. High-frequency and high-speed behavior of passive components. Frequency spectrum of digital signals. Digital device driver and receiver modeling. Transmission line impedance discontinuity and termination techniques. Electric and magnetic field coupling mechanisms for capacitive and inductive crosstalk. Ground noise, power plane noise and resonance. Signal and power integrity issues in high-speed digital systems at both the printed-circuit board and chip levels.

ECE 351 Analog Electronics 3R-3L-4C F,W

Prerequisites: ECE 205W,S, and ECE 250S,F
Corequisites: There are no corequisites for this course.
Amplifier design and analysis including discrete and integrated circuit topologies. Cascaded amplifier, input and output stages, frequency response. Linear and non-linear op-amp circuits. Introduction to the non-ideal properties of op-amps. Integral laboratory.

ECE 362 Principles of Design 3R-0L-3C W,S

Prerequisites: ECE 204 F,W, and ECE 205W,S, ECE 230W,S, and ECE 233F, W, S, and ECE 250S,F, and ECE 300F, S
Corequisites: There are no corequisites for this course.
A formal design course that emphasizes the design process. Project management, project reporting and decision-making are learned by student teams as they carry a project through several stages of a formal design process.

ECE 370 Electric Machinery 3R-3L-4C W,S

Prerequisites: ECE 204 F,W
Corequisites: There are no corequisites for this course.
An introduction to electric machinery fundamentals. Operating principles and detailed analysis of single-phase and three-phase transformers, power electronics in the context of generators and motors, synchronous generators and motors, induction motors and generators, and dc motors and generators. Integral laboratory.

ECE 371 Conventional & Renewable Energy Systems 3R-3L-4C W

Prerequisites: ECE 204 F,W
Corequisites: There are no corequisites for this course.
Conventional and modern sources of energy for power generation in electric power industry with the imposed economic, regulatory, and environmental constraints. Wind, solar-photovoltaic, micro-hydropower, biomass, and fuel cell systems. Integral laboratory.

ECE 380 Discrete-Time Signals and Systems 4R-0L-4C F,W

Prerequisites: ECE 300F, S, and MA 381F,W,S
Corequisites: There are no corequisites for this course.
System properties: linearity and time-invariance. Sampling and reconstruction. Convolution in discrete-time systems. Z-transform, FIR and IIR filters. Discrete-time filter design. Discrete Fourier transform. Random Variables and Random Processes.

ECE 398 Undergraduate Projects 1-4C

Prerequisites: Arranged Prereq: Consent of instructor
Corequisites: There are no corequisites for this course.
Special design or research projects.

ECE 412 Software Defined Radio 4R-0L-4C See Dept Advising Site

Prerequisites: ECE 380F,W
Corequisites: There are no corequisites for this course.
Essential concepts of wireless communications. Software defined radio (SDR) architecture. Analog and digital modulation formats. Transmitter and receiver system design and implementation methods. Synchronization techniques. Term project.

ECE 414 Wireless Systems 4R-0L-4C W

Prerequisites: ECE 310W, S
Corequisites: There are no corequisites for this course.

Introduction to wireless communications and networks. Wireless channel models, vector space, modulation and demodulation, optimal receiver design, equalization, channel capacity, multipleaccess techniques, spread spectrum, and multiple-antenna systems. Additional recommended prerequisite: MA371 or MA373 with a grade of B or higher.

ECE 415 Wireless Electronics 2R-6L-4C

Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
Design, fabrication, and testing of a high frequency transmitter-receiver system including but not limited to oscillators, mixers, filters, amplifiers, and matching networks. Integral laboratory.

ECE 416 Introduction to MEMS: Fabrication & Applications 3R-3L-4C S

Prerequisites: Junior or Senior standing
Corequisites: There are no corequisites for this course.
Properties of silicon wafers; wafer-level processes, surface and bulk micromachining, thin-film deposition, dry and wet etching, photolithography, process integration, simple actuators. Introduction to microfluidic systems. MEMS applications: capacitive accelerometer, cantilever and pressure sensor. Cross-listed with CHE 405, EP 410, and ME 416.

ECE 418 Fiber Optic Systems 4R-0L-4C S

Prerequisites: ECE 310W, S Consent of instructor
Corequisites: There are no corequisites for this course.
Analysis and design of common photonic systems such as fiber optic communication links, optical sensing systems, and optical networks. Topics include basic architectures, component overview, system design, and expected degradations along with mitigation techniques. An oral presentation of a technical paper is required.

ECE 419 Advanced MEMS: Modeling and Packaging 3R-3L-4C F

Prerequisites: EP 410S or equivalent course
Corequisites: There are no corequisites for this course.
Design process, modeling; analytical and numerical. Actuators; dynamics and thermal issues. Use of software for layout and simulation. Characterization and reliability of MEMS devices. Electrical interfacing and packaging of MEMS. Microsensors, microfluidic systems, applications in engineering, biology, chemistry, and physics. Cross-listed with EP 411, and CHE 419.

ECE 420 Discrete-Time Control Systems 4R-0L-4C See Dept Advising Site

Prerequisites: ECE 320W,S
Corequisites: There are no corequisites for this course.
Sampled systems and z-transforms. Transfer function and state-variable models of systems. Discrete-time control of systems including state variable feedback and observer construction.

ECE 425 Introduction to Mobile Robotics 3R-3L-4C W

Prerequisites: CSSE 120F,W,S, and ECE 320W,S or ME 406F or BE 350F or CHE 340F, W
Corequisites: There are no corequisites for this course.
This course will introduce the basic principles of mobile robotics history, theory, hardware and control. Topics will include robot components, effectors and actuators, locomotion, sensors, feedback control, control architectures, representation, localization and navigation. This is a project-oriented course and the student will have hands-on

experience with a real mobile robot. The student will be required to complete several laboratory assignments and a multidisciplinary team design project.

ECE 430 Microcontroller-Based Systems 3R-3L-4C F

Prerequisites: ECE 250S,F* *For ECE students, consent of instructor for other students.

Corequisites: There are no corequisites for this course.

Microcontroller register set, addressing modes and instruction set. Microcontroller peripheral support modules. Assembly language and C programming. Fundamental data structures. Interrupts. Real time programming. Data communications. Microcontroller interface to displays, digital and analog devices, sensors, and actuators. Embedded system design, implementation and applications. Integrated development environment. Formal final report and oral presentation. Integral laboratory. Credit cannot be obtained for both ECE 331 and ECE 430.

ECE 433 Advanced Digital System Design with Verilog 3R-3L-4C F

Prerequisites: ECE 233F, W, S

Corequisites: There are no corequisites for this course.

Concepts and designs of combinational and sequential digital systems; Modern design methodology; ASM and ASMD charts for behavioral modeling; Synthesizable Verilog descriptions and synthesis techniques; Design verification and functional simulations; FPGA implementations of digital systems; Timing analysis and constraints; Storage devices; Implementation options; I/O clocking techniques; Synchronous and asynchronous designs; Complex digital systems; IP core applications. Integrated Development Environment. Integral laboratory.

ECE 434 Embedded Linux 3R-3L-4C W

Prerequisites: CSSE 332W,S or ECE 230W,S with a grade of B or better; or graduate standing, Operating Systems and Linux experience.

Corequisites: There are no corequisites for this course.

Brief introduction to Linux on an embedded processor. Software development in various languages (C, shell scripts, Python, JavaScript, etc.). Hardware interfacing. Kernel development. Software tools (IDE, gcc, make, node.js, etc.)

ECE 436 Internet of Things 4R-0L-4C S

Prerequisites: ECE 230W,S or CSSE 132F,S, and ECE 312F, W or CSSE 432S or consent of instructor

Corequisites: There are no corequisites for this course.

Introduction to the design and development of an Internet of Things (IoT) solution. Provides breadth of knowledge on a broad range of topics, such as sensors, communication, power, cloud storage, data analysis, automation, privacy and security. Focuses on a team design project to provide a complete IoT solution for a real-world application. This is a required course for the minor in Internet of Things for students earning a primary or secondary major in EE, CPE, CS, or SE. Students cannot earn credit for both MDS210 and ECE436.

ECE 452 Power Electronics 3R-3L-4C F

Prerequisites: ECE 250S,F

Corequisites: There are no corequisites for this course.

Analysis and design of networks that use electronic devices as power switches. Silicon-controlled rectifiers, power transistors, power MOSFETS, and IGBTs are used to form phase-controlled rectifiers, AC voltage controllers, choppers, and inverters. Integral laboratory.

ECE 454 System Level Analog Electronics 3R-3L-4C W

Prerequisites: ECE 351F,W
Corequisites: There are no corequisites for this course.
Analysis and design of Op-Amp circuits: wave shaping circuits, Schmitt triggers, power amplifiers, high power buffers, controlled current sources, peak detectors, sample and hold circuits. Precision Op-Amp Circuits. Non-ideal properties of Op-Amps. Integral laboratory.

ECE 460 Engineering Design I 1R-6L-3C F

Prerequisites: ECE 362W,S, and either ECE 230W,S*, and ECE 310W, S*, and ECE 320W,S*, and ECE 341W,S*, and ECE 351F,W*, and ECE 370W,S* or ECE 371W*, and ECE 380F,W* or CSSE 332W,S**, and CSSE 230F,W,S**, and ECE 250S,F**, and ECE 230W,S**, and ECE 312F, W**, and ECE 332W, S**, and ECE 343W,S**, and either ECE 380F,W** or ECE 320W,S** *For EE: Prereq or concurrent registration in the remainder of course. **For CPE: Prereq or concurrent registration in the remainder of course.
Corequisites: There are no corequisites for this course.
A continuation of a sequence of formal design courses that emphasizes completion of a client-driven project using a formal design process. Student teams carry a project from inception to completion to satisfy the need of a client. Integral laboratory.

ECE 461 Engineering Design II 1R-9L-4C W

Prerequisites: ECE 460F
Corequisites: There are no corequisites for this course.
Continuation of the design project from ECE460. Integral laboratory.

ECE 462 Engineering Design III 1R-3L-2C W,S

Prerequisites: ECE 461W
Corequisites: There are no corequisites for this course.
Completion of the design project from ECE 460 and ECE 461. Integral laboratory.

ECE 470 Power Systems Analysis I 3R-3L-4C F

Prerequisites: ECE 370W,S
Corequisites: There are no corequisites for this course.
Modeling of power system components that encompass transmission lines, power transformers, synchronous generators, and loads for power system representation and per unit analysis. Formulation of power system representation in the context of power flow analysis. The industry standard Siemens-PTI PSS/E software package will be used for solutions of the large-scale power flow. Economic dispatch by optimum allocation of generation, control of system voltage profile, and real and reactive power flow control by tap-changing transformers. Integral laboratory.

ECE 471 Power Systems Analysis II 4R-0L-4C W

Prerequisites: ECE 470F
Corequisites: There are no corequisites for this course.
Modeling of power system components that encompass transmission lines, power transformers, synchronous generators for analysis of power systems during balanced and unbalanced faults/short-circuits with symmetrical components. The industry standard ASPEN One-Liner software package will be used for simulation of large-scale faulted systems. Power system grounding and its impact on fault levels. Power system stability and generator rotor dynamics phenomenon with use of equal-area criterion. Modern approaches to power system stability analysis are introduced. Integral laboratory.

ECE 472 Power Systems Protection 3R-3L-4C S
Prerequisites: ECE 470F, and ECE 471W
Corequisites: There are no corequisites for this course.
Design and application of relaying schemes for protection of transformers, buses, distribution lines, transmission lines, generators, motors, capacitors, and reactors. Integral laboratory.

ECE 473 Control of Power Systems 3R-3L-4C W
Prerequisites: Senior standing or consent of instructor
Corequisites: There are no corequisites for this course.
Principles of interconnected operation of power systems. Optimum scheduling of generation using economic dispatch and unit commitment. Primary and secondary load-frequency control. Voltage and reactive-power flow control. Principles of state estimation. Integral laboratory.

ECE 480 Introduction to Image Processing 3R-3L-4C W
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Basic techniques of image processing. Discrete and continuous two dimensional transforms such as Fourier and Hotelling. Image enhancement through filtering and histogram modification. Image restoration through inverse filtering. Image segmentation including edge detection and thresholding. Introduction to image encoding. Relevant laboratory experiments.

ECE 481 Electronic Music Synthesis 4R-0L-4C S
Prerequisites: ECE 380F,W
Corequisites: There are no corequisites for this course.
Analog synthesis techniques. Instrument control using MIDI. FM, additive and subtractive synthesis. Physical modeling and sound spatialization. Course project.

ECE 483 DSP System Design 3R-3L-4C F
Prerequisites: ECE 380F,W, and MA 381F,W,S
Corequisites: There are no corequisites for this course.
Study of finite word length effects in DSP systems. Cascaded filter structures. Coefficient quantization, roundoff noise, scaling for overflow prevention. Discrete-time noise, filtering noise, power spectral density. Polyphase filtering, interpolation and decimation. Implementation and system design and test issues for a SSB communication system. Integral laboratory based on a fixed point programming project.

ECE 497 Special Topics in Electrical Engineering 1-4C
Prerequisites: Arranged prerequisite consent of instructor and department head
Corequisites: There are no corequisites for this course.
Topics of current interest to undergraduate students.

ECE 498 Undergraduate Projects 1-4C
Prerequisites: Arranged prerequisite consent of instructor
Corequisites: There are no corequisites for this course.
Special design or research projects.

ECE 510 Error Correcting Codes 4R-0L-4C F (odd years)
Prerequisites: ECE 310W, S* *Graduate standing or with a grade of B or better, or consent of instructor
Corequisites: There are no corequisites for this course.

Coding for reliable digital communication. Topics to be chosen from: Hamming and BCH codes, Reed-Solomon codes, convolutional codes, Viterbi decoding, turbo codes, and recent developments, depending on interests of class and instructor. Mathematical background will be developed as needed.

ECE 511 Data Communications 4R-0L-4C F (even years)

Prerequisites: ECE 310W, S*, and MA 381F,W,S* or ECE 310W, S**, and MA 381F,W,S** *Graduate standing **with a grade of B or better in both courses, or consent of instructor

Corequisites: There are no corequisites for this course.

Design of digital communication systems. Autocorrelation function and power spectrum, vector space models of signals and noise, optimal receiver structures and performance, bandlimited channels and equalization, convolutional coding.

ECE 512 Probability, Random Processes, and Estimation 4R-0L-4C W

Prerequisites: MA 381F,W,S, and ECE 380F,W

Corequisites: There are no corequisites for this course.

Review of probability and random variables, random vectors, topics in estimation and detection theory, linear and nonlinear estimation, orthogonality principle, hypothesis testing, random processes, stationarity, correlation functions, and spectra. Additional topics chosen from Wiener and Kalman filtering, and Markov chains.

ECE 516 Introduction to MEMS: Fabrication & Applications 3R-3L-4C S

Prerequisites: Junior or Senior class standing

Corequisites: There are no corequisites for this course.

Properties of silicon wafers; wafer-level processes, surface and bulk micromachining, thin-film deposition, dry and wet etching, photolithography, process integration, simple actuators. Introduction to microfluidic systems. MEMS applications: capacitive accelerometer, cantilever and pressure sensor. Cross-listed with BE 516, CHE 505, EP 510, and ME 516.

ECE 519 Advanced MEMS: Modeling & Packaging 3R-3L-4C F

Prerequisites: EP 410S or equivalent course

Corequisites: There are no corequisites for this course.

Design process, modeling; analytical and numerical. Actuators; dynamics and thermal issues. Use of software for layout and simulation. Characterization and reliability of MEMS devices. Electrical interfacing and packaging of MEMS. Microsensors, microfluidic systems, applications in engineering, biology, chemistry, and physics. Cross-listed with ME 519, EP 511, and CHE 519.

ECE 530 Advanced Microcomputers 3R-3L-4C S

Prerequisites: ECE 230W,S* *Graduate standing; or with a grade of B or better; or consent of instructor

Corequisites: There are no corequisites for this course.

32-bit microcontroller architecture. Software development in both assembly language and C language. Hardware interfacing. Use of a real-time-operating system (RTOS). System-on-a-chip (SOC) hardware/software design using a field programmable gate array (FPGA) chip containing an embedded microcontroller cores. Software debugging tools. Integral laboratory.

ECE 531 Digital Test & Product Engineering 3R-3L-4C S

Prerequisites: ECE 230W,S*, and ECE 233F, W, S*, and ECE 250S,F* *Graduate standing; or with grades of B or better in all three courses; or consent of instructor.

Corequisites: There are no corequisites for this course.

Industrial testing techniques for microcontrollers and other digital integrated circuits. Includes common digital system fault modeling, test generation, and design for testability in addition to memory testing strategies. Integral labs using an industrial grade automatic test environment (ATE).

ECE 532 Advanced Topics in Computer Architecture 4R-0L-4C W

Prerequisites: ECE 332W, S with a B or better.

Corequisites: There are no corequisites for this course.

Superscalar processors. Out-of-Order Execution. Register Renaming. Dynamic Random Access Memory (DRAM). Prefetching. Trace Cache. Victim Cache. 3D DRAM. Multithreading. Multicore. Cache Coherence. Transactional Memory. Performance Modeling. Power Modeling. Intel Pentium Pro Architecture. Transmeta Crusoe Architecture. Code Morphing. ARMv7 Architecture. Nvidia G80 Architecture.

ECE 534 Advanced Signal & Power Integrity 4R-0L-4C W

Prerequisites: ECE 341W,S*, and ECE 342F,S* or ECE 343W,S* *Graduate standing; or all courses with a grade of B or better; or ECE342 with a grade of B or better, or consent of instructor

Corequisites: There are no corequisites for this course.

Signal and power integrity modeling and measurement in high-speed digital systems at IC, PCB, and chassis levels. High-frequency behavior of passive components and packages. Behavior and SPICE models of drivers and receivers. Lossy transmission lines and discontinuity characterization. Mixedmode s-parameters and other network parameters. Frequency and time-domain modeling of capacitive and inductive crosstalk. Differential signaling techniques; timing conventions. Synchronization. Signal equalization. Power plane noise and resonance. High-speed PCB design guidelines. Measurement techniques including time-domain reflectometry, vector network analyzer and impedance analyzer. PCB simulation. Full-wave simulations.

ECE 540 Antenna Engineering 3R-3L-4C W

Prerequisites: ECE 341W,S* Graduate standing (course not required); *or with a grade of B or better; or consent of instructor.

Corequisites: There are no corequisites for this course.

Electromagnetic radiation, antenna terminology and characteristics, dipole antennas, arrays, aperture antennas, measurements, computer-aided analysis, design projects and reports.

ECE 541 Microwave/Millimeter-Wave Engineering 4R-0L-4C S

Prerequisites: ECE 341W,S Graduate standing; or with grade of B or better, or consent of instructor

Corequisites: There are no corequisites for this course.

Wave-guiding structures, microwave network analysis, scattering parameters, Z, Y and ABCD parameters, passive devices and components, design, fabrication, simulation and measurement of microwave devices and components, matching strategies, multi-conductor transmission lines and crosstalk.

ECE 542 Advanced Electromagnetics 4R-0L-4C F

Prerequisites: ECE 341W,S and Graduate standing; or with grade of B or better, or consent of instructor

Corequisites: There are no corequisites for this course.

Maxwell's equations, EM field theorems, potential functions, power and energy, material properties, wave propagation, reflection and transmission, radiation, scattering, Green's functions, metamaterials and metamaterial-inspired structures, modeling & simulation, measurement technique.

ECE 543 Electromagnetic Metamaterials 4R-0L-4C

Prerequisites: ECE 341W,S* Graduate standing (course not required) *or with grade of B or better; or consent of instructor

Corequisites: There are no corequisites for this course.

Electromagnetic fundamentals, control of permittivity and permeability, dispersion, causality, double-negative materials, epsilon near-zero materials, transmission line-based metamaterials, composite right/left handed wave-guiding structures, even/odd mode analysis, differential signaling, electromagnetic bandgap structures, phase control, dual band devices, enhanced bandwidth devices, zeroth-order resonators, full wave simulation, device fabrication and laboratory measurement.

ECE 551 Digital Integrated Circuit Design 3R-3L-4C F

Prerequisites: ECE 250S,F, and ECE 233F, W, S both with a grade of B or better; or graduate standing.

Corequisites: There are no corequisites for this course.

Design, performance analysis, and physical layout of CMOS logic. Custom and standard cell methodologies. Use of commercial CAD tools. Design issues such as interconnect, timing, and testing methods. Integral laboratory and project.

ECE 552 Analog Integrated Circuit Design 3R-3L-4C W

Prerequisites: ECE 351F,W, and ECE 380F,W Graduate standing; or with a grade of B or better in both courses; or consent of instructor

Corequisites: There are no corequisites for this course.

Design, performance analysis, and physical layout of analog integrated circuits. Focus on operational amplifier design and op-amp circuits. Introduction to mixed-signal circuit design such as switch-capacitors, A/D, or D/A systems. Integral laboratory and design project.

ECE 553 Radio-Frequency Integrated Circuit Design 3R-3L-4C S

Prerequisites: ECE 310W, S, and ECE 351F,W Graduate standing (courses not required); or with a grade of B or better; or consent of instructor

Corequisites: There are no corequisites for this course.

Design, analysis, and physical layout of high-frequency analog integrated-circuits for modern RF transceivers. Circuit design for each primary transceiver component. General issues such as impedance matching and design of inductors on integrated circuits. Integral laboratory and design project.

ECE 554 Instrumentation 4R-0L-4C S

Prerequisites: ECE 351F,W Graduate standing; or with grade of B or better; or consent of instructor

Corequisites: There are no corequisites for this course.

Transducers and their applications. Analog signal processing techniques using operational amplifiers. A/D and D/A converters. Protection from electric shock. Measurement of biological potential waveforms (ECG, EMG, EEG, ENG, EOG, ERG). Ultrasound techniques and instrumentation. X-ray CAT techniques. No laboratory, but many in-class demonstrations and emphasis on circuit simulation.

ECE 556 Power Electronics: DC Power Supplies 3R-3L-4C S

Prerequisites: ECE 351F,W Graduate standing; or with grade of B or better; or consent of instructor

Corequisites: There are no corequisites for this course.

Analysis and design of AC-DC and DC-DC converters. Linear, basic switching, charge-pump, and fly-back topologies. Introduction to devices used in a power switching supplies. Thermal management. Integral laboratory.

ECE 557 Analog Test & Product Engineering 3R-3L-4C F

Prerequisites: ECE 300F, S, and ECE 351F,W Graduate standing; or with a grade of B or better in both courses, or consent of instructor

Corequisites: There are no corequisites for this course.

Fundamental skills necessary to be an industrial integrated circuit test engineer or product engineer. Includes the economics associated with testing, impact of fabrication variation on devices, instrumentation associated with industrial testing, turning a data sheet into a test plan, industrial testing techniques for analog circuits, trade-offs between test time and test accuracy, statistical analysis of the data and statistical process control, the use of device interface boards necessary to control device loading for different tests. Integral labs with an industrial grade automatic tester (ATE).

ECE 558 Mixed-Signal Test & Product Engineering 3R-3L-4C W

Prerequisites: ECE 300F, S, and ECE 233F, W, S, and ECE 351F,W Graduate standing; or with grades of B or better in all three courses; or consent of instructor.

Corequisites: There are no corequisites for this course.

Industrial testing techniques for AC and DC tests of mixed-signal integrated circuits using an automatic test environment (ATE). Includes the structure and operation of comparators and standard data converters (DACs, ADCs), common data converter datasheet specifications, impact of data converter design on testing strategies, and statistical analysis of accuracy-time trade-offs. Integral labs using an industrial grade ATE.

ECE 580 Digital Signal Processing 4R-0L-4C W

Prerequisites: ECE 380F,W, and MA 381F,W,S *Graduate standing (courses not required); or with grade of B or better in both courses; or consent of instructor. MA367 with a grade of B or higher recommended.

Corequisites: There are no corequisites for this course.

Digital filters. Fundamental concepts of digital signal processing. Analysis of discrete-time systems. Sampling and reconstruction. Theory and application of z-transforms. Design of recursive and nonrecursive digital filters. Window functions. Discrete Fourier transforms and FFT algorithm.

ECE 581 Digital Signal Processing Projects 2R-2L-2 or 4C

Prerequisites: ECE 580W concurrent registration

Corequisites: There are no corequisites for this course.

Computer-aided design of digital filters and other DSP modules. Software and hardware realization using modern DSP chips. DSP chip architectures, C-language programming, and interfacing techniques. Optional advanced project may be done to earn four credit hours; otherwise two credit hours are given. Integral laboratory.

ECE 582 Advanced Image Processing 3R-3L-4C S

Prerequisites: CSSE 120F,W,S Senior standing or Graduate standing

Corequisites: There are no corequisites for this course.

Introduction to image segmentation and recognition. Use of neural networks, fuzzy logic and morphological methods for feature extraction. Advanced segmentation, detection, recognition and interpretation. Relevant laboratory experiments and required project. Cross-listed with OE 537.

ECE 584 Medical Imaging Systems 4R-0L-4C

Prerequisites: ECE 300F, S* or BE 321W or OE 392W (every other year) *Graduate standing; or ECE300 with grade of B or better; or consent of instructor
Corequisites: There are no corequisites for this course.
Engineering principles of major imaging techniques/modalities for biomedical applications and health care including diagnostic x-ray, computed tomography, nuclear techniques, ultrasound, and magnetic resonance imaging. Topics include general characteristics of medical images; physical principles, signal processing to generate an image, and instrumentation of imaging modalities. Clinical applications of these technologies are also discussed. Cross-listed with BE541 and OE584.

Prerequisites Notes:

Prerequisites - Clarification:
ECE 300 - Continuous-Time Signals & Systems and Graduate standing;
or ECE 300 Continuous-Time Signals & Systems with a grade of B or better
or BE 340 – Biomedical Signal Processing
or OE 392 – Linear Optical Systems with a grade of B or better;
or consent of instructor

ECE 596 Independent Study in Electrical Engineering 1C-4C
Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
Special research or project based work that is done in consultation with a faculty member. Participation in these projects should require a graduate level of involvement and expectations, otherwise ECE498 Undergraduate Projects should be used. No more than 8 credit hours of ECE596 can be counted towards a graduate degree in the ECE Department without ECE Department Head Approval.

ECE 597 Special Topics in Electrical Engineering 4C
Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
Special topics courses of current interest to graduate students and senior undergraduates.

ECE 598 Thesis Research 1-4C
Prerequisites: Arranged
Corequisites: There are no corequisites for this course.
Thesis topic selected in consultation with adviser. Graduate students only.

ECE 699 Professional Experience 1R-0L-1C
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The work experiences should be informative or integral to the advancement or completion of the student's program requirements. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

Engineering Design

A Bachelor of Science in Engineering Design

An engineering design degree opens the door to various positions in industry and graduate school. Your experience with client-focused design, prototyping, and professional skills will allow you to contribute to companies in any phase of the design process: identification of stakeholder needs, concept generation, feasibility studies, risk analysis, detail design, manufacturing, testing, validation, maintenance, and product lifecycle analysis.

Facilities and Resources

Hands-on learning and prototyping is a key component of engineering design. Engineering design students use prototyping technology in design studios developed to encourage creativity and communication with all stakeholders. Students routinely use tools from a variety of on-campus shops after appropriate instruction.

Laboratories

Design studios include laboratory equipment for design, prototyping, and testing. Students use current technologies to bring their ideas to life. Students also work with external clients starting in their first quarter on campus.

Engineering Design

Engineering design is a human-centered endeavor that grew out of investigations of creativity. While design is an integral part of all engineering fields, design methodology gained more attention during the 1980s as global competition demanded higher quality design and system complexity increased. The role of the designer is to create a system, process, product, or service based on stakeholder needs while considering social, environmental, economic, and safety requirements. The designer must have both a mindset and skillset for improving the impact of design on society. The mindset requires the vision and drive necessary to create value. The skillset includes the tools and techniques critical to realize the design.

The Engineering Design major prepares students by giving them repeated, intensive design experiences with real clients. From the first quarter to the senior year, students participate in authentic design experiences and practice professional skills. The first year gives students a broad understanding of modeling systems across disciplines and repeated practice in prototyping solutions for clients. Students select a concentration and prepare for their practicum as they continue deeper in the design process. Second year students also learn the process of on-boarding into existing projects as they work with seniors one quarter and freshmen another. Transitioning to the third year, students participate in two 20-week practicums. Students are required to delve into the design process. In the junior year, the curriculum is structured to allow study-work abroad and/ or cooperative work experiences. In their senior year, students complete their concentrations and participate in a year-long, multidisciplinary capstone design experience.

After completion of this curriculum, students will be prepared to enter the engineering profession or advanced study. A student may also use this academic background as a stepping stone to a position in management, administration, or some other non-engineering field.

Engineering Design Mission Statement

Engineering Design employs repeated, immersive design experiences to cultivate students who

- Embrace the ambiguity of design
- Select design processes from multiple disciplines as appropriate to the project
- Tackle projects with gusto
- Commit to professional and ethical responsibilities while remembering global, social, economic, and environmental considerations
- Communicate respectfully and effectively
- Create collaborative and inclusive teams

Engineering Design Program Educational Objectives

In support of our mission and based on the needs of our constituents, alumni from our program are expected to attain:

- Ethically-minded solutions to open-ended problems using engineering and/or design principles
- Recognition as skilled engineers and/or designers
- Meaningful, collaborative work
- Active involvement in professional & personal development
- Contributions to society locally, nationally, or globally
- Recognition as facilitators of multidisciplinary teams

Student Outcomes

Attainment of these outcomes prepares graduates to enter the professional practice of engineering.

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 judgement to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies

The engineering design program is accredited by the Engineering Accreditation Commission of ABET, https://www.abet.org, under the commission’s General Criteria with no applicable program criteria.

Technical Electives

Engineering Design students have 24 credit-hours for technical electives. Students should use these credits to gain in-depth knowledge of a specific technical area. With careful planning, students may use these technical electives to obtain a minor or concentration in an area of interest.

Technical electives must:

1. Consist of 24 credit-hours of bio-math, computer science, engineering, engineering management, mathematics, or science courses
2. At least two courses must be 300 level or higher
3. Not include any named required courses

Practicum Courses:

All engineering design students must take 16 hours of practicum courses. Enrollment in a practicum course requires professional employment such as an internship or co-op. Professional employment must average a minimum of 25 hours per week of work and have a duration of at least eight weeks. Professional employment must include some aspects of the design process such as commercialization, conceptual design, manufacturing, modeling, process improvement, product design, product improvement, quality methods, testing, or design validation. Practicum courses are generally 300-level courses with the term “Practicum” in the catalog description.

Plan of Study

Freshman

Fall

Course	Credit
ENGD 100 Design & Communication Studio	8
MA 111 Calculus I	5
RHIT 100 Foundations for Rose-Hulman Success	1
PH 111 Physics I	4
	Total Credits: 18

Winter

Course	Credit
ENGD 110 Circuits, Software Development, and Societal Impact Design Studio	6
PH 112 Physics II	4
MA 112 Calculus II	5
ENGD 205 Systems Accounting and Modeling I	3
	Total Credits: 18

Spring

Course	Credit
ENGD 120 Integrating Electrical, Software, and Societal Systems	6
MA 113 Calculus III	5
ENGD 150 Independent Design Project	2
ENGD 151 Problem Solving and Data Representation	1
ENGD 215 Systems Accounting and Modeling II	3
	Total Credits: 17

Sophomore

Fall

Course	Credit
ENGD 260 Product Design Studio	6
BE 211 Circuits, Sensors, and Measurements	3
MA 223 Statistics	4
CHEM 111 General Chemistry I	3
CHEM 111 General Chemistry I Lab	1
	Total Credits: 17

Winter

Course	Credit
ENGD 240 User Experience Design Studio	6
ENGD 270 Vertically Integrated Project I	2
MA 221 Matrix Algebra and Differential Equations I	4
BE 222 Mechanics of Materials	4
	Total Credits: 16

Spring

Course	Credit
ENGD 250 Human-Computer Interface Studio	6
ENGD 271 Design Testing	2
MA 222 Matrix Algebra and Differential Equations II	4
Tech Elective 1	4

	Total Credits: 16

Summer Immersive

Course	Credit
PRAC Practicum I	4
	Total Credits: 4

Junior

Fall Immersive

Course	Credit
PRAC Practicum II	4
	Total Credits: 4

Winter

Course	Credit
Tech Elective 2	4
Tech Elective 3	4
HSSA Elective	4
HSSA Elective	4
	Total Credits: 16

Spring Immersive

Course	Credit
PRAC Practicum III	4
	Total Credits: 4

Summer Immersive

Course	Credit
PRAC Practicum IV	4
	Total Credits: 4

Senior

Fall

Course	Credit
MDS 410 Multidisciplinary Capstone Design I	4
Tech Elective 4	4
HSSA Elective	4
BIO Appropriate Biology Elective with lab	4

HUMH 230 Engineering Design Social Capstone	2
	Total Credits: 18

Winter

Course	Credit
MDS 420 Multidisciplinary Capstone Design II	4
HSSA Elective	4
Tech Elective 5	4
MA/SCI Math/Science Elective	4
	Total Credits: 16

Spring

Course	Credit
MDS 430 Multidisciplinary Capstone Design III	4
HSSA Elective	4
Tech Elective 6	4
MA/SCI Math/Science Elective	4
	Total Credits: 16

NOTES:

*Students who want to take a foreign language may postpone these courses and graduate on time with careful scheduling.

Engineering Design - Course Descriptions

ENGD 100 Design and Communication Studio 6R-10L-8C F
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Integrates rhetorical analysis, research methods, and the conventions of academic writing into the design process. Introduces disability studies, a multi-disciplinary field that identifies, challenges, and re-conceptualizes representations of disability. Includes problem definition, analysis, alternate solutions, and specifications of final solutions. Uses sketching, computer-aided drawings, and traditional orthographic drawings to communicate design decisions. Introduces teamwork through group design efforts and instruction. Successful completion of this studio satisfies the requirements of HUM H140, EM 103, and EM 104. Students may not receive credit towards graduation for both ENGD 100 and any of HUM H140, EM 103, and EM 104.

ENGD 101 Representations of Design Studio 1R-5L-2C Not offered
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Uses sketching, computer-aided drawings, and traditional orthographic drawings to develop and communicate design decisions. Emphasizes design intent. Successful

completion of ENGD 101 satisfies the requirements of EM 104. Students may not receive credit towards graduation for both ENGD 101 and EM 104.

ENGD 102 Design Realization Studio 1R-5L-2C Not offered

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Includes problem definition, stakeholder analysis, design and manufacturing processes, prototyping, and communicating the design. Successful completion of ENGD 102 satisfies the requirements of EM 103. Students may not receive credit towards graduation for both ENGD 102 and EM 103.

ENGD 103 Designing for Disabilities Studio 4R-0L-4C Not offered

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Introduces disability studies, a multi-disciplinary field that identifies, challenges, and re-conceptualizes representations of disability. Integrates concepts from ENGD 101 and ENGD 102 to meet the needs of a client with disabilities. Includes ethnographic observations. Successful completion of ENGD 103 satisfies the requirements of HUM H140. Students may not receive credit towards graduation for both ENGD 103 and HUM H140.

ENGD 110 Circuits, Software Development, and Societal Impact Design Studio 4R-12L-6C W

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Extends the design process to include the development of software, the use of instrumentation and measurement techniques, and the consideration of scientific research and technological development within cultural, historical, and social contexts and values. Introduces fundamental principles and techniques of programming, including classes, objects, and methods. Surveys types of sensors and basic principles of circuit design (including Ohm's Law, Kirchoff's Laws). Supplies context in ideas about technical progress and scientific facts, the role of design in social institutions, and issues of gender facing technical professionals and knowledge domains. Students may not receive credit towards graduation for both ENGD110 and any of BE 121, CSSE 120, ES 213, ES 213L, or HUM H190.

ENGD 111 Science, Technology, and Society in Design 02R-0L-2C Not offered

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Considers scientific research and technological development with cultural, historical, and social contexts and values. Examines role of metrics in design. Successful completion of ENGD 111 and ENGD 121 satisfies the requirements of HUM H190. Students may not receive credit towards graduation for ENGD 111 and HUM H190.

ENGD 112 DC Circuits 1R-6L-2C Not offered

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Introduces the fundamentals of DC circuit design and analysis. DC circuit analysis tools such as Kirchhoff's laws, mesh and nodal analysis, superposition, and source transformations are utilized. Surveys types of sensors and basic principles of circuit design. Successful completion of ENGD 112 satisfies the requirements of BE 121. Students may not receive credit towards graduation for both ENGD 112 and any of BE 121, ES213, or ES213L.

ENGD 113 Software Development Principles 1R-6L-2C Not offered

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

An introduction to procedural and object-oriented programming with an emphasis on problem solving. Problems may include visualizing scientific or commercial data, interfacing with external hardware such as robots, or solving numeric problems from a variety of engineering disciplines. Introduces fundamental principles and techniques of programming, including classes, objects, and methods. Successful completion of ENGD 113 and ENGD 123 satisfies the requirements of CSSE 120. Students may not receive credit towards graduation for both ENGD 113 and CSSE 120.

ENGD 120 Integrating Electrical, Software, and Societal Systems 4R-12L-6C S

Prerequisites: ENGD 110W

Corequisites: There are no corequisites for this course.

Continues the design process with software development, instrumentation and measurement techniques, and cultural, historical, and social contexts and values surrounding scientific and technological development work. Adds more advanced programming concepts (implicit loops and conditionals) and tasks of software development (such as development of user interfaces). Includes use of electronic components (op amps, capacitors, inductors) and signal processing (amplifiers and filters). Social contexts for analysis of technology and its history include gender and work. Students may not receive credit towards graduation for ENGD120 and any of CSSE120, ES213, or HUM H190. Successful completion of ENGD110 and ENGD120 satisfies the requirements of BE 131, ES213, ES213L, CSSE120, and HUM H190.

ENGD 121 Science, Technology, and Society in Design 2R-0L-2C Not offered

Prerequisites: ENGD 110W or ENGD 111Not offered

Corequisites: There are no corequisites for this course.

Considers scientific research and technological development with cultural, historical, and social contexts and values. Scheduled with ENGD 122 and ENGD 123. Successful completion of ENGD 111 and ENGD 121 satisfies the requirements of HUM H190. Students may not receive credit towards graduation for both ENGD 121 and HUM H190.

ENGD 122 AC Circuits 1R-6L-2C Not offered

Prerequisites: ENGD 110W or BE 121W or ENGD 112Not offered

Corequisites: There are no corequisites for this course.

This course introduces the fundamentals of AC circuit design and analysis. Topics include RLC circuits, equivalent impedance, phasor domain analysis (nodal analysis, mesh current, source superposition, source transformation), and Thevenin and Norton theorems. The concept of linear systems and the use of electronic components (op-amps, capacitors, inductors) will also be introduced. Successful completion of ENGD 122 satisfies the requirements of BE 131. Students may not receive credit towards graduation for both ENGD 122 and any of BE 131, ES213, or ES213L.

ENGD 123 Software Development Principles 1R-6L-2C Not offered

Prerequisites: ENGD 110W or ENGD 113Not offered

Corequisites: There are no corequisites for this course.

Adds more advanced programming concepts (implicit loops and conditionals) and tasks of software development (such as development of user interfaces). Successful completion of ENGD 113 and ENGD 123 satisfies the requirements of CSSE 120. Students may not receive credit towards graduation for both ENGD 123 and CSSE 120.

ENGD 150 Independent Design Project 1R-2L-2C S

Prerequisites: ENGD majors only
Corequisites: There are no corequisites for this course.
Selected design projects. May include computer-aided design, testing, or design methodology. Plan of study for students' specialization must be approved.

ENGD 151 Problem Solving and Data Representation 0.5R-1.5L-1C S

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Discusses scientific data representation. Examines efficient methods for acquiring a new programming language. Uses both Excel and MATLAB for problem solving and data representation.

ENGD 190 Selected Topics in Engineering Design 1-4C Arranged F,W,S

Prerequisites: ENGD majors only, approval of director, advisor, and course instructor
Corequisites: There are no corequisites for this course.
Selected design projects. Projects may emphasize certain phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

ENGD 200 Systems Accounting and Modeling I 2R-0L-2C W

Prerequisites: MA 111F,W
Corequisites: There are no corequisites for this course.
Covers systems accounting and modeling approach to engineering science, conservation of mass, linear and angular momentum. 2D and 3D vectors will be introduced and reinforced with examples.

ENGD 205 Systems Accounting and Modeling I 3R-0L-3C W

Prerequisites: MA 111F,W
Corequisites: There are no corequisites for this course.
Covers systems accounting and modeling approach to engineering science, conservation of mass, linear and angular momentum. 2D and 3D vectors will be introduced and reinforced with examples. Basic stress-strain, impact/impulse, relative motion, and tipping will be covered.

ENGD 210 Systems Accounting and Modeling II 4R-0L-4C S

Prerequisites: ENGD 200W or EM 121F, W, S equivalent
Corequisites: There are no corequisites for this course.
A common framework for engineering analysis is extended using the concepts of a system, accounting and conservation of extensive properties, constitutive relations, constraints, and modeling assumptions. Stress, strain, and deformation under axial loading are defined. Equilibrium is defined. Conservation equations for mass, charge, momentum and energy, and an entropy accounting equation are developed. Applications are developed from multiple engineering disciplines. Students may not receive credit towards graduation for both ENGD210 and ES201.

ENGD 215 Systems Accounting and Modeling II 3R-0L-3C S
Prerequisites: ENGD 205W or EM 121F, W, S or equivalent
Corequisites: There are no corequisites for this course.
This course is a continuation of ENGD 205 and emphasizes engineering problem solving using common engineering science concepts: systems, conservation and accounting principles for extensive properties, material properties, constitutive equations, and physical constraints. This framework, combined with appropriate mathematics, provides a powerful tool for modeling and predicting the behavior of the physical world. The course introduces two- and three-dimensional force systems, equilibrium, distributed forces, and strength and elastic deflection of engineering materials under axial loading. Students may not receive credit towards graduation for both ENGD215 and ES201.

ENGD 240 User Experience Design Studio 4R-12L-6C W
Prerequisites: ENGD 120S
Corequisites: There are no corequisites for this course.
Provides students with instruction and practice in analyzing contexts, audiences, and genres. Stakeholder analysis will be emphasized. SCRUM project management techniques will be introduced. Object-oriented programming concepts, including the use of inheritance, interfaces, polymorphism, abstract data types, and encapsulation to enable software reuse and assist in software maintenance will be introduced. Habits of rhetorical analysis, skills in teaming and collaboration, and techniques for presenting content and evidence will be presented. Systems engineering models will be integrated with software development. User experience and usability testing will be emphasized. Students may not receive credit toward graduation for ENGD 240 and either ENGL H290 or CSSE 220.

ENGD 241 Technical Communication in Design 2R-0L-2C Not offered
Prerequisites: See below
Corequisites: There are no corequisites for this course.
Habits of rhetorical analysis, skills in teaming and collaboration, and techniques for presenting content and evidence will be presented. User experience and usability testing will be emphasized. Students may not receive credit toward graduation for both ENGD 241 and ENGL H290.

ENGD 242 Design Thinking 1R-6L-2C Not offered
Prerequisites: See below
Corequisites: There are no corequisites for this course.
This course expands design processes to include decision making, design of experiments, and additional processes for monitoring customer requirements.

ENGD 243 Software Development Principles 1R-6L-2C Not offered
Prerequisites: See below
Corequisites: There are no corequisites for this course.
SCRUM project management techniques will be introduced. Object-oriented programming concepts, including the use of inheritance, interfaces, polymorphism, abstract data types, and encapsulation to enable software reuse and assist in software maintenance will be introduced. Systems engineering models will be integrated with software development. User experience and usability testing will be emphasized. Students may not receive credit toward graduation for both ENGD 243 and CSSE 220.

ENGD 250 Human Computer Interfaces Studio 4R- 12L-6C S
Prerequisites: ENGD 240W

Corequisites: There are no corequisites for this course.
Extends the design process to include development of human-computer (HCI) interfaces. Continues with object-oriented programming concepts such as use of common object-based data structures, including stacks, queues, lists, trees, sets, maps, and hash tables. Space/time efficiency analysis. Testing. Introduction to UML. Crafting documents to meet the demands and constraints of professional situations; integrating all stages of the writing process; and collaborating effectively within and across teams will be emphasized. Systems engineering models will be used. Successful completion of both ENGD 240 and ENGD 250 meet the prerequisite requirements of ENGL H290 and CSSE 220. Students may not receive credit toward graduation for both ENGD 250 and either of ENGL H290 or CSSE 220.

ENGD 251 Technical Communication in Design II 2R-0L-2C Not offered
Prerequisites: See below
Corequisites: There are no corequisites for this course.
Crafting documents to meet the demands and constraints of professional situations; integrating all stages of the writing process; user experience; usability testing; and collaborating effectively within and across teams will be emphasized. Successful completion of ENGD 241 and ENGD 251 meets the requirements of ENGL H290. Students may not receive credit toward graduation for both ENGD 251 and ENGL H290.

ENGD 252 Design of Human-Computer Interfaces 1R-6L-2C Not offered
Prerequisites: See below
Corequisites: There are no corequisites for this course.
Extends the design process to include development of human-computer (HCI) interfaces. User experience will be emphasized.

Prerequisites Notes:

ENGD 240, or both CSSE 220 and ENGD 241, or both ENGD 241 and ENGD 243

ENGD 253 Software Development Principles 1R-6L-2C Not offered
Prerequisites: See below
Corequisites: There are no corequisites for this course.
Continues with object-oriented programming concepts such as use of common object-based data structures, including stacks, queues, lists, trees, sets, maps, and hash tables. Space/time efficiency analysis. Testing. Introduction to UML. Successful completion of ENGD 243 and ENGD 253 meets the requirements of CSSE 220. Students may not receive credit toward graduation for both ENGD 253 and CSSE 220.

Prerequisites Notes:

ENGD 240, or both CSSE 220 and ENGD 241, or both ENGD 241 and ENGD 243

ENGD 260 Product Design Studio 4R-12L-6C F
Prerequisites: ENGD 100 F equivalent
Corequisites: There are no corequisites for this course.
Continues the design process by examining the interactions between design and manufacturing from the designer's point of view. Common manufacturing processes will be introduced and design guidelines will be developed for each process. Emphasizes a systems engineering approach for new product development. Applies several design methods to integrate concepts of form and function to realize value for the user.

Explores the intersections of beauty and utility in design. Visceral, behavioral, and reflective aspects of emotional design are examined.

ENGD 270 Vertically Integrated Project I 1R-2L-2C W

Prerequisites: ENGD majors only

Corequisites: There are no corequisites for this course.

This course emphasizes ethics, professionalism, and codes and standards. Students apply concepts to an external situation, either with other majors and/or students in other academic years.

ENGD 271 Design Testing 1R-2L-2C S

Prerequisites: ENGD majors only

Corequisites: There are no corequisites for this course.

Students write test plans, conduct experimentation, and reflect on the results.

ENGD 290 Selected Topics in Engineering Design 1-4C Arranged F,W,S

Prerequisites: ENGD majors only, approval of director, advisor, and course instructor

Corequisites: There are no corequisites for this course.

Selected design projects. Projects may emphasize certain phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 300 Engineering Practicum I 4R-0L-4C See Department

Prerequisites: Student must obtain professional work experience such as an internship or co-op

Corequisites: There are no corequisites for this course.

Requires in-depth experience in engineering design processes. May emphasize certain phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 301 Creative Design Practicum 4R-0L-4C See department

Prerequisites: Student must obtain professional employment such as an internship or co-op.

Corequisites: There are no corequisites for this course.

Applies creativity techniques to the student’s work environment. The work environment must contain some phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 302 Human Factors Practicum 4R-0L-4C See department

Prerequisites: Student must obtain professional employment such as an internship or co-op.

Corequisites: There are no corequisites for this course.

Human factors engineering aims to improve human interaction with systems by enhancing safety (reducing the risk of injury), performance (increasing productivity), and satisfaction (acceptance, comfort). Students will learn and be able to identify critical human factors in a system that affect safety, performance, and satisfaction. Students will apply course concepts to their work environment. The work environment must contain some phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling. Students may not receive credit for both ENGD 302 and EGMT 540.

ENGD 303 Systems Architecture Practicum 4R-0L-4C See department

Prerequisites: Student must obtain professional employment such as an internship or co-op.
Corequisites: There are no corequisites for this course.
This class will introduce students to the art and science of systems architecting, where systems architecting refers to uncovering the fundamental structure of a system (functional, physical, logical, operational) defined in terms of system's elements, interfaces, processes, constraints, and behaviors that must operate under specific requirements and constraints. Focus will be placed on investigating the broader meaning of architectures, as they relate to organizations and businesses, in addition to engineered systems and products. Students will apply course concepts to their work environment. The work environment must contain some phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling. Students may not receive credit for ENGD 303 and either of EMGT 464 or EMGT 564.

ENGD 304 Material Properties Practicum 2R-0L-2C See department
Prerequisites: Student must obtain professional employment such as an internship or co-op.
Corequisites: There are no corequisites for this course.
Introduces properties of metals, ceramics, polymers, and composites. Describes the similarities and differences in the mechanical properties, structure, and processing. Relates material processing to properties through underlying material structure. Students will apply course concepts to their work environment. The work environment must contain some phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 305 Material Selection Practicum 2R-0L-2C See department
Prerequisites: ENGD 304See department or ME 328W or CHE 315F,S or BE 233W or CE 320S and student must obtain professional employment such as an internship or co-op.
Corequisites: There are no corequisites for this course.
Explains the definition of common mechanical properties and identifies when a property is important for a given component or application. Carries out design translation to define the function, constraints, objectives, and free variables of an engineering component. Selects the best material for a given application considering all classes of materials including metals, ceramics, polymers, and composites. Students will apply course concepts to their work environment. The work environment must contain some phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 306 Parametric & Equation Based Modeling Practicum 2R-0L-2C See department
Prerequisites: EM 104F or ENGD 100 F and student must obtain professional employment such as an internship or co-op.
Corequisites: There are no corequisites for this course.
Students will supplement their prior SolidWorks CAD tool knowledge by 1) using advanced modeling techniques like parametric modeling and equation-based design, 2) designing, modeling, and analyzing complex mechanical parts and assemblies using techniques like top-down design, and 3) modeling common, but complex geometries like thread. Students will apply course concepts to their work environment. The work environment must contain some phases of the design process such as stakeholder

analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 307 Curves and Surfaces Practicum 2R-0L-2C See department

Prerequisites: EM 104F or ENGD 100 F or BE 118F or ENGD 101Not offered ; and student must obtain professional employment such as an internship or co-op.
Corequisites: There are no corequisites for this course.
Students will supplement their prior SolidWorks CAD tool knowledge by practicing the fundamentals of curve and surface design and designing parts with surfaces. Students will apply course concepts to their work environment. The work environment must contain some phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 308 Lean Manufacturing Process Fundamental Practicum 2R-0L-2C See department

Prerequisites: Student must obtain professional employment such as an internship or co-op.
Corequisites: There are no corequisites for this course.
An overview of fundamental lean concepts and application of concepts across value streams. Students will apply course concepts to their work environment. The work environment must contain some phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 309 Lean Manufacturing Kaizen Fundamentals Practicum 2R-0L-2C

Prerequisites: ENGD 308See department student must obtain professional employment such as an internship or co-op.
Corequisites: There are no corequisites for this course.
Application of lean concepts at a workstation. Requires Lean Manufacturing Process Fundamentals. Students will apply course concepts to their work environment. The work environment must contain some phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 310 Design for Assembly Practicum 2R-0L-2C See department

Prerequisites: EM 204F, S or BE 222W or EM 203W ; and student must obtain professional employment such as an internship or co-op.
Corequisites: There are no corequisites for this course.
Application of the Boothroyd and Dewhurst methods for estimating assembly costs and designing products for improved assembly and maintenance. Students will apply course concepts to their work environment. The work environment must contain some phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 311 Tolerance Analysis and Application Practicum 2R-0L-2C See department

Prerequisites: EM 104F or BE 118F or ENGD 101Not offered or ENGD 100 F ; and student must obtain professional employment such as an internship or co-op.
Corequisites: There are no corequisites for this course.
This is an introductory course in tolerance analysis. Students will perform tolerance calculations by hand and using CAD tools. Students will also use worst-case and statistically based techniques to analyze tolerance problems, assembly shift, and make design decisions. The work environment must contain some phases of the design

process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 312 Design for Sheet Metal Fabrication Practicum 2R-0L-2C See department

Prerequisites: EM 104F or BE 118F or ENGD 101Not offered or ENGD 100 F ; and student must obtain professional employment such as an internship or co-op.
Corequisites: There are no corequisites for this course.
Introduction to methods and guidelines for designing sheet metal parts. Students will use CAD tools to design and analyze manufacturable parts. Students will apply course concepts to their work environment. The work environment must contain some phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 313 Design for Metal Forming Practicum 2R-0L-2C See department

Prerequisites: EM 104F or BE 118F or ENGD 100 F or ENGD 101Not offered ; and student must obtain professional employment such as an internship or co-op.
Corequisites: There are no corequisites for this course.
Introduction to methods and guidelines for designing extruded and forged parts. Students will use CAD tools to design and analyze manufacturable parts. Students will apply course concepts to their work environment. The work environment must contain some phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling. Introduction to methods and guidelines for designing extruded and forged parts. Students will use CAD tools to design and analyze manufacturable parts. Students will apply course concepts to their work environment. The work environment must contain some phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 390 Selected Topics in Engineering Design 1-4C Arranged F,W,S

Prerequisites: ENGD majors only, approval of director, advisor, and course instructor
Corequisites: There are no corequisites for this course.
Selected design projects. Projects may emphasize certain phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

ENGD 490 Selected Topics in Engineering Design 1-4C Arranged F,W,S

Prerequisites: ENGD majors only, approval of director, advisor, and course instructor
Corequisites: There are no corequisites for this course.
Selected design projects. Projects may emphasize certain phases of the design process such as stakeholder analysis, conceptual design, risk analysis, detail design, manufacturing, testing, validation, or recycling.

NanoEngineering

The Department of Physics and Optical Engineering has provided both science and engineering foundation at Rose-Hulman Institute of Technology through its physics and optics engineering programs. Physics is the foundation subject to all engineering and through the study in nanoengineering we aim at blending a strong physics component with relevant engineering backgrounds that are usually necessary to work in areas such as semiconductor, optical technologies, biomedical applications, mechanical, electrical, and civil engineering, and polymer and biochemistry. The students will get their traditional undergraduate engineering education that has a broad foundation in mathematics, engineering sciences and technology. This program emphasizes problem solving skills and an understanding of engineering design to address the needs and challenges of the technology age and allow students to take a broad range of engineering careers.

NanoEngineering emphasizes micro-nanoscale engineering courses necessary to work in areas such as semiconductor manufacturing, molecular electronics, integrated silicon photonics, nanomedicine, micro- and nano-electromechanical systems, thin film technologies, and other applications of nanotechnology. The engineering coursework is grounded in a strong foundation of mathematics and physics. This program uses multidisciplinary approaches in solving problems with a global understanding of engineering design, systems optimization, and fabrication techniques. Graduates will address the comNanoEngineeringplex needs and challenges of cutting-edge nanotechnology using manufacturing, characterization, and analysis tools including those in a cleanroom environment. Rose-Hulman's NanoEngineering graduates are trained to take up any demanding jobs for the development of new technologies or to pursue graduate school for further studies in engineering or physics.

Mission: To provide a coherent foundation of physics and cutting-edge engineering that leads to a large variety of possibilities for its graduates. NanoEngineering graduates are trained in design, optimization, fabrication, and testing of semiconductor and nanoscale systems. Graduates are enabled to practice their dynamic and progressive engineering profession in emerging fields as responsible citizens of the global society.

Vision: To cultivate in students the responsibility, independence, and knowledge that allows them to be fully engaged engineers in all disciplines, to continuously improve their knowledge and skills, and to be engaged in the development process of emerging nanotechnologies and semiconductor manufacturing.

NE Program Educational Objectives

Based on our mission and the needs of our constituents, our graduates will:

- solve complex problems, create new knowledge, and incorporate innovative solutions.
- be a good citizen of the world, participate in solving major world problems such as climate change and poverty, and develop products and policies that are ethically, socially, and economically responsible.
- adopt and learn new skills, engage in lifelong learning, continue developing their knowledge, and teach others the benefits and limitations of their field.
- explain complex problems to a wide audience of different backgrounds and bridge the gap between different fields of study.
- collaborate, work well in a diverse and interdisciplinary team, and build relationships.

NE Student Learning Outcomes

Outcome 1:	an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

Outcome 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
Outcome 3:	an ability to communicate effectively with a range of audiences
Outcome 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
Outcome 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
Outcome 6:	an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
Outcome 7:	an ability to acquire and apply new knowledge as needed, using appropriate learning strategies

The nanoengineering program is accredited by the Engineering Accreditation Commission of ABET, https://www.abet.org, under the commission's General Criteria with no applicable program criteria.

Courses taken in the respective departments:

Subjects	#Classes	Hours
Physics (PH)	11	44
Math (MA)	6	27
Chemistry (CHEM)	2	8
CSSE/ME	1	4
EM	2	4
RHIT100	1	1
ES	1	4
HSSA	9	36
Engineering Physics (EP)	7	26
Engineering Physics Design (EP)	3	12

Electives (SEM, Eng. and Free)	6	24
Total	**50**	**194**

SUMMARY OF GRADUATION REQUIREMENTS FOR NANOENGINEERING

1. All the courses listed above by the number.
2. The program must be approved by the EP advisor.
3. A list of the engineering electives is provided.
4. SEM (Science, Engineering, Math) electives are courses that need to be taken at the 200 level (CHEM115 is allowed) or above in biology, biomathematics, chemistry, computer science, engineering, mathematics or physics.
5. A free electives is any course in engineering, science, humanities, military science, or air science.

Classes by Subjects	Hours
Physics Coursework*	44
Chemistry and Mathematics Coursework**	35
Humanities, Social Science, and the Arts (Standard requirement)	36
EM, ES, ME, RHIT100 Courses	13
Electrical Engineering Courses	8
Optical Engineering Courses	4
EP Courses	30
EP Capstone Design	12
Engineering Electives	16
SEM and Free Electives	8
Total	**194**

Foundation Physics Classes

Course	Description	Hours
PH 235	Many Particle Physics	4
PH 255	Modern Physics	4
PH 316	Electric & Magnetic Fields	4
PH 317	Electromagnetism	4
PH 328	Advanced Physics Lab I	4
PH 327	Thermodynamics and Statistical Mechanics	4
PH 401	Introduction to Quantum Mechanics	4
PH 405	Semiconductor Materials and Applications	4
Total		**32**

General Foundation Classes

Course	Description	Hours
PH 111	Physics I	4
PH 112	Physics II	4
PH 113	Physics III	4
MA 111	Calculus I	5
MA 112	Calculus II	5
MA 113	Calculus III	5
MA 221	Matrix Algebra & Differential Equations I	4
MA 222	Matrix Algebra & Differential Equations II	4
MA 223 or MA 381	Engineering Statistics I or Intro to Probability w/ Apps to Stats	4
CHEM 111	General Chemistry I	4
CHEM 113	General Chemistry II	4
Total		**47**

Engineering Foundation

Course	Description	Hours
EM 104	Graphical Communications	2
EP 180	Engineering at Nanoscale	2
EP 280	Introduction to Nano-engineering	4
EP 320	Fundamentals of Thin Films: Fabrication and Applications	4
EP 380	Nanotechnology, Entrepreneurship and Ethics	4
EP 395	Nanoscale Fabrication & Characterization Techniques	4
EP 406	Semiconductor Devices and Fabrication	4
EP 407	Nanoscale and Semiconductor Devices	4
EP 410	Introduction to MEMS; Fabrication and Applications	4
ES 213	Electrical Systems	3

ES 213L	Electical Systems Lab	1
ME123	Computer Programming	4
	Engineering Elective	16
Total		**56**

Design Sequence

Course	Description	Hours
EM 103	Introduction to Design	2
EP 415	Engineering Physics Design I	4
EP 416	Engineering Physics Design II	4
EP 417	Engineering Physics Design III	4
Total		**14**

Approved Engineering 200-Level Electives (4 credit hours required)

- ECE 205 Circuits and Systems
- ES 201 Conservation and Accounting Principles
- ES 202 Fluid and Thermal Systems
- EM 204 Statics II
- OE 280 Geometric Optics
- EP 290 Directed Study
- EP 490 Directed Study

Approved Engineering Electives

- OE 360 Optical Materials
- OE 393 Fiber Optics
- OE 437 Introduction to Image Processing
- OE 450 Laser Systems and Applications
- OE 495 Optical Metrology
- EP 330 Materials Failure
- EP 411 Advanced Topics in MEMS
- EP 450 Nanomedicine
- EP 470 Special Topics in Engineering Physics
- EP 490 Directed Study
- CHE 315 Materials Science and Engineering
- ME 328 Materials Engineering
- ME 417 Advanced materials Engineering
- ME 422 Finite Elements for Engineering Applications
- EM 403 Advanced Mechanics of Materials
- ECE 351 Analog Electronics
- ECE 250 Electronic Device Modeling

Plan of Study

Freshman

Fall

Course	Credit
PH 111 Physics I	4
MA 111 Calculus I	5
RHIT 100 Foundations for Rose-Hulman Success	1
CHEM 111 General Chemistry I	4
EM 104 Graphical Communications	2
	Total Credits: 16

Winter

Course	Credit
PH 112 Physics II	4
MA 112 Calculus II	5
CHEM 113 General Chemistry II	4
HUM H190 First-Year Writing Seminar	4
	Total Credits: 17

Spring

Course	Credit
PH 113 Physics III	4
MA 113 Calculus III	5
ME 123 Computer Applications I or CSSE 120 Intro to Sftwr. Dev	4
EP 180 Engineering at Nanoscale*	2
EM 103 Introduction to Design	2
	Total Credits: 17

Sophomore

Fall

Course	Credit
ES 213 Electrical Systems	3
ES 213L	1
PH 235 Many Particle Physics	4
Science, Engineering or Math Elective	4
200-Level Engineering Elective	4

	Total Credits: 16

Winter

Course	Credit
EP 280 Intro to Nano Engineering	4
PH 255 Foundations of Modern Physics	4
MA 221 Matrix Algebra & Differential Equations I	4
ECON S151 Intro to Micoeconomics or ECON S152 Intro to Macroeconomics	4
	Total Credits: 16

Spring

Course	Credit
EP 380 Nano Technology Entrepreneurship & Ethics	4
PH 325 Advanced Physics Lab I	4
MA 222 Matrix Algebra and Differential Equations II	4
Engineering Elective	4
	Total Credits: 16

Junior

Fall

Course	Credit
PH 316 Electric & Magnetic Fields	4
EP 320 Fundamentals of Thin Fils: Fab & Applications or EP 395 Nanoscale Fabrication & Characterization Techniques	4
PH 405 Semiconductor Materials & Applications	4
HSSA Elective	4
	Total Credits: 16

Winter

Course	Credit
MA 381 Intro to Probability or MA 223 Eng Statistics I	4
PH 317 Electromagnetism	4
ENGL H290 Technical & Professional Communication.	4

EP 406 Semiconductor Devices & Fabrication	4	
		Total Credits: 16

Spring

Course	Credit	
PH 327 Thermodynamics & Stat Mech	4	
EP 410 Intro to MEMS	4	
EP 415 Engineering Physics Project I	4	
HSSA Elective	4	
		Total Credits: 16

Senior

Fall

Course	Credit	
EP 416 Engineering Physics Project II	4	
EP 407 Semiconductor Fabrication & Characterization	4	
EP 320 Fundamentals of Thin Films: Fab and Applications or EP 395 Nanoscale Fabrication & Characterization Techniques	4	
HSSA Elective	4	
		Total Credits: 16

Winter

Course	Credit	
EP 417 Engineering Physics Project III	4	
300/400-Level Engineering Elective	4	
HSSA Elective	4	
PH 401 Intro Quantum Mechanics	4	
		Total Credits: 16

Spring

Course	Credit	
HSSA Elective	4	
HSSA Elective	4	
Engineering Elective	4	
Free Elective	4	
		Total Credits: 16

NOTES

*If students miss EP 180 in the freshmen or sophomore year, this requirement must be replaced with a 300 or 400-level EP course of at least 2 credits.
EP course descriptions are listed under the Physics and Optical Engineering Department.

NanoEngineering - Course Descriptions

EP 180 Engineering at the Nanoscale 2R-0L-2C S

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Introduction to nanoscience and engineering: properties and behavior of materials, devices, and systems (natural and artificial) at nanoscale, applications of nanoscience. Characterization techniques: Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), and thin film measurements. Basic cleanroom safety and experience, microfabrication processing techniques: photolithography, thin film deposition. Intro to design and data analysis software.

EP 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

EP 280 Introduction to Nanoengineering 3.5R-1.5L-4C W

Prerequisites: There are no prerequisites for this course.
Corequisites: PH 113 3.5R-1.5L-4C S,F,W
Scaling laws in small systems; electronics and photonics devices and systems, basics of quantum and statistical mechanics, nanomaterials and fabrication: examples of zero, one, two, and three dimensional nanostructures, carbon nanotubes, Nanoelectronics: basics of solid state physics; electron energy band, semiconductors, tunneling and quantum structures, molecular electronics, Nanophotonics in metals and semiconductors, surface plasmon resonance and applications, photonic bandgap crystals.

EP 290 Directed Study 1-4C

Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
Research for freshmen and sophomore students under the direction of a physics or optical engineering faculty member. May earn up to a maximum of 2 credits for meeting the graduation requirements. The student must make arrangements with a faculty member for the research project prior to registering for this course.

EP 320 FUNDAMENTALS OF THIN FILMS: FABRICATION AND APPLICATIONS 3R-3L-4C F (every other year)

Prerequisites: EP 280W
Corequisites: There are no corequisites for this course.
Two- and three-dimensional nanostructures, including thin film materials, single and multi-layer nano-films, electronic energy band structures, thin-film and high-k electronics, multiple quantum well devices, and optical bandgap engineering. Thin

film characterization, thermal properties of thin films, growth kinetics, coating and thin film fabrication techniques: sputtering, thermal evaporation, PECVD, and atomic layer deposition.

EP 330 Material Failure 3R-3L-4C W

Prerequisites: PH 112W,S,F

Corequisites: There are no corequisites for this course.

Principles of material failure; appearance, physical cause and mathematical description with emphasis on the materials used for micro-scale devices and assemblies. Failure types considered include Rupture, Fatigue, Creep, Corrosion, Electromigration, Electrical Overstress, Electrical Discharge and Thermal. Experiments illustrate the failure type and the machines used to study them. These include Electron, Optical and X-ray microscopes, Spectroscopy and Tension machines. A brief description of the working of each machine will be given.

EP 380 Nanotechnology, Entrepreneurship & Ethics 3.5R-1.5L-4C S

Prerequisites: EP 280W

Corequisites: There are no corequisites for this course.

Scaling laws in small systems; mechanical, biological, fluidics, and thermal systems. Nanomaterials and nanofabrication. Nanomechanics: cantilever oscillation, atomic-force microscopy (AFM) and its applications, nano-biotechnology, machinery of cell, and molecular motors. Nanoscale optics, Nanoscale heat: conduction, convection, and blackbody radiation. Basics of fluidics, nanoscale fluidics and applications, entrepreneurship and ethics, concepts and tools in innovation and social impacts of nanotechnology.

EP 395 NANOSCALE FABRICATION & CHARACTERIZATION TECHNIQUES 3R-3L-4C F (every other year)

Prerequisites: EP 280W

Corequisites: There are no corequisites for this course.

Fabrication and characterization techniques for zero- and one-dimensional nanoscale materials and devices. Process design and development. Bottom-up and top-down synthesis techniques. Assembly and self-assembly of nanomaterials into macro-articles. Synthesis techniques including liquid phase growth, chemical vapor deposition, and plasma synthesis. Characterization techniques such as microscopies, various spectroscopies, thermogravimetric analysis, and differential scanning calorimetry. Laboratory is a team project in which students will design, fabricate, and characterize nanomaterials.

EP 406 Semiconductor Devices & Fabrication 3R-3L-4C W

Prerequisites: PH 405F or PH 505F

Corequisites: There are no corequisites for this course.

Physical properties and applications of semiconductor devices including bipolar junction transistors (BJT), metal-semiconductor contacts (Schottky and ohmic), junction field effect transistors (JFET and MESFET), metal-oxide semiconductor (MOS) interfaces and field effect transistors (MOSFET and CMOS), photoconductors, photodetectors (PIN and APD), solar cells, light emitting diodes (LED), and laser diodes. Laboratory experiments will cover the following topics: characterization of semiconductor devices, op-amps, CMOS, NAND and other logic and analog components. Cross-listed with EP 506.

EP 407 NANOELECTRONIC AND SEMICONDUCTOR DEVICES 2R-6L-4C F

Prerequisites: EP 406W or EP 506W

Corequisites: There are no corequisites for this course.
Fabrication and characterization of micro/nanoelectronic devices; Process integration of various technologies, including CMOS, 2D materials, and nanowires; Surface processing for improved performance, including passivation, anti-reflection structures, and protective coatings. Process and device simulators illustrate concepts introduced in class. Laboratory is an integral component of this class in which students will fabricate a multi-junction semiconductor device. In-process measurement results are compared with final electrical test results and simulated designs.

EP 408 Microsensors and Actuators 3R-3L-4C S

Prerequisites: EP 410S Junior or Senior standing, and consent of instructor
Corequisites: There are no corequisites for this course.
Microelectromechanical (MEMS) systems composed of microsensors, microactuators, and electronics integrated onto a common substrate. Design, fabrication, and operation principles. Examples of microsensors covered in the course include: thermal, radiation, mechanical, chemical, and biological. Laboratory is a team design project in which the students fabricate sensing devices such as pressure or thermal sensors and then characterize their behavior. Cross-listed with EP 508.

EP 410 Introduction to MEMS: Fabrication & Applications 3R-3L-4C S

Prerequisites: Junior or Senior class standing
Corequisites: There are no corequisites for this course.
Properties of silicon wafers, wafer-level processes, vacuum systems, thin-film deposition via PVD, dry and wet etching, photolithography, surface and bulk micromachining, process integration, MEMS applications: heat actuators, capacitive accelerometer, DLP, bio-sensor, and pressure sensor. Cross-listed with ME 416, ECE 416, and CHE405.

EP 411 Advanced topics in MEMS 3R-3L-4C F

Prerequisites: EP 410S or equivalent course
Corequisites: There are no corequisites for this course.
Topics such as: Microlithography, design process, modeling; analytical and numerical. Use of software for layout design and device simulation. Characterization and reliability of MEMS devices. MEMS and microelectronic packaging. Introduction to microfluidic systems. Applications in engineering, biomedicine, and chemistry. Cross-listed with ECE 419, and CHE 419.

EP 415 Engineering Physics Design I 2R-6L-4C S

Prerequisites: EP 380S and Junior or Senior standing
Corequisites: ENGL H290 4R-OL-4C F, W, S
Principles of design. Codes of ethics appropriate to engineers. Case studies related to optical engineering and nanoengineering professional practice, teamwork, contemporary issues, patents and intellectual property. Team-oriented design project work on selected topics in optical engineering and nanoengineering. Introduction to product development practices, product research, planning and project management. Preliminary design of a product and product specifications. Deliver a design document specific to customer needs and constraints. Cross-listed with OE 415.

EP 416 Engineering Physics Design II 2R-6L-4C F

Prerequisites: EP 415S
Corequisites: There are no corequisites for this course.
Team-based capstone design project following structured design processes and utilizing knowledge gained from prior coursework. Project planning and budgeting,

development of product/process specifications, application of engineering standards, system design and prototyping subject to multiple realistic constraints (cost, schedule, and performance). Formal midterm design review. Deliver initial statement of work and interim technical report. Laboratory activities supporting the formal design process. Cross-listed with OE 416.

EP 417 Engineering Physics Design III 2R-6L-4C W

Prerequisites: EP 416F

Corequisites: There are no corequisites for this course.

Continuation of EP 416. System design and prototyping, performance testing, and data analysis. Formal midterm design review. Demonstration of a functional prototype. Deliver oral presentation and final technical report. Cross-listed with OE 417.

EP 450 Nanomedicine 4R-0L-4C

Prerequisites: PH 113S,F,W or Junior or Senior standing and consent of instructor

Corequisites: There are no corequisites for this course.

Material presented includes the functions and properties of medical nanodevices, the design and fabrication of nanorobots and nanoparticles, the current and potential applications of nanomedicine. Introduction to cancer cell biology and techniques for selective targeting of cancer cells, simulations of the optical and thermal properties of normal and cancerous cell organelles. Nanoplasmonics: Lorentz-Mie simulations of optical properties of nanoparticles, the use of plasmonic nanoparticles in diagnosis and therapy. Introduction to the nanophotodynamic therapies and the new dynamic modes in selective nanophotothermolysis of cancer, the design and methods of activation of nanodrugs. Time and space evolutions of thermal fields in and around the nano- bio-particles and nanoclusters. Ablation of the soft and hard biological tissues by activated nanoparticles.

EP 470 Special Topics in Engineering Physics 2-4C

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

Lectures on special topics in engineering physics.

EP 490 Directed Study 1-4C

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

Research for junior and senior students under the direction of a physics and optical engineering faculty member. May earn up to a maximum of 2 credits for meeting the graduation requirements. The student must make arrangements with a faculty member for the research project prior to registering for this course.

EP 506 Semiconductor Devices & Fabrication 3R-3L-4C W

Prerequisites: PH 405F or PH 505F

Corequisites: There are no corequisites for this course.

Physical properties and applications of semiconductor devices including bipolar junction transistors (BJT), metal-semiconductor contacts (Schottky and ohmic), junction field effect transistors (JFET and MESFET), metal-oxide semiconductor (MOS) interfaces and field effect transistors (MOSFET and CMOS), photoconductors, photodetectors (PIN and APD), solar cells, light emitting diodes (LED), and laser diodes. Laboratory experiments will cover the following topics: characterization of semiconductor devices, op-amps, CMOS, NAND and other logic and analog components. Graduate credit requires a more advanced project. Cross-listed with EP 406.

EP 507 NANOELECTRONIC AND SEMICONDUCTOR DEVICES 2R-6L-4C F

Prerequisites: EP 406W or EP 506W or consent of instructor
Corequisites: There are no corequisites for this course.
Fabrication and characterization of micro/nanoelectronic devices; Process integration of various technologies, including CMOS, 2D materials, and nanowires; Surface processing for improved performance, including passivation, anti-reflection structures, and protective coatings. Process and device simulators illustrate concepts introduced in class. Laboratory is an integral component of this class in which students will fabricate a multi-junction semiconductor device. In-process measurement results are compared with final electrical test results and simulated designs. Students must do additional project work on a topic selected by the instructor. Students may not receive credit for both EP 407 and EP 507.

EP 508 Microsensors and Actuators 3R-3L-4C S
Prerequisites: EP 410S Junior or Senior standing and consent of instructor
Corequisites: There are no corequisites for this course.
Microelectromechanical (MEMS) systems composed of microsensors, microactuators, and electronics integrated onto a common substrate. Design, fabrication, and operation principles. Examples of microsensors covered in the course include: thermal, radiation, mechanical, chemical, and biological. Laboratory is a team design project in which the students fabricate sensing devices such as pressure or thermal sensors and then characterize their behavior. Cross-listed with EP 408.

EP 510 Introduction to MEMS: Fabrication & Applications 3R-3L-4C S
Prerequisites: Junior or Senior standing
Corequisites: There are no corequisites for this course.
Properties of silicon wafers, wafer-level processes, vacuum systems, thin-film deposition via PVD, dry and wet etching, photolithography, surface and bulk micromachining, process integration, MEMS applications: heat actuators, capacitive accelerometer, DLP, bio-sensor, and pressure sensor. Students must do additional project work on a topic selected by the instructor. Cross-listed with BE 516, CHE 505, ECE 516, and ME 516.

EP 511 Advanced topics in MEMS 3R-3L-4C F
Prerequisites: EP 410S or EP 510S or consent of instructor
Corequisites: There are no corequisites for this course.
Topics such as: Microlithography. Design process, modeling; analytical and numerical. Use of software for layout design and device simulation. Characterization and reliability of MEMS devices. MEMS and microelectronic packaging. Introduction to microfluidic systems. Applications in engineering, biomedicine, and chemistry. Students must do additional project work on a topic selected by the instructor. Cross-listed with ME 519, ECE 519, and CHE 519.

International Computer Science

The International Computer Science curriculum prepares students for careers in all areas of the computer industry as well as for graduate studies in computer science and computer related fields. Students have also found a computer science major to be excellent preparation for careers in law, medicine, business administration, industrial engineering, biomedical engineering, and other technical and non-technical fields.

Computer science is a rapidly changing discipline. The lifetime of a particular computer system or software package can be very short. The international computer science curriculum is designed to prepare students for multiple careers in a rapidly changing, global environment. The program's courses emphasize fundamental concepts and techniques that will last longer than present technology.

International computer science majors complete a core of basic computer science courses that includes the study of algorithms, data structures, database concepts, computer systems, computer architecture, programming languages, operating systems, and software engineering. Advanced courses in theory of computation, computer networks, distributed systems, security, and real time systems add depth to the degree program. A three-term senior thesis provides students the opportunity to research in depth an area of computer science that is of interest to them under the mentorship of a faculty member. Majors also complete important courses in closely related fields, e.g., discrete mathematics and probability and statistics, as well as study a foreign language. The major requires students to study all aspects of the science of computing, including hardware, software, and theory.

Five free electives allow students to tailor their undergraduate education to their specific goals and pursue topics of interest to them. Students may choose to do advanced elective work in computer science and software engineering and/or in the humanities and social sciences, and/or pursue a minor or double major in another discipline.

Programming assignments and large projects are part of most computer science courses. These assignments familiarize students with the wide variety of tasks performed by software professionals. Programming assignments include system specification, system feasibility studies, system design, system maintenance studies, and user interface design in addition to system implementation (i.e., coding), testing (verification and validation), and documentation. Projects include both individual and team activities and require appropriate written and oral presentations.

The department has its own local area network. This network is connected to the campus-wide network and the Internet. Department laboratories provide docking stations and large screen monitors for students to attach their laptops to. International computer science majors have unlimited access to the department's laboratories.

The department has active programming teams that compete in the ACM Programming Contest and the Collegiate Cyber Defense Competition. The national computer science honor society, Upsilon Pi Epsilon, has chartered its Indiana Alpha Chapter at Rose-Hulman; it sponsors several seminars throughout the year.

International Computer Science Program Educational Objectives

Graduates from the international computer science program will be prepared for many types of careers in the field of computing and prepared for graduate study in computer science and in closely related disciplines. In the early phases of their careers, we expect Rose-Hulman international computer science graduates to be:

1. Computing professionals in a variety of organizations, including ones doing traditional software development, technological innovation, and cross-disciplinary work
2. Business and technological leaders within existing organizations
3. Entrepreneurial leaders
4. Recognized by their peers and superiors for their communication, teamwork, and leadership skills
5. Actively involved in social and professional service locally, nationally, and globally

6. Graduate students and researchers
7. Leaders in government and law as government employees, policy makers, governmental advisors, and legal professionals

International Computer Science Student Outcomes

By the time students graduate with an international computer science degree from Rose-Hulman, they will be able to:

1. Effectively apply a variety of computing resources, programming languages, programming paradigms, operating systems, networks, and software development tools
2. Anticipate complexities and problems involved in the development of large computing systems
3. Analyze requirements, design computing systems that satisfy those requirements, and implement that system
4. Analyze problems and design solutions using ideas of problem complexity, models of computation, decidability, and scalability
5. Analyze algorithms in terms of correctness, as well as time and space efficiency
6. Evaluate and discuss the legal, social, and ethical aspects of significant events that arise in the field of computing both domestically and internationally
7. Interact effectively with colleagues and clients located abroad and overcome challenges that arise from geographic distance, cultural differences, and multiple languages
8. Communicate effectively, both orally and in writing
9. Collaborate effectively in teams
10. Recognize the need for, and engage in, lifelong learning
11. Understand the structure and functionality of modern computer systems
12. Live and work in the computing field in a country other than their native country
13. Demonstrate proficiency in a second language that allows them to interact effectively with colleagues and clients in their field

The faculty strives to maintain an open atmosphere that encourages mutual respect and support as well as learning and sharing of knowledge.

Summary of graduation requirements for the international computer science major

HSS electives must be distributed as required by HSS. Science elective is any CHEM, PH, GEOL, or BIO course(s) totaling at least 4 credits.

To complete the major in international computer science a student must complete the following:

1. All required courses listed by number, symbol, or name in the schedule of courses above: CSSE 120, CSSE 132, CSSE 212, CSSE 220, CSSE 230, CSSE 232, CSSE 304, CSSE333, CSSE or MA 473, CSSE or MA 474, and CSSE 494-6; MA 111, MA 112, MA 113, MA 221, MA 276, MA 371 or MA 373, MA 374, MA 381; PH 111, PH 112; CHEM 111; HUM H190, ENGL H290; GER L111, GER L112, GER L113; RHIT 100; Software Project (CSSE 371), Seminar (CSSE 400), Programming 3 (CSSE 225), Digital Systems(ECE 233), Software Engineering

(CSSE 374), Operating Systems (CSSE 332), Computer Networks (CSSE-432), Technical German.
2. Eight credits of additional computer science courses (Special Subject A (Module I) and Special Subject A (Module II)) numbered between 200 and 492. No more than four credits may be at the 200 level, and none of the credits may be from CSSE 372, 373, 375, 376, and 477. The students academic advisor must approve the courses to satisfy this requirement. (Use of computer science courses numbered 490 through 492 to fulfill this requirement must be approved by the department head).
3. Four credits of science electives, which can be any CHEM, PH, BIO, or GEOL courses not already required for the international computer science major.
4. Twelve credits of additional courses offered by the Department of Humanities and Social Sciences and/or appropriate humanities or social science courses offered at Hochschule Ulm. The distribution of these courses must meet the requirements of the Department of Humanities and Social Sciences at Rose-Hulman.
5. Sixteen credits of free elective courses. These courses must have the approval of the student's academic adviser. Free electives may be selected from any Rose-Hulman course.
6. A total of 192 credits.

See Computer Science for course descriptions.

Plan of Study

Freshman

Fall

Course	Credit
CSSE 120 Introduction to Software Development	4
MA 111 Calculus I	5
PH 111 Physics I	4
HUM H190 First-Year Writing Seminar	4
RHIT 100 Foundations for Rose-Hulman Success	1
	Total Credits: 18

Winter

Course	Credit
CSSE 220 Object-Oriented Software Development	4
MA 112 Calculus II	5
PH 112 Physics II	4
HSS Elective	4
	Total Credits: 17

Spring

Course	Credit
CSSE 132 Inroduction to Computer Systems	4
MA 113 Calculus III	5
CHEM 111 General Chemistry I	4
HSSA Elective	4
	Total Credits: 17

Sophomore

Fall

Course	Credit
CSSE 280 Intro to Web Programming	4
GE 111 German Language and Culture I	4
MA 221 Matrix Algebra & Differential Equations I	4
CSSE 230 Data Structures & Algorithm Analysis	4
	Total Credits: 16

Winter

Course	Credit
CSSE 304 Programming Language Concepts	4
ENGL H290 Technical & Professional Communication	4
GE 112 German Language & Culture II	4
MA 276 Introduction to Proofs	4
	Total Credits: 16

Spring

Course	Credit
MA 374 Combinatorics	4
GE 113 German Language and Culture III	4
MA 381 Introduction to Probability with Statistical Applications	4
CSSE 333 Database Systems	4
	Total Credits: 16

Junior

Fall

Course	Credit
(CSSE225) Programming 3	4
(CSSE371) Software Project	4
(CSSE400) Seminar	4
(CSSE Elective) Special Subject A (Module 1)	4
(HSS Elective) Technical German	4
(ECE233) Digital Systems	4
	Total Credits: 24

Winter

Course	Credit
(CSSE212) Hardware-oriented Programming	4
(CSSE332) Operating Systems	4
(CSSE374) Software Engineering	4
(CSSE432) Computer Networks	4
(CSSE Elective) Special Subject A (Module 2)	4
Free Elective	4
	Total Credits: 24

Senior

Fall

Course	Credit
CSSE 494 Senior Thesis I	4
MA371 Linear Algebra I or MA373 Applied Linear Algebra for Engrs	4
Science Elective	4
CSSE 232 Computer Architecture I	4
	Total Credits: 16

Winter

Course	Credit
CSSE 495 Senior Thesis II	4
CSSE/MA 473 Design and Analysis of Algorithms	4
HSS Elective	4

Course	Credit
Free Elective	4
	Total Credits: 16

Spring

Course	Credit
CSSE 496 Senior Thesis III	4
CSSE/MA 474 Theory of Computation	4
Free Elective	4
	Total Credits: 12

NOTES:

*Junior Year is at Hochschule Ulm, Germany and is two semesters.

Mathematics

Why study mathematics? Many of the new wonders that we take for granted in our modern technological society have mathematical ideas and applications as their basis, though this role is often hidden from view. Complex economic and planning decisions, scientific discoveries that improve our lives, and new technologies and products are often possible only after mathematical or statistical analysis, or a computer visualization, simulation, design and implementation based on mathematics. Therefore, mathematicians, as well as mathematically educated scientists, engineers and economists, make important daily contributions in the understanding and advancement of science, the improvement and discovery of new technology, and decision-making and planning in business, industry and government. Students interested in using their mathematical skills in solving real world problems are well prepared, by majoring or minoring in mathematics, for careers such as in the insurance industry, software design, data and systems analysis, scientific computing, combustion research, the animated movie industry, and cryptanalysis to name a few, or a graduate degree in a related technical field. Those students with a very strong interest in mathematics itself can pursue graduate study in mathematics in preparation for careers as university or college mathematics teachers and in the development of new mathematical and statistical concepts and methods as researchers in academia, government and industry.

The curriculum of the program in the Department of Mathematics is designed to provide a broad education in both theoretical and applied mathematics. It also develops the scientific knowledge and the problem solving, computing, and communications skills that are critical to a successful mathematically based career. This preparation is greatly enhanced by taking advantage of the wide variety of science and engineering courses available to students and developing good communications skills, both through technical courses and the strong humanities program. The program offers a solid grounding in the foundational areas of calculus, differential equations, linear algebra, discrete and combinatorial algebra, and probability and statistics. These basic courses are complemented by a varied selection of upper division courses for further elective study in areas such as numerical analysis, operations research, advanced statistics, mathematical modeling, optimization, and other advanced topics in mathematics. Students are encouraged to develop a strong background in an area of science or engineering through election of courses leading to a minor or double major. By appropriate course selection students may complete a double major in mathematics and another field such as computer science, physics, chemistry, applied biology, or economics.

PROGRAM GOALS AND OBJECTIVES

To provide a foundation for further learning as well as contributing to the general education of students, the programs at Rose-Hulman all have a heavy investment in mathematics and science in the first two years. The freshman and sophomore mathematics curriculum is designed to contribute to this foundation by ensuring that students are familiar with basic mathematical and statistical concepts, and mathematical and statistical reasoning and modeling. Students will also understand the use of mathematics in other disciplines as well as developing an appreciation of mathematics as a discipline in its own right. In addition, students will learn to be competent users of mathematics, especially in problem solving, and be able to effectively communicate mathematically. The curriculum makes strong use of computer methods to develop students' mathematical understanding and to enhance their ability to use the computer in modeling, computation and problem solving.

For students seeking a major in mathematics, the curriculum prepares them for a mathematically based career after graduation or further graduate study. The major builds upon the goals and objectives of the freshman and sophomore curriculum. In addition to a deeper and broader study of mathematics, majors will further develop their ability to formulate and solve problems from a mathematical perspective, become familiar with the use of mathematics in other fields, and develop competence at the application of mathematics to at least one other field. Graduates will also be able to use technology effectively in mathematics and the application of mathematics. To complement these technical skills graduates will learn the professional skills of effective communication with both technical and non-technical audiences and the ability to work cooperatively with others.

Mathematics Program Goals and Student Learning Outcomes

Mathematics majors should be able to meet the following Student Learning Outcomes

Goal 1: Students will learn the fundamental principles underlying the major areas of mathematics

- SLO 1.1. Perform calculations and prove statements about objects, morphisms, and structure theorems in vector spaces and abstract algebra.
- SLO 1.2. Write rigorous proofs and state key counterexamples in the areas of sequences, continuity, differentiability, and integrability.
- SLO 1.3. Select, and produce appropriate characterizations for, a model for a random process through functions of random variables (e.g., expectation or probability statements).

Goal 2: Students will have a well-rounded scientific and mathematical background

- SLO 2.1. Develop focused further knowledge of at least one of the fields of mathematical sciences.
- SLO 2.2. Synthesize new and previous knowledge in cooperation with a faculty member.
- SLO 2.3. Demonstrate basic literacy in a number of scientific areas

Goal 3: Students will be able to use technology in a mathematical setting.

- SLO 3.1. Describe and implement computational approaches to solving a mathematical model.
- SLO 3.2. Use mathematical technology to analyze mathematical problems in at least one area.

Goal 4: Students will develop and utilize effective written and oral communication skills in a mathematical setting

- SLO 4.1. Rigorously write and critique mathematical proofs.
- SLO 4.2. Speak about mathematics in an articulate, sound, and well-organized fashion.
  - SLO 4.3. Write a formal mathematical thesis or report.

Goal 5: Students will develop a broad appreciation for mathematics both as a discipline and as a tool for solving real world problems.

- SLO 5.1. Construct, analyze, and interpret a mathematical model to explain and predict relationships for given deterministic systems and random systems from science or industry.
- SLO 5.2. Create, manipulate, and interpret discrete models and continuous models to illustrate dynamics of a system over time.
- SLO 5.3. Generalize properties of numbers and functions to other algebraic, analytic, topological, or geometric structures.

DEGREE REQUIREMENTS

Major Concentrations: Mathematics majors choose to complete their program in one of four concentrations: Mathematics, Continuous Applied Mathematics, Discrete Applied Mathematics, or Statistics and Operations Research. The Mathematics concentration provides the foundational mathematical depth of a traditional mathematics major and is intended for students planning on graduate study in an area of mathematics. In applied mathematics there are two areas: the Continuous Applied Mathematics concentration and the Discrete Applied Mathematics concentration. Students selecting these concentrations may tailor their programs to interface with another major or to enhance industrial employment or graduate school opportunities. The Statistics and Operations Research concentration is recommended for students pursuing careers in actuarial science, graduate study in statistics, or employment in government or industry in a statistical capacity. It is strongly recommended that students considering graduate education in mathematics include MA 376 Abstract Algebra among their elective mathematics courses. Upon graduation a student may request the Head of the Mathematics Department to issue a letter attesting to the fact that the requirements in the chosen concentration have been completed.

Mathematics Coursework Requirements: All mathematics majors must complete a common core consisting of 39 credit hours of mathematics coursework, which provides breadth across the main areas of mathematics. A mathematics major must also complete an additional 12 credit hours of mathematics coursework specified for the selected major concentration plus an additional 12 credit hours earned in free elective mathematics or biomathematics courses. A mathematics major must additionally complete an 8-credit hour capstone experience. A total of 71 credit hours of mathematics courses is required for the major. None of the credits in the 71 hours above may be taken from the courses MA190, MA351-MA356, MA450 or MA223 (unless approved by the department head). These courses (except MA190) may be taken as free electives. Finally, a student taking a degree program in which mathematics is the primary major must also take MA190. A student whose second major is mathematics is not required to take MA 190, but is strongly encouraged to do so.

Common Required Core		**39 hrs.**
MA 111, 112, 113 Calculus I, II, III	15 hrs.	
MA 221 Matrix Algebra and Differential Equations I	4 hrs.	
MA 222 Matrix Algebra and Differential Equations II	4 hrs.	
MA 276 Introduction to Proofs	4 hrs.	
MA 366 Introduction to Real Analysis	4 hrs.	
MA 371 Linear Algebra I	4 hrs.	
MA 381 Introduction to Probability with Applications to Statistics	4 hrs.	

Mathematics Concentration Core			**12 hrs.**
Three courses selected as follows:			
MA 367	Functions of a Complex Variable	4 hrs.	
MA 376	Abstract Algebra	4 hrs.	
One of the following		4 hrs.	
MA 433	Numerical Analysis		
MA 436	Introduction to Partial Differential Equations		
MA 446	Combinatorial Optimization		
MA 481	Introduction to Mathematical Statistics		

Continuous Applied Mathematics Concentration Core			**12 hrs.**
Three courses selected per the list below. Students completing the Continuous Applied Mathematics Concentration are strongly urged to complete mathematics coursework in statistics as elective coursework.			
MA 330	Vector Calculus	4 hrs.	
MA 336	Boundary Value Problems	4 hrs.	
MA 433	Numerical Analysis	4 hrs.	

Discrete Applied Mathematics Concentration Core		12 hrs.
Three courses selected per the list below. Students completing the Discrete Applied Mathematics Concentration are strongly urged to complete mathematics coursework in statistics as elective coursework.		
MA 374	Combinatorics	4 hrs.
MA 444	Deterministic Models in Operations Research	4 hrs.
One of the following		4 hrs.
MA 376	Abstract Algebra	
MA 475	Topics in Discrete Mathematics	
MA 476	Algebraic Codes	
MA 477	Graph Theory	

Statistics and Operations Research Concentration Core		12 hrs.
Three courses selected per the list below. Students completing the Statistics and Operations Research Concentration are strongly urged to complete mathematics coursework in applied mathematics as elective coursework.		
MA 382	Introduction to Statistics with Probability	4 hrs.
MA 444	Deterministic Models in Operations Research	4 hrs.
One of the Following		4 hrs.
MA 445	Stochastic Models in Operations Research	
MA 446	Combinatorial Optimization	
MA 481	Introduction to Mathematical Statistics	
MA 485	Applied Regression Analysis and Introduction to Time Series	
MA 487	Design of Experiments	
It is strongly suggested that the student take as many of the above courses as possible.		

Free Mathematics Electives—12 hrs.

Additional mathematics and biomathematics coursework in courses numbered 300 or above (MA 351- MA 356, MA 450, BMTH496-498 not allowed).

MA 190 – Contemporary Mathematical Problems (2 hrs.) A student taking a degree program in which mathematics is the primary major must also take MA 190. A student whose second major is mathematics is not required to take MA190, but is strongly encouraged to do so.

- **Senior Capstone (8 hrs.)** A student must complete an 8-credit hour Senior Capstone by completing MA496 (4 hrs.), MA497 (2 hrs.), and MA498 (2 hrs.). Note that MA491 may replace 2 hours of MA496 and that MA497 and MA498 must be taken in separate terms. The capstone is an important experience for the mathematics major, representing a sustained effort to solve a complex problem in the mathematical sciences. The Senior Capstone must involve significant individual work, and it must culminate with both a written report and an oral presentation. Both the report and the presentation must be submitted to the department.

  Students double majoring in mathematics and another program who complete the senior project courses for that program must also complete MA491 for the senior project to satisfy the Senior Capstone requirement within the mathematics major. Students double majoring in mathematics and another program who complete the senior thesis courses for that program can directly use those courses to satisfy the Senior Capstone requirement within the mathematics major. The Mathematics Capstone does not constitute a culminating major engineering design experience for students also majoring in an ABET accredited program.

Summary of Requirements		
Mathematics Coursework - core, concentration and electives (MA351-MA356, MA450, BMTH496-498 not allowed)		63 hrs.
Mathematics Senior Capstone		8 hrs.
MA 190 - Contemporary Mathematical Problems (primary major only)		2 hrs.
Physical and Life Sciences*		24 hrs.
Computer Science**		8 hrs.
Humanities, Social Sciences, and the Arts (standard requirement, one course must be ENGL H290)		36 hrs.
Technical Electives***		24 hrs.
Free Electives		28 hrs.
Miscellaneous****		2 hr.
Total hours required for graduation		**195 hrs.**
*	PH 111, 112, and 113 — Physics I, II, and III	12 hrs.

	BIO 101 — Essential Biology (or higher-level BIO course)	4 hrs.
	CHEM 111 — General Chemistry I	4 hrs.
	4 additional credit hours in Physical or Life Sciences	4 hrs.
**	CSSE 120 — Introduction to Software Development	4 hrs.
	CSSE 220 — Object-Oriented Software Development	4 hrs.
	MA 332 - Introduction to Computational Science - may be taken instead of CSSE 220 but then MA 332 cannot be counted towards the 63 hours of mathematics coursework	
***	200 level or above coursework, approved by the major advisor, in areas of science, engineering, or economics in which 12 credit hours constitute a coherent set of three courses representing a specific area of technical depth and 12 credit hours represent technical breadth. Coursework in mathematics and biomathematics is not allowed.	24 hrs.
****	RHIT 100 — Foundations of Rose-Hulman Success MA 200 - Career Preparation (primary major only)	1 hr. 1 hr.

SUGGESTED SCHEDULE

The schedule (Course Sequence) on the right is a suggested schedule only. Scheduling of courses may be altered, subject to the approval of the advisor, in order to take advantage of advanced placement or to accommodate a second major, area minor or other special program. However, note that some courses are offered only at certain times during the year, and all prerequisites must be met. In the schedule an MA elective is either a concentration elective or free math elective, as described above, and a science elective is a physical or life science elective as defined on this page.

Alternate Science Schedule: The recommended science schedule of six science courses starts with PH 111. If CHEM 111 is required in the fall quarter because of a double major or minor, then the alternate science sequence may be completed by taking the second science course in each place where a choice is given. Two science courses are to be taken in the winter quarter of freshman year.

COMPUTATIONAL SCIENCE MAJOR (CPLS) (Second Major Only)

Computational methods are widely employed in science and engineering for simulation, experimentation, analysis, and design. In many areas the use of high-performance computing is essential. The Computational Science major provides Rose-Hulman students with the opportunity to add to their primary major a second major that increases their knowledge and skill in applied scientific and engineering computation.

Computational Science Program Student Learning Objectives:

Graduates with a second major in CPLS will have an ability to:

1.) Develop goals for a computational model such that the results will inform a scientific/ engineering decision or provide a desired level of understanding

2.) Choose a computational modelling approach that meets the goals and implement it

3.) Validate a computational model of a complex phenomenon or system and demonstrate that the goals have been met

Requirements for a second major in Computational Science (72 credit hours)

The second major in Computational Science is open to all students. It requires 72 credit hours, including a 52 credit hour core and a 20 credit hour specialization. The courses used to satisfy the requirements in the Advanced Core may not be counted toward any other major or minor. All Computational Science programs of study are subject to approval by the Chair of the Computational Science Steering Committee.

Computational Science Core (52 credit hours)

Fundamentals (31 credit hours)

- MA 111, 112, 113 Calculus I, II, III
- MA 221 Matrix Algebra and Differential Equations I
- MA 222 Matrix Algebra and Differential Equations II
- CSSE 120 Introduction to Software Development, or any of BE 100, CE 111*, CHE 110*, ENGD 120, ME 123
- MA 332 Introduction to Computational Science, or any of CHE 310, ME 323*, ME 327

*Courses marked with an asterisk carry only 2 credits and must be augmented by an additional 2 credits of course work, as approved by the Chair of the Computational Science Steering Committee.

Advanced (21 credit hours; these courses may not be counted toward any other major or minor)

- CSSE/MA 335 Introduction to Parallel Computing
- MA 336 Boundary Value Problems
- MA 342 Computational Modeling and MDS 442 Applied Computational Modeling
- MDS 442 Applied Computational Modeling
- MA 435 or ME 422 Finite Difference Methods, Finite Element Methods for Engineering Applications

Any course from the list of Approved Computational Science Electives (or another upper-level course if approved by the Chair of the Computational Science Steering Committee):

- BE 340 Biomedical Signal Processing
- BE 510 Biomedical Signal and Image Processing
- BMTH 312 Bioinformatics
- BMTH 413 Computational Biology
- CHE 310 Numerical Methods for Chemical Engineers
- CE 310 Computer Applications in Civil Engineering
- CSSE 304 Programming Language Concepts
- ECE 480/OE 437 Introduction to Image Processing
- ECE 483 DSP System Design
- EMGT 534/MA 534 Management Science
- MA 323 Geometric Modeling
- MA 384 Data Mining
- MA 433 Numerical Analysis
- MA 434 Topics in Numerical Analysis
- MA 435 Finite Difference Methods
- MA 439 Mathematical Methods of Image Processing
- MA 444 Deterministic Models in Operations Research
- MA 446 Combinatorial Optimization
- ME 422 Finite Element Methods for Engineering Applications
- ME 427 Introduction to Computational Fluid Dynamics
- ME 430 Mechatronic Systems
- ME 522 Advanced Finite Elements Analysis
- ME 536 Computational Intelligence in Control Engineering
- PH 540 Computer Physics

Area of Concentration (20 credit hours): Each student must complete 20 credit hours of advanced work reflecting an Area of Concentration within Computational Science. Courses used to satisfy the core requirements may not be used to satisfy the area of concentration requirements. The 20 credit hours shall consist of at least 16 credit hours within a single Area of Concentration, as specified below, and an additional 4 credit hours from any of the Areas of Concentration, or from the list of Approved Computational Science Electives. Exceptions may be made on occasion (e.g. when an appropriate special topics course has been taken).

Computational Methods

- MA 371 or MA 373 Linear Algebra I, Applied Linear Algebra for Engineers
- MA 433 Numerical Analysis
- Eight credit hours chosen from BMTH 413, CSSE 304, CSSE/MA 473, MA 384, MA 386, MA 434, MA 435, MA439, MA 444, MA 446, MA 485, ME 422

Computational Mechanics

- MA 435 or ME 422 Finite Difference Methods, Finite Element Methods for Engineering Applications
- ME 401 Foundations of Fluid Mechanics
- ME 427 Introduction to Computational Fluid Dynamics
- ME 522 Advanced Finite Element Analysis

Computational Signals and Image Processing

- ECE 380 Discrete-Time Signals and Systems
- ECE 480/OE 437 Introduction to Image Processing
- ECE 483 DSP System Design
- MA 439 Mathematical Methods of Image Processing

Computational Physics and Chemistry

- CHEM 361 Physical Chemistry I*
- CHEM 362 Physical Chemistry II*
- CHEM 363 Quantum Chemistry & Molecular Spectroscopy
- OE 450 Nanomedicine
- PH 540 Computer Physics

*For CHE students, CHEM 361 and CHEM 362 may be substituted by CHE 303, CHE 304 and CHEM 360

Computational Biomedics

- BE 482/MA 482 Bioengineering Statistics
- BE 535/OE 535 Biomedical Optics
- BE 541/ECE 584 Medical Imaging Systems
- BMTH 310 Mathematical Biology
- BMTH 413 Computational Biology

DATA SCIENCE MAJOR (SECOND MAJOR ONLY)

Data Science is open to all students as a second major; this means that the student will have some other discipline as their primary major. Students whose primary major is in Computer Science, Software Engineering or Mathematics will find the Data Science program the easiest since there is considerable overlap between those programs and the Data Science requirements Students from other disciplines are also encouraged to participate, but will have to take more courses. All students are encouraged to take the individual courses in the program, regardless of whether they wish to fulfill the second major requirements. Learn more about Data Science requirements.

MINOR IN MATHEMATICS

Any student not pursuing a major or second major in either mathematics or in biomathematics may obtain a minor in mathematics by taking 10 or more mathematics courses as follows:

- **Six courses in foundational mathematics**
  - Calculus, Matrix Algebra and Differential Equations, Introduction to Proofs : MA 111, MA 112, MA 113, MA 221, and either MA 222 or MA276.
  - Introductory Statistics or Probability: either MA 223 or MA 381
- **Sixteen additional credit hours of "upper division" courses:**
  - Courses selected from MA 222, MA 223, MA 276, all MA courses numbered 300 or higher (except MA351-356 and MA450, MA492-494, and MA496-498), all BMTH courses numbered 300 or higher (except BMTH 496-498), or other MA courses approved by the minor advisor for mathematics. Computer Science majors cannot use either MA 473 or MA 474 to satisfy both their computer science major requirements and the requirements of the mathematics minor.

Approval and Math Minor Form

All minors must be approved by the minor advisor and the student's advisor. The department has a form for the planning and approval of a mathematics minor.

Notes and Limitations on Requirements:

- Almost all students are required to take six foundational courses as a requirement for their major; therefore only four "extra courses" are required for most students.
- Only MA111, MA112, MA113, MA221, MA222 and one of MA223, MA381, or MA382 can be counted towards any combination of the multiple minors offered by the mathematics department.
- No student can take both MA 371 and MA 373 for credit.
- No student can take both MA223 and MA382 for credit
- Except as noted above, if MA 381 is being counted towards the four additional courses then, MA 223 may be taken and counted towards the Introductory Statistics and Probability.
- Science and engineering, especially the most recent "high tech" developments, have sophisticated mathematical and statistical concepts and methodologies as their foundation. Thus a well-chosen set of courses for a mathematics minor (or a second major in mathematics) will greatly enhance a student's analytical and computational skills. Students thinking of going on to graduate school should especially give consideration to this option.

MINOR IN COMPUTATIONAL SCIENCE

Any student may obtain a minor in Computational Science by taking the following courses:

- Five courses in foundational mathematics: MA111, MA112, MA113, MA221, MA222
- Basic computing course: CSSE 120 or departmental equivalent of at least 4 credit hours
- Introductory Computational Science courses:
  - MA332 Introduction to Computational Science
  - MA342 Computational Modeling

- Four credit hours of applied Computational Science course from list A
- Four credit hours of additional Computational Science course from list B

List A: Applied Computational Science courses

- MA323 – Geometric Modeling
- MA439 – Mathematical Methods of Image Processing
- MA444 – Deterministic Models in Operations Research
- CSSE351 – Computer Graphics
- CSSE451 - Advanced Computer Graphics
- CSSE413 – Artificial Intelligence
- CSSE453 – Topics in Artificial Intelligence
- CSSE461 – Computer Vision
- CSSE463 - Image Recognition
- CE522 - Advanced Finite Element Analysis
- ME422 – Finite Elements for Engineering Applications
- ME427 - Introduction to Computational Fluid Dynamics
- ME511 - Numerical Methods for Dynamic Systems Analysis
- ME522 - Advanced Finite Elements Analysis
- 4XX – Introduction to MEMS:Fabrication and Applications
- 5XX – Advanced Topics in MEMS
- CHE521 – Advanced Chemical Engineering Computation
- BE510 – Biomedical Signal and Image Processing
- EMGT526 - Technology Forecasting
- MA534/EMGT534 - Management. Science
- ECE420 - Nonlinear Control Systems
- ECE480//PH437 – Introduction to Image Processing
- ECE582/PH537 – Advanced Image Processing
- ECE483 - DSP System Design

List B: Additional Computational Science courses

- MA/CSSE335 - Introduction to Parallel Computing
- MA433 - Numerical Analysis
- MA434 – Topics in Numerical Analysis
- MA446 - Combinatorial Optimization
- CSSE304 - Programming Language Concepts
- CSSE371 - Software Requirements and Specification

Electives not on list A or B may be substituted with other courses with the approval of the area minor advisor.

The minor must be approved by the minor advisor for Computational Science and the student's advisor. The department has a form for the planning and approval of a minor.

Notes and limitations on requirements

- Almost all students are required to take the five foundational courses as a requirement for their major
- Most majors should be able to apply the basic computing requirement and/or one of the elective courses towards their major.

- Math majors or double majors are not allowed to count MA332 and MA342 for both the minor and the major.
- A student may not apply the four upper-division courses toward both this minor and a math or statistics minor.

MINOR IN STATISTICS

Any student may obtain a minor in statistics by taking ten or more mathematics courses (24 credit hours) including the following:

4 credit hours – Foundational Statistics Course:

One of the following:

- MA 223 Engineering Statistics I
- MA 382 Introduction to Statistics with Probability

If MA 381 is taken before MA223/MA382, it will be strongly recommended the student take MA382 instead of MA223.

20 credit hours – Additional Coursework:

Five courses selected from the following list, at least two of which must be starred (*). Courses not on this list may count towards the minor if approved by the statistics minor advisor.

- MA 381 Introduction to Probability with Applications to Statistics
- MA 383 Engineering Statistics II
- MA 386 Statistical Programming
- MA 481 Mathematical Statistics
- MA 482* Biostatistics
- MA 483* Bayesian Data Analysis
- MA 485* Applied Linear Regression
- MA 487* Design of Experiments
- MA 480 Topics in Probability and Statistics
- EMGT472 Reliability Engineering

All minors must be approved by the minor advisor and the student's advisor. The department has a form for the planning and approval of a minor.

Notes and Limitations on Requirements

1. Almost all students are required to take either MA223 or MA381 as a requirement for their major; therefore, only five “extra courses” are required for most students.
2. Only one of MA223, MA381, or MA382 can be counted towards any combination of the multiple minors offered by the mathematics department.
3. Mathematics majors or biomathematics majors must have at least 16 credit hours of separation between their major and this minor.
4. No student can take both MA223 and MA382 for credit.
5. Note that MA481, MA483, and EMGT472 have MA381 as a pre-requisite.

Plan of Study

Freshman

Fall

Course	Credit
MA 111 Calculus I	5
PH 111 Physics I or CHEM 111 General Chemistry I	4
HUM H190 First-Year Writing Seminar or HSSA Elective	4
RHIT 100 Foundations for Rose-Hulman Success	1
CSSE 120 Introduction to Software Development	4
	Total Credits: 18

Winter

Course	Credit
MA 112 Calculus II	5
PH 112 Physics II or PH 111 Physics I	4
CHEM 111 General Chemistry I or BIO 101 Essential Biology (or higher level BIO course)	4
HSSA Elective or HUM H190 First-Year Writing Seminar	4
	Total Credits: 17

Spring

Course	Credit
MA 113 Calculus III	5
PH 113 Physics III or PH 112 Physics II	4
MA 190 Contemporary Mathematics Problems	2
HSSA Elective	4
	Total Credits: 15

Sophomore

Fall

Course	Credit
MA 221 Matrix Algebra & Differential Equations I	4
MA 276 Introduction to Proofs	4
BIO 101 Essential Biology (or higher level BIO course) or PH 113 Physics III	4
*CSSE 220 Object-Oriented Software Development	4
	Total Credits: 16

Winter

Course	Credit
MA 222 Matrix Algebra & Differential Equations II	4
Science Elective	4
Technical Elective	4
HSSA Elective	4
**MA 200 Career Preparation	1
	Total Credits: 17

Spring

Course	Credit
MA 381 Introduction to Probability	4
MA 371 Linear Algebra I	4
Technical Elective	4
HSSA Elective	4
	Total Credits: 16

Junior

Fall

Course	Credit
MA Elective	4
Technical Elective	4
Technical Elective	4
HSSA Elective or ENGL H290 Technical & Professional Communication	4
	Total Credits: 16

Winter

Course	Credit
MA 366 Introduction to Real Analysis	4
MA Elective	4
Technical Elective	4
HSSA Elective or ENGL H290 Technical & Professional Communication	4
	Total Credits: 16

Spring

Course	Credit
MA Elective	4
MA Elective	4
Technical Elective	4
HSSA Elective or ENGL H290 Technical & Professional Communication	4
	Total Credits: 16

Senior

Fall

Course	Credit
MA496 Senior Capstone I (4hrs) or MA 491 Intro to Math Modeling (2 hrs.) and MA 496 (2 hrs.)	4
Free Elective	4
Free Elective	4
HSSA Elective	4
	Total Credits: 16

Winter

Course	Credit
MA 497 Senior Capstone II (2 hrs.)	2
MA Elective	4
Free Elective	4
Free Elective	4
Free Elective	4
	Total Credits: 18

Spring

Course	Credit
MA 498 Senior Capstone III (2 hrs.)	2
MA Elective	4
Free Elective	4
Free Elective	4
	Total Credits: 14

Notes:

*MA 332 - Introduction to Computational Science - may be taken instead of CSSE 220 but then MA 332 cannot be counted towards the 63 hours of mathematics coursework
**MA 200 - Career Preparation - may be taken in the winter quarter of the sophomore year

Notes and Definitions

- The suggested four year plan is a guideline.
- Close consultation with the advisor on electives is required, especially for electives after the freshman year, or if a double major or minor is planned.

The following definitions of electives are specific to the Mathematics Department.

- **Math Elective:** A course either required by the concentration or a true math elective.
- **Science Elective:** Any Physical or Life Sciences elective (not Computer Science) at any level.
- **Technical Elective:** Non-mathematics courses numbered 200 or above in Engineering, Science or Economics; coursework in mathematics and biomathematics is not allowed.
- **Free Elective:** Any course.

Mathematics - Course Descriptions

MA 105 Calculus A 5R-0L-5C F
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Calculus and analytic geometry in the plane. Algebraic and trigonometric functions. Limits and continuity. Differentiation, geometric and physical interpretations of the derivative. Introduction to integration and the Fundamental Theorem of Calculus. A student cannot earn credit for both MA 105 and MA 111.

MA 106 Calculus B 4R-0L-4C W
Prerequisites: MA 105F
Corequisites: There are no corequisites for this course.
Definitions, properties, and derivatives of exponentials and logarithms. Antiderivatives, integral properties, integration by substitution, integration by parts, integrals of transcendental functions, numerical integration, applications of integration, and improper integrals. Applications of integration, e.g. area, displacement, volumes of revolution, arc length, surface area of revolution, and work. Newton’s method. Computer algebra systems.

MA 107 Calculus C 4R-0L-4C S

Prerequisites: MA 106W
Corequisites: There are no corequisites for this course.
Partial fractions and Integration. Hyperbolic functions. Separable first order differential equations, applications of separable first order differential equations. Series of constants, power series, Taylor polynomials, Taylor and McLaurin series. Computer algebra systems.

MA 111 Calculus I 5R-0L-5C F,W

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Calculus and analytic geometry in the plane. Algebraic and transcendental functions. Limits and continuity. Differentiation, geometric and physical interpretations of the derivative, Newton's method. Introduction to integration and the Fundamental Theorem of Calculus. A student cannot earn credit for both MA 105 and MA 111.

MA 112 Calculus II 5R-0L-5C F,W,S

Prerequisites: MA 111F,W
Corequisites: There are no corequisites for this course.
Techniques of integration, numerical integration, applications of integration. L'Hopital's rule and improper integrals. Separable first order differential equations, applications of separable first order differential equations. Series of constants, power series, Taylor polynomials, Taylor and McLaurin series.

MA 113 Calculus III 5R-0L-5C F,W,S

Prerequisites: MA 112F,W,S
Corequisites: There are no corequisites for this course.
Vectors and parametric equations in three dimensions. Functions of several variables, partial derivatives, maxima and minima of functions of several variables, multiple integrals, and other coordinate systems. Applications of partial derivatives and multiple integrals.

MA 190 Contemporary Mathematical Problems 2R-0L-2C S

Prerequisites: There are no prerequisites for this course.
Corequisites: MA 113 5R-0L-5C F,W,S
A seminar-style course consisting of an overview of selected contemporary problems and areas in the mathematical sciences. Problems to be discussed will be selected from recent publications in research and applications, famous problems, and outstanding problems of great significance.

MA 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

MA 200 Career Preparation 1R-0L-1C W

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
This course is for mathematics majors to be taken in the second year. The course addresses career choices, summer opportunities, employment and graduate school

preparation, and curriculum vitae and resumes preparation. Cross-listed with CHEM 200 and PH200.

MA 221 Matrix Algebra & Differential Equations I 4R-0L-4C F,W,S

Prerequisites: MA 113F,W,S

Corequisites: There are no corequisites for this course.

First order scalar differential equations including basic solution techniques and numerical methods. Second order linear, constant coefficient differential equations, including both the homogeneous and non-homogeneous cases. Basic matrix algebra with emphasis on understanding systems of linear equations from algebraic and geometric viewpoints, and eigenvalues and eigenvectors. Introduction to complex arithmetic. Applications to problems in science and engineering.

MA 222 Matrix Algebra & Differential Equations II 4R-0L-4C F,W,S

Prerequisites: MA 221F,W,S

Corequisites: There are no corequisites for this course.

Laplace transforms. Solution of systems of first order linear differential equations by matrix methods and investigation of their solution structure determined by eigensystems. Phase portrait analysis and classification of the nature of the stability of critical points for linear and nonlinear systems. Fourier series and application to solving elementary boundary value problems. Applications to problems in science and engineering.

MA 223 Engineering Statistics I 4R-0L-4C F,W,S

Prerequisites: MA 111F,W, and ENGL H100F,W or ENGD 100 F or HUM H190F, W

Corequisites: There are no corequisites for this course.

This is an introductory course in applied statistics emphasizing data analysis. The course is designed to support the research cycle including the formulation of a question of interest, effective data collection techniques, informative data summaries, and appropriate inferences from data. Communication of results and statistical concepts is emphasized. Statistical software will be used for the data analysis throughout, including analysis of variance and simple linear regression. A student cannot take both MA223 and MA382 for credit.

MA 276 Introduction to Proofs 4R-0L-4C F, W

Prerequisites: MA 112F,W,S

Corequisites: There are no corequisites for this course.

Introduction to writing mathematical proofs. Logic: direct proof, contradiction, contrapositive, counterexamples. Induction. Recursion. Sets: relations (order, equivalence), functions. Properties of infinite sets. Basic number theory. Important preparation for further courses in theoretical mathematics.

MA 290 Topics in Mathematics Variable 1-4 Hours See Dept

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

Variable Topics in Mathematics

MA 323 Geometric Modeling 4R-0L-4C W (Even years)

Prerequisites: MA 113F,W,S

Corequisites: There are no corequisites for this course.

Covers some of the mathematical methods for describing physical or virtual objects in computer aided geometric design (CAGD) and computer graphics. Emphasizes methods for curve and surface modeling, and discusses both the underlying geometric concepts and the practical aspects of constructing geometric models of objects. Topics covered include Bezier curves, Hermite curves, B-splines, Bezier patches, subdivision surfaces. In discussing these, ideas from analytic geometry, differential geometry, affine geometry, combinatorial geometry, and projective geometry will be introduced.

MA 327 Low Dimensional Topology 4R-0L-4C W (odd years)

Prerequisites: MA 113F,W,S or consent of instructor

Corequisites: There are no corequisites for this course.

An introduction to the topology of one-, two-, and three-dimensional manifolds and its application to other areas of mathematics and science. Topics may include, but are not restricted to, classification of curves and surfaces, Euler characteristic, tiling and coloring theorems, graph embeddings, vector fields, knots and links, and elementary algebraic topology. Intended for science and engineering majors as well as mathematics majors.

MA 330 Vector Calculus 4R-0L-4C F,S

Prerequisites: MA 222F,W,S

Corequisites: There are no corequisites for this course.

Calculus of vector- valued functions of one and several variables. Topics include differentiation (divergence, gradient and curl of a vector field) and integration (line integrals and surface integrals). Applications of Green’s theorem, Stokes’ theorem and the divergence theorem to potential theory and/or fluid mechanics will be provided.

MA 332 Introduction to Computational Science 4R-0L-4C F,W

Prerequisites: MA 221F,W,S

Corequisites: There are no corequisites for this course.

An introduction to Computational Science using Matlab. Floating point arithmetic, Matlab programming, solution of nonlinear equations, interpolation, least squares problems, numerical differentiation and integration, solution of linear systems.

MA 335 Introduction to Parallel Computing 4R-0L-4C S

Prerequisites: MA 221F,W,S and programming experience

Corequisites: There are no corequisites for this course.

Principles of scientific computation on parallel computers. Algorithms for the solution of linear systems and other scientific computing problems on parallel machines. Course includes a major project on RHIT's parallel cluster. Same as CSSE 335.

MA 336 Boundary Value Problems 4R-0L-4C F,S

Prerequisites: MA 222F,W,S

Corequisites: There are no corequisites for this course.

Introduction to boundary value problems and partial differential equations. Emphasis on boundary values problems that arise from the wave equation, diffusion equation, and Laplace’s equation in one, two and three dimensions. Solutions to such boundary value problems will be discussed using Fourier series, numerical techniques, and integral transforms.

MA 341 Topics in Mathematical Modeling 4R-0L-4C W

Prerequisites: MA 222F,W,S

Corequisites: There are no corequisites for this course.

An introduction to techniques of mathematical modeling involved in the analysis of meaningful and practical problems arising in many disciplines including mathematical sciences, operations research, engineering, and the management and life sciences. Topics may include creative and empirical model construction, model fitting, models requiring optimization, and modeling dynamic behavior. Student participation in significant individual and group projects will be emphasized.

MA 342 Computational Modeling 4R-0L-4C S

Prerequisites: MA 222F,W,S, and either CE 310S or CHE 310See Department or MA 332F,W or ME 327W,S

Corequisites: There are no corequisites for this course.

Computational modeling and simulation of scientific problems using Matlab. Students will create and utilize computer-based models to solve practical problems. Monte Carlo methods, linear systems, solution of ODEs.

MA 351-6 Problem Solving Seminar 1R-0L-1C F,W,S

Prerequisites: consent of instructor

Corequisites: There are no corequisites for this course.

An exposure to mathematical problems varying widely in both difficulty and content. Students will be expected to participate actively, not only in the solution process itself but also in the presentation of finished work, both orally and in writing. A student may earn a maximum of six credits in MA 351-6. Cannot count toward mathematics major core hours or the math minor.

MA 366 Introduction to Real Analysis 4R-0L-4C F, W

Prerequisites: MA 371F,S, and MA 276F, W

Corequisites: There are no corequisites for this course.

Calculus of functions of a single variable. A more careful development of the basic concepts of analysis, including sequences, limits, continuity, differentiability, integration, infinite series, power series, Taylor's Theorem, and uniform convergence, with an emphasis on proof.

MA 367 Functions of a Complex Variable 4R-0L-4C S

Prerequisites: MA 221F,W,S

Corequisites: There are no corequisites for this course.

Elementary properties of analytic functions including Cauchy's theorem and its consequences, Laurent series, the Residue Theorem, and mapping properties of analytic functions.

MA 371 Linear Algebra I 4R-0L-4C F,S

Prerequisites: MA 221F,W,S or consent of instructor

Corequisites: There are no corequisites for this course.

Similar to MA373, but with an emphasis on the theory behind matrices and vector spaces. Systems of linear equations, Gaussian elimination, and the LU decomposition of a matrix. Projections, least squares approximations, and the Gram-Schmidt process. Eigenvalues and eigenvectors of a matrix. The diagonalization theorem. The singular value decomposition of a matrix. Introduction to vector spaces. Some proof writing will be required. Those interested in applications of matrices and vector spaces should take MA373. A student cannot take both MA 371 and MA 373 for credit.

MA 373 Applied Linear Algebra for Engineers 4R-0L-4C W

Prerequisites: MA 221F,W,S or consent of instructor

Corequisites: There are no corequisites for this course.

Similar to MA 371, but with emphasis on applications of matrices and vector spaces. Systems of linear equations, Gaussian elimination, and the LU decomposition of a matrix. Projections, least squares approximations, and the Gram-Schmidt process. Eigenvalues and eigenvectors of a matrix. The diagonalization theorem. The singular value decomposition of a matrix. Those interested in the theory behind matrices and vector spaces should take MA 371. A student cannot take both MA 371 and MA 373 for credit.

MA 374 Combinatorics 4R-0L-4C F, W, S
Prerequisites: MA 112F,W,S
Corequisites: There are no corequisites for this course.
A first course in combinatorics. Basic counting principles, permutations, combinations. Combinatorial proof. The pigeonhole principle. The principle of inclusion/exclusion. Generating functions. Recurrence relations. Additional topics in combinatorics, which may include permutation groups and Burnside's Lemma, Polya enumeration, multivariate generating functions, combinatorial designs, Ramsey theory, order relations, or other topics at the discretion of the instructor.

MA 376 Abstract Algebra 4R-0L-4C S
Prerequisites: MA 276F, W
Corequisites: There are no corequisites for this course.
An introduction to Group Theory. Topics include: matrix groups, groups of integers modulo a natural number, symmetric and dihedral groups, homomorphisms, subgroups, cosets, quotient groups and group actions. Applications, possibly including games and puzzles, cryptography, and coding theory. Other topics may also be introduced according to time and student interest.

MA 378 Number Theory 4R-0L-4C S
Prerequisites: consent of instructor
Corequisites: There are no corequisites for this course.
Divisibility, congruences, prime numbers, factorization algorithms, RSA encryption, solutions of equations in integers, quadratic residues, reciprocity, generating functions, multiplicative and other important functions of elementary number theory. Mathematical conjecture and proof, mathematical induction.

MA 381 Introduction to Probability with Applications to Statistics 4R-0L-4C F,W,S
Prerequisites: MA 113F,W,S
Corequisites: There are no corequisites for this course.
Introduction to probability theory; axioms of probability, sample spaces, and probability laws (including conditional probabilities). Univariate random variables (discrete and continuous) and their expectations including these distributions: binomial, Poisson, geometric, uniform, exponential, and normal. Introduction to moment generating functions. Introduction to jointly distributed random variables. Univariate and joint transformations of random variables. The distribution of linear combinations of random variables and an introduction to the Central Limit Theorem. Applications of probability to statistics.

MA 382 Introduction to Statistics with Probability 4R-0L-4C F
Prerequisites: MA 381F,W,S
Corequisites: There are no corequisites for this course.
This is an introductory course in statistics. Dual emphasis is placed on deriving statistical techniques and using the methods within data analyses. Study design and informative data summaries motivate the statistical inference techniques for linear models. Statistical thinking and communication skills are developed through analysis of data from a variety of fields. A statistical programming language is used for data visualization, analysis, and simulations. A student cannot take both MA 223 and MA 382 for credit.

MA 383 Engineering Statistics II 4R-0L-4C F
Prerequisites: MA 223F,W,S or MA 382F
Corequisites: There are no corequisites for this course.

Hypothesis testing, confidence intervals, sample size determination, and power calculations for means and proportions; two factor analysis of variance (with and without interactions); analysis of several proportions; confidence and prediction intervals for estimated values using simple linear regression; Pearson (linear) correlation coefficient; introduction to multiple regression to include polynomial regression; review of fundamental prerequisite statistics will be included as necessary.

MA 384 Data Mining 4R–0L–4C

Prerequisites: CSSE 120F,W,S, and MA 221F,W,S, and either MA 223F,W,S or MA 381F,W,S

Corequisites: There are no corequisites for this course.

An introduction to data mining for large data sets, include data preparation, exploration, aggregation/reduction, and visualization. Elementary methods for classification, association, and cluster analysis are covered. Significant attention will be given to presenting and reporting data mining results.

MA 386 Statistical Programming 4R-0L-4C

Prerequisites: MA 223F,W,S or MA 382F and previous programming course

Corequisites: There are no corequisites for this course.

Computational data analysis is an essential part of modern statistics. This course provides a practical foundation for students to compute with data. This course will introduce students to tools for data management, manipulation and analysis that are common in statistics and data science. The R computing language will be introduced. Topics will include data structures in R, writing functions, webscraping, data cleaning (both quantitative and textual data), processing unstructured data, static and interactive graphical presentations of data, and coding of modern algorithms for data analysis (bootstrapping and Monte Carlo methods).

MA 390 Topics in the Mathematics of Engineering 1-2C Arranged

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

A succinct mathematical study that is supportive of the engineering curricula. Topics could be chosen from signal processing, fluid dynamics, thermodynamics, as well as others. A student may take the course for credit more than once provided the topics are different.

MA 415 Machine Learning 4R-0L-4C S

Prerequisites: MA 221F,W,S*, and either MA 223F,W,S or MA 381F,W,S, and either CHE 310See Department or CSSE 220F,W,S or ECE 230W,S or MA 332F,W or MA 386F,W or ME 323W,S or ME 327W,S Prerequisite Clarification for MA415: Junior standing and MA221, and either MA223 or MA381, and one of CHE310, CSSE220, ECE230, MA332, MA386 or (ME323 or ME327).

Corequisites: There are no corequisites for this course.

An introduction to machine learning. Topics include: error metrics, accuracy vs interpretability trade-off, feature selection, feature engineering, bias-variance trade-off, under-fitting vs. overfitting, regularization, cross-validation, the bootstrap method, the curse of dimensionality and dimensionality reduction using the singular value decomposition. Both parametric and nonparametric methods are covered including: k-nearest neighbors, linear and logistic regression, decision trees and random forests, and support vector machines. Same as CSSE415.

MA 416 Deep Learning 4R-0L-4C Arranged

Prerequisites: MA 221F,W,S, and either MA 223F,W,S or MA 381F,W,S, and either CHE 310See Department or CSSE 220F,W,S or ECE 230W,S or MA 332F,W or MA 386F,W or ME 327W,S
Corequisites: There are no corequisites for this course.
An introduction to deep learning using both fully-connected and convolutional neural networks. Topics include: least squares estimation and mean square error, maximum likelihood estimation and cross-entropy, convexity, gradient descent and stochastic gradient descent algorithms, multivariate chain rule and gradient computation using back propagation, linear vs nonlinear operations, convolution, over-fitting vs under-fitting and hyper-parameter optimization, L2, early stopping and dropout regularization, data augmentation and transfer learning.

MA 421 Tensor Calculus & Riemannian Geometry 4R-0L-4C Fall (Odd years)
Prerequisites: MA 330F,S
Corequisites: There are no corequisites for this course.
An introduction to the calculus of tensor fields and the local geometry of manifolds.Topics covered include: manifolds, tangent space, cotangent spaces, vector fields, differential forms, tensor fields, Riemannian metrics, covariant derivative and connections, parallel transport and geodesics, Ricci tensor, Riemannian curvature tensor. Applications will be given in physics (general relativity, mechanics, string theory) and engineering (continuum mechanics).

MA 423 Topics in Geometry 4R-0L-4C Arranged
Prerequisites: MA 371F,S or MA 373W or consent of instructor
Corequisites: There are no corequisites for this course.
An advanced geometry course with topics possibly chosen from the areas of projective geometry, computational geometry, differential geometry algebraic geometry, Euclidean geometry or non-Euclidean geometry. A student may take the course for credit more than once provided the topics are different.

MA 430 Topics in Applied Mathematics 4R-0L-4C Arranged
Prerequisites: Instructor permission
Corequisites: There are no corequisites for this course.
A topics course in the general area of continuous applied mathematics. Topics may include mathematical physics, mathematical biology, mathematical finance, mathematics of vision, PDEs, image processing methods, continuum mechanics, dynamical systems, and mathematical modeling. A student may take the course for credit more than once provided the topics are different.

MA 431 Calculus of Variations 4R-0L-4C Arranged
Prerequisites: MA 330F,S
Corequisites: There are no corequisites for this course.
Euler-Lagrange and Hamiltonian equations, with possible applications in mechanics, electrostatics, optics, quantum mechanics and elasticity theory. An introduction to “direct methods.” Applications will be chosen in accordance with the interest of the students. Both classical and numerical methods have their place in this course.

MA 433 Numerical Analysis 4R-0L-4C W
Prerequisites: MA 332F,W or MA 366F, W or MA 371F,S or MA 435 W
Corequisites: There are no corequisites for this course.
Root-finding, computational matrix algebra, nonlinear optimization, polynomial interpolation, splines, numerical integration, numerical solution of ordinary differential equations. Principles of error analysis and scientific computation. Selection of

appropriate algorithms based on the numerical problem and on the software and hardware (such as parallel machines) available.

MA 434 Topics in Numerical Analysis 4R-0L-4C Arranged

Prerequisites: MA 433W

Corequisites: There are no corequisites for this course.

An extension of the material presented in MA433. Topics may include numerical problems, numerical solution of partial differential equations (finite differences, finite elements, spectral methods), sparse matrices, global optimization, approximation theory. A student may take the course for credit more than once provided the topics are different.

MA 435 Finite Difference Methods 4R-0L-4C W

Prerequisites: MA 332F,W or MA 371F,S or MA 373W or MA 433W

Corequisites: There are no corequisites for this course.

An introduction to finite difference methods for linear parabolic, hyperbolic, and elliptic partial differential equations. Consistency, stability, convergence, and the Lax Equivalence Theorem. Solution techniques for the resulting linear systems.

MA 436 Introduction to Partial Differential Equations 4R-0L-4C F (even years)

Prerequisites: MA 330F,S

Corequisites: There are no corequisites for this course.

Partial differential equations, elliptic, hyperbolic, and parabolic equations. Boundary and initial value problems. Separation of variables, special functions. Eigenfunction expansions. Existence and uniqueness of solutions. Sturm-Liouville theory, Green's function.

MA 438 Advanced Engineering Mathematics 4R-0L-4C W

Prerequisites: MA 222F,W,S senior standing

Corequisites: There are no corequisites for this course.

A fast-paced course in advanced applied mathematics for engineering and physics students that combines aspects of MA330, MA336, and MA373. Applied linear algebra, including abstract vector spaces, linear operators, eigentheory, diagonalization, and the matrix exponential; review of partial differentiation and multiple integration, including Lagrange multipliers and other optimization topics; vector analysis, including the Jacobian matrix and the del operator in standard coordinate systems; and Fourier series with application to the solution of partial differential equation boundary value problems. Students who receive credit for MA438 may only receive credit for at most one of MA330, MA336, MA371, and MA373.

MA 439 Mathematical Methods of Image Processing 4R-0L-4C F (Odd years)

Prerequisites: MA 221F,W,S

Corequisites: There are no corequisites for this course.

Mathematical formulation and development of methods used in image processing, especially compression. Vector space models of signals and images, one- and two-dimensional discrete Fourier transforms, the discrete cosine transform, and block transforms. Frequency domain, basis waveforms, and frequency domain representation of signals and images. Convolution and filtering. Filter banks, wavelets and the discrete wavelet transform. Application to Fourier based and wavelet based compression such as the JPEG compression standard. Compression concepts such as scalar quantization and measures of performance.

MA 444 Deterministic Models in Operations Research 4R-0L-4C W

Prerequisites: MA 371F,S or MA 373W , and programming experience

Corequisites: There are no corequisites for this course.
Formulation of various deterministic problems as mathematical optimization models and the derivation of algorithms to solve them. Optimization models studied include linear programs, integer programs, and various network models. The course will emphasize modeling, algorithm design, and the associated mathematical theory, e.g. polyhedral, duality, convex analysis. Some computer programming is expected.

MA 445 Stochastic Models in Operations Research 4R-0L-4C S (even years)

Prerequisites: MA 381F,W,S, and MA 221F,W,S
Corequisites: There are no corequisites for this course.
Introduction to stochastic mathematical models and techniques that aid in the decision-making process. Topics covered include a review of conditional probability, discrete and continuous Markov chains, Poisson processes, queueing theory (waiting line problems), and reliability.

MA 446 Combinatorial Optimization 4R-0L-4C S (odd years)

Prerequisites: MA 276F, W, and CSSE 220F,W,S
Corequisites: There are no corequisites for this course.
An introduction to graph- and network-based optimization models, including spanning trees, network flow, and matching problems. Focus is on the development of both models for real-world applications and algorithms for their solution.

MA 450 Mathematics Seminar 1R-0L-1C F,W,S

Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
A student must attend at least 10 mathematics seminars or colloquia and present at one of the seminars, based on material mutually agreed upon by the instructor and the student. A successful presentation is required for a passing grade. As seminars may not be offered every week during the quarter a student may extend the course over more than one quarter, but it must be completed within two consecutive quarters. A student may take this course a maximum of four times.

MA 460 Topics in Analysis 4R-0L-4C Arranged

Prerequisites: Instructor permission
Corequisites: There are no corequisites for this course.
An advanced topics course in analysis. Topic of the course could be advanced topics in real analysis, advanced topics in complex analysis, analysis on manifolds, measure theory or an advanced course in applied analysis (differential equations). May be taken more than once provided topics are different

MA 461 Topics in Topology 4R-0L-4C Arranged

Prerequisites: MA 366F, W or consent of instructor
Corequisites: There are no corequisites for this course.
Introduction to selected topics from point-set topology or algebraic topology from a rigorous point of view. Possible topics include metric spaces, general topological spaces, compactness, connectedness, separation axioms, compactification and metrization theorems, homotopy and homology, and covering spaces. Intended for mathematics majors planning to pursue graduate study in mathematics.

MA 466 Introduction to Functional Analysis 4R-0L-4C Arranged

Prerequisites: MA 366F, W
Corequisites: There are no corequisites for this course.

An introduction to the theory of Banach spaces emphasizing properties of Hilbert spaces and linear operators. Special attention will be given to compact operators and integral equations.

MA 470 Topics in Algebra 4R-0L-4C Arranged

Prerequisites: Instructor permission
Corequisites: There are no corequisites for this course.
An advanced topics course in algebra. Topic of the course could be commutative algebra, Galois theory, algebraic geometry, Lie groups and algebras, or other advanced topics in algebra. May be taken more than once provided topics are different.

MA 471 Linear Algebra II 4R-0L-4C S (even years)

Prerequisites: MA 371F,S or MA 373W
Corequisites: There are no corequisites for this course.
Continuation of Linear Algebra I. Properties of Hermitian and positive definite matrices and factorization theorems (LU, QR, spectral theorem, SVD). Linear transformations and vector spaces.

MA 473 Design & Analysis of Algorithms 4R-0L-4C W

Prerequisites: CSSE 230F,W,S, and MA 276F, W, and MA 374F, W, S
Corequisites: There are no corequisites for this course.
Students study techniques for designing algorithms and for analyzing the time and space efficiency of algorithms. The algorithm design techniques include divide-and-conquer, greedy algorithms, dynamic programming, randomized algorithms and parallel algorithms. The algorithm analysis includes computational models, best/average/worst case analysis, and computational complexity (including lower bounds and NP-completeness). Same as CSSE 473.

MA 474 Theory of Computation 4R-0L-4C S

Prerequisites: CSSE 230F,W,S, and MA 276F, W, and MA 374F, W, S
Corequisites: There are no corequisites for this course.
Students study mathematical models by which to answer three questions: What is a computer? What limits exist on what problems computers can solve? What does it mean for a problem to be hard? Topics include models of computation (including Turing machines), undecidability (including the Halting Problem) and computational complexity (including NP-completeness). Same as CSSE 474.

MA 475 Topics in Discrete Mathematics 4R-0L-4C Arranged

Prerequisites: MA 276F, W, and MA 374F, W, S ; additional prerequisites may be required at the discretion of the instructor
Corequisites: There are no corequisites for this course.
An extension of the material presented in MA 276 and 374. Topics may include combinatorial design, Fibonacci numbers, or the Probabilistic Method, among others. A student may take the course for credit more than once provided the topics are different.

MA 476 Algebraic Codes 4R-0L-4C S (odd years)

Prerequisites: MA 276F, W, and MA 374F, W, S
Corequisites: There are no corequisites for this course.
Construction and theory of linear and nonlinear error correcting codes. Generator matrices, parity check matrices, and the dual code. Cyclic codes, quadratic residue codes, BCH codes, Reed-Solomon codes, and derived codes. Weight enumeration and information rate of optimum codes.

MA 477 Graph Theory 4R-0L-4C S (even years)

Prerequisites: MA 276F, W, and MA 374F, W, S
Corequisites: There are no corequisites for this course.
An introduction to the theory and applications of directed and undirected graphs. Possible topics include the following: Connectivity, subgraphs, graph isomorphism, Euler trails and circuits, planarity and the theorems of Kuratowski and Euler, Hamilton paths and cycles, graph coloring and chromatic polynomials, matchings, trees with applications to searching and coding, and algorithms dealing with minimal spanning trees, articulation points, and transport networks

MA 478 Topics in Number Theory 4R-0L-4C Arranged

Prerequisites: MA 378S or MA 374F, W, S or consent of the instructor
Corequisites: There are no corequisites for this course.
Advanced topics in Number Theory. Topics may include elliptic curve cryptography, the Fermat-Wiles Theorem, elliptic curves, modular forms, p-adic numbers, Galois theory, diophantine approximations, analytic number theory, algebraic number theory. A student may take the course for credit more than once provided the topics are different.

MA 479 Cryptography 4R-0L-4C S

Prerequisites: CSSE 220F,W,S, and MA 276F, W
Corequisites: There are no corequisites for this course.
Introduction to basic ideas of modern cryptography with emphasis on mathematical background and practical implementation. Topics include: the history of cryptography and cryptanalysis, public and private key cryptography, digital signatures, and limitations of modern cryptography. Touches upon some of the societal issues of cryptography (same as CSSE 479)

MA 480 Topics in Probability or Statistics 4R-0L-4C Arranged

Prerequisites: Instructor permission
Corequisites: There are no corequisites for this course.
An advanced course in probability or statistics. Possible topics include (but are not restricted to) reliability, discrete event simulation, multivariate statistics, Bayesian statistics, actuarial science, nonparametric statistics, categorical data analysis, and time series analysis. May be taken more than once provided topics are different.

MA 481 Mathematical Statistics 4R-0L-4C W (even years)

Prerequisites: MA 382F, or both MA 381F,W,S and consent of instructor
Corequisites: There are no corequisites for this course.
An introduction to mathematical statistics. Review of distributions of functions of random variables. Moment generating functions. Limiting distributions. Point estimation and sufficient statistics. Fisher information and Rao-Cramer inequality. Theory of statistical tests.

MA 482 Biostatistics 4R-0L-4C S

Prerequisites: MA 223F,W,S or MA 382F
Corequisites: There are no corequisites for this course.
This course introduces statistical techniques for addressing the challenges that arise in the analysis of data from the biological sciences (including biology, biomedical engineering, and the medical community). Topics include linear regression modeling, nonlinear regression, repeated measures analysis (including mixed models), and survival/reliability analysis (analysis of time-to-event data). Flexible modeling strategies including relaxing linearity and distributional assumptions are discussed. Additional topics are introduced when discussing articles found in the literature, including properties of study design, power, meta-analysis, missing data, and causal inference.

No prerequisite knowledge of biology is assumed. Review of fundamental prerequisite statistics will be included as necessary.

MA 483 Bayesian Data Analysis 4R-0L-4C W (Odd years)

Prerequisites: MA 381F,W,S

Corequisites: There are no corequisites for this course.

This course offers an introduction to statistical inference under the Bayesian framework in addition to elements of basic study design. Building from Bayes' Rule for probability computations, we develop a framework of estimation, hypothesis testing and prediction. Topics include the construction of prior distributions to quantify a priori beliefs about unknown parameters, modeling available data, and using data to update beliefs about parameters. Applications include inference for a single response, comparing groups, and regression models; modern applications will be covered, time permitting. The course will make use of heavy use of computational tools for Bayesian inference, including Markov Chain Monte Carlo (MCMC) methods.

MA 485 Applied Linear Regression 4R-0L-4C W (odd years)

Prerequisites: MA 221F,W,S, and either MA 223F,W,S or MA 382F

Corequisites: There are no corequisites for this course.

This is an applied course in multiple linear regression. The techniques presented, all with respect to linear models, develop skills in selecting an appropriate model and performing statistical inference. The use of data from a variety of fields helps demonstrate method implementation and the communication of results in practice. A statistical programming language aids in creating reproducible analysis results.

MA 487 Design of Experiments 4R-0L-4C W (even years)

Prerequisites: MA 223F,W,S or MA 382F

Corequisites: There are no corequisites for this course.

This is an applied course in design of experiments. Emphasis is placed on designing statistical studies to solve problems in engineering and science. A variety of designs are presented, including the full factorial, screening, response surface, and split plot. It is demonstrated how constraints on the randomization process due to the design are related to the appropriate analysis method and meaning of the results. Statistical software is used for data analysis throughout.

MA 490 Topics in Mathematics Variable credit

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

This course will cover advanced topics in mathematics not offered in listed courses.

MA 491 Introduction to Mathematical Modeling 2C F

Prerequisites: Senior Standing or permission of the instructor

Corequisites: There are no corequisites for this course.

An introduction to the process of mathematically modeling a problem, including data collection, defining the appropriate mathematical model and interpreting the results of the proposed model. Emphasis placed on the modeling process, using examples from both continuous and discrete mathematics.

MA 495 Research Project in Mathematics Variable Credit

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

An undergraduate research project in mathematics or the application of mathematics to other areas. Students may work independently or in teams as determined by the instructor. Though the instructor will offer appropriate guidance in the conduct of the research, students will be expected to perform independent work and collaborative work if on a team. The course may be taken more than once provided that the research or project is different.

MA 496 Senior Capstone I 2C or 4C See Department

Prerequisites: Senior Standing or permission of the instructor

Corequisites: There are no corequisites for this course.

Individual study and research of a topic in mathematics. Topic is expected to be at an advanced level.

MA 497 Senior Capstone II 2C See Department

Prerequisites: MA 496See Department or permission of instructor

Corequisites: There are no corequisites for this course.

Individual study and research of a topic in mathematics. Topic is expected to be at an advanced level.

MA 498 Senior Capstone III 2C See Department

Prerequisites: MA 497See Department or permission of instructor

Corequisites: There are no corequisites for this course.

Individual study and research of a topic in mathematics. Topic is expected to be at an advanced level.

MA 538 Advanced Engineering Mathematics 4R-0L-4C W

Prerequisites: Graduate standing

Corequisites: There are no corequisites for this course.

A fast-paced course in advanced applied mathematics for graduate-level engineering students. Applied linear algebra, including abstract vector spaces, linear operators, eigentheory, diagonalization, and the matrix exponential; review of partial differentiation and multiple integration, including Lagrange multipliers and other optimization topics; vector analysis, including the Jacobian matrix, the del operator in standard coordinate systems, and line integrals; and Fourier series with application to the solution of partial differential equation boundary value problems. Students may not receive credit for both MA438 and MA538.

MA 580 Topics in Advanced Probability Theory & Its Applications 4R-0L-4C Arranged

Prerequisites: MA 381F,W,S

Corequisites: There are no corequisites for this course.

Advanced topics in probability theory as well as applications that are not offered in the listed courses.

MA 581 Topics in Advanced Statistics 4R-0L-4C Arranged

Prerequisites: MA 223F,W,S or MA 381F,W,S Consent of instructor

Corequisites: There are no corequisites for this course.

This course will cover advanced topics in mathematical statistics as well as applied statistics that are not offered in the listed courses.

MA 590 Graduate Topics in Mathematics Variable Credit

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

This course will cover graduate-level topics in mathematics not offered in listed courses.

Mechanical Engineering

Mechanical engineering is a broad field of endeavor with opportunities in many areas of industry: production and manufacturing; aeronautics and aerospace; robotics and automation; conventional and renewable energy; automotive and transportation; and many others. Additional opportunities for mechanical engineers include careers in government, education, and private consulting. The mechanical engineering curriculum is designed to prepare students for this wide range of options by providing them with a strong foundation in the fundamental principles of science and engineering to tackle the complex technological problems of today and adapt for the challenges of tomorrow.

The required courses of the undergraduate mechanical engineering curriculum provide the basic mathematical and scientific fundamentals underlying the practice of mechanical engineering. Technical, free, and math/science elective courses allow the student flexibility in adapting the program to their interests in pursuit of their specific career goals. Electives in the humanities, social sciences, and the arts help to foster the links between society and engineering so that the mechanical engineering graduate is aware of the roles of engineering and science in solving complex technological and social problems as well as of the impacts of social and environmental factors on engineering activities such as design. For those undergraduates who choose to continue their education at Rose-Hulman, graduate work leading to a Master of Science in Mechanical Engineering or a Master of Engineering in Mechanical Engineering is offered by the department.

Mission: To provide the curriculum, the educational environment, and the individual support necessary to graduate mechanical engineers who are technically competent, effective in practice, creative, ethical, and mindful of their responsibility to society.

Vision: To graduate the best baccalaureate mechanical engineers.

Mechanical Engineering Program Educational Objectives and Student Outcomes

Program Educational Objectives

The mechanical engineering curriculum aims to prepare students for productive careers in industry, government, education, and private consulting, as well as for graduate study. By providing a strong foundation in the fundamental principles of science and engineering and by illuminating the links between society and engineering, the curriculum enables students to apply what they have learned and to teach themselves new skills to address complex technological problems within the social and environmental context of our world. Thus, within a few years of graduation, we expect our graduates to attain the following educational objectives, which are based on the needs of our constituencies:

1. Our alumni will be successful in their careers.
2. Our alumni set and meet their own goals for career fulfillment.
3. Our alumni will continue professional development.
4. Our alumni will be cognizant of the international dimensions of their profession.

Student Outcomes

Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the skills, knowledge, and behaviors that students acquire as they progress through the program. We expect our graduates to have the ability to:

1. Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. 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. Communicate effectively with a range of audiences.
4. 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. Function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
6. Develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusion.
7. Acquire and apply new knowledge as needed, using appropriate learning strategies.

The mechanical engineering program is accredited by the Engineering Accreditation Commission of ABET, https://www.abet.org, under the commission's General Criteria and Program Criteria for Mechanical and Similarly Named Engineering Programs.

Summary of degree requirements

The freshman year of the mechanical engineering program includes courses in mathematics and foundational sciences, as well as introductory courses in engineering and design. Foundational sciences include physics, biology, and chemistry. The sophomore year features courses in mathematics, foundational sciences, and the engineering sciences. The final two years of the program stress the design and analysis of systems, machines and their components, and the transfer and transformation of energy. In addition to the required mathematics, science, and engineering courses, the program includes required writing and communication courses and an array of technical electives and free electives, a math/science elective, and elective courses in the humanities, social sciences, and the arts (HSSA). The requirements for an undergraduate degree in mechanical engineering are summarized in the following table:

Category	Credits
Required engineering (ME, ES, EM) courses	86
Required math courses	27
Required foundational science courses	16
Required HSSA writing and communication courses	8
Required RHIT 100 course	1
Technical electives	16
Free electives	8

Math/science elective	4
HSSA electives	28
Total	**194**

Minor in Manufacturing Engineering

The goal of this minor is to provide interested students with an opportunity to broaden their knowledge of the methods, processes and technologies related to the analysis and design of manufacturing systems.

At the completion of this minor, students will be able to:

1. Describe methods, processes and /or technologies used in manufacturing.
2. Identify, formulate, and solve problems in the area of manufacturing.
3. Analyze and design manufacturing technologies and systems within reasonable constraints such as economic, manufacturability, sustainability and environmental by applying appropriate theories and methods.
4. Communicate effectively about manufacturing engineering problem solutions, technologies, and system designs.
5. Describe interactions between humans and systems in the workplace.

Requirements

To earn the Minor in Manufacturing Engineering, a student must complete 28 credit hours according to the guidelines shown below.

Core Course (4 credits)

Select one from the following list of two courses:

- ME 317 Design for Manufacturing or
- EngD 260 Product Design Studio

Manufacturing Electives (16-20 credits)

Select 16 - 20 credit hours (4-5 courses) from the following list of manufacturing elective courses:

- EMGT 330 Introduction to Engineering Management
- EMGT 524 Production/Operations Management
- EMGT 427 Project Management
- EMGT 445 Quality Methods
- EMGT 446 Statistical Methods in Six Sigma
- EMGT 588 Quality Management
- EMGT 589 Manufacturing Systems
- EMGT 570 Lean Six Sigma
- ME 412 Lean Manufacturing
- ME 435 Robotics
- ME 517 Mechanics of Metal Forming
- ME 520 Computer Aided Design and Manufacturing
- EMGT 538 Product Realization
- EMGT 540 Human Factors

- EMGT 541 Work Analysis and Design
- EM 304 Advanced CAD – Professional Certification
- EM 305 Advanced CAD – Parametric and Equation Driven Design

HSSA Electives (4-8 credits)

Select 4 - 8 credit hours (1-2 courses) from the following HSSA courses:

- ECON S151 Introduction to Microeconomics
- ECON S152 Introduction to Macroeconomics
- PSYC S100 Introduction to Psychology
- PSYC S220 Social Psychology
- ECON S253 Managerial Economics
- ECON S352 Corporate Finance

Minor in Thermal-Fluids*

To complete the requirements of the Minor in Thermal-Fluids, a student must fulfill the following three expectations:

(1) Completion of a set of 2 courses covering basic fluid mechanics and basic thermodynamics. These are commonly required for most engineering majors. Acceptable sets include:

- ES 201 Conservation & Accounting Principles
  ES 212 Fluid Systems
  or
- CE 205 Thermodynamics
  EM 301 Fluid Mechanics
  or
- CHE 201 Conservation Principles & Balances
  CHE 301 Fluid Mechanics

(2) One of the following foundational prerequisites.

- ME 301 Applications of Thermodynamics
- CHE 303 Chemical Engineering Thermodynamics
- ME 302 Heat Transfer
- CHE 320 Fundamentals of Heat and Mass Transfer

(3) Three of the thermal-fluids electives listed below.
Thermal-Fluid Systems

- ME 408 Renewable Energy
- ME 410 Internal Combustion Engines
- ME 411 Propulsion Systems
- ME 426 Turbomachinery

Thermal-Fluid Sciences

- ME 401 Foundations of Fluid Mechanics

- ME 405 Theoretical Aerodynamics
- ME 427 Introduction to Computational Fluid Dynamics
- ME 450 Combustion
- ME 510 Gas Dynamics

Successful completion of a minor is indicated on the student's transcript. A student interested in pursuing the Minor in Thermal-Fluids should consult with the head of the Department of Mechanical Engineering.

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* ME Majors do **not** qualify for the Minor in Thermal-Fluids, but may pursue ME areas of concentration.

Areas of Concentration

Students who complete recommended courses in an area of concentration may receive, upon request, a letter from the Department Head attesting to the fact that the student has completed the requirements in the selected area of concentration in the Mechanical Engineering Department. With proper planning, students should be able to take these course offerings without overload. Students may add special topics courses or new courses not yet listed in the catalog to the list of acceptable courses for a concentration with written permission from the mechanical engineering department head.

Automotive Area of Concentration
Automotive Engineering is a very broad field covering many topics including system modeling, combustion, electrification, autonomous driving, materials, and virtual design. To help prepare for a career in this field, the Automotive Concentration is offered. One required and four elective courses are necessary, allowing students to gain either breadth or depth according to their interests.

Required Course:

- ME 359 Vehicle System Modeling

Elective Courses (choose any four):

- CSSE 461 Computer Vision
- CSSE 463 Image Recognition
- EM 402 Three Dimensional Dynamics
- EM 403 Advanced Mechanics of Materials
- MA 416 Deep Learning
- ME 401 Foundations of Fluid Mechanics
- ME 406 Control Systems
- ME 408 Renewable Energy
- ME 410 Internal Combustion Engines
- ME 422 Finite Elements for Engineering Applications
- ME 423 Fatigue
- ME 424 Mechanics of Composites
- ME 427 Introduction to Computational Fluid Dynamics
- ME 450 Combustion
- ME 506 Advanced Control Systems

- ME 522 Advanced Finite Element Analysis
- OE 450 Laser Systems & Applications
- PH 470 Automotive Lighting

Aerospace Engineering Area of Concentration

The aerospace industry provides job opportunities each year for many mechanical engineering graduates. The aerospace engineering area of concentration is intended to provide specialty courses which focus the application of basic mechanical engineering skills to aerospace systems.

The courses required to complete the concentration are as follows:

- ME 305 Introduction to Aerospace Engineering
- Plus any 4 of the following:
  - ME 401 Foundations of Fluid Mechanics
  - ME 405 Theoretical Aerodynamics
  - ME 410 Internal Combustion Engines
  - ME 411 Propulsion Systems
  - ME 422 Finite Elements for Engineering Applications
  - ME 426 Turbomachinery
  - ME 427 Introduction to Computational Fluid Dynamics
  - ME 461 Aerospace Design
  - ME 510 Gas Dynamics
  - ME 522 Advanced Finite Element Analysis
  - EM 402 Three-Dimensional Dynamics
  - EM 403 Advanced Mechanics of Materials
  - MA 336 Boundary Value Problems
  - MA 438 Advanced Engineering Mathematics
  - PH 322 Celestial Mechanics

CAD Area of Concentration

The CAD Concentration is intended to prepare students for careers with a focus in computer-aided design and analysis. The Concentration is divided into two sets of courses: Design and Analysis. The Design courses provide students with expertise in the use of modern Computer-Aided Design tools to model three-dimensional shapes and to communicate these designs graphically. The Analysis courses explore the mathematics behind modern CAD tools, giving students a solid background in computer-aided kinematics and finite element analysis.

To earn the CAD Concentration, students must complete the following three Design classes:

- EM104 Graphical Communication or ENGD100 Design and Communication Studio or BE118 Design Thinking and Communication
- EM304 Advanced CAD – Professional Certification
- EM305 Advanced CAD – Parametric and Equation Driven Design

In addition, students must choose three Analysis courses from the following list

- ME422 Finite Elements for Engineering Applications
- ME522 Advanced Finite Element Analysis
- ME304 Introduction to the Design of Mechanisms

- ME404 Advanced Design of Mechanisms
- ME480 Machine Component Design (for non-ME majors)

Dynamic Systems & Control Area of Concentration
Mechanical engineering graduates may work in industries, such as the automotive and aerospace industries, in which the understanding and control of a system's dynamic response is critical. The dynamic systems & control concentration provides students with experiences in modeling, analysis, and simulation of the dynamic behavior of systems with and without feedback control, as well as opportunities to explore data collection for vibratory systems and control algorithm implementation in a laboratory setting.

To complete the requirements of the area of concentration in Dynamics Systems & Control, students must complete five courses from this list:

- EM 402 Three-Dimensional Dynamics
- EM 406 Vibration Analysis
- EM 502 Advanced Dynamics
- EM 503 Advanced Vibration Analysis
- ME 304 Introduction to the Design of Mechanisms
- ME 404 Advanced Design of Mechanisms
- ME 406 Control Systems
- ME 441 Advanced Modeling and Simulation Techniques
- ME 445 Robot Dynamics and Control
- ME 506 Advanced Control Systems
- PH 322 Celestial Mechanics

Thermal Fluid Area of Concentration
The Thermal Fluid concentration is designed to prepare students for careers with a focus on thermodynamics, fluid dynamics, and heat transfer. The concentration comprises two balanced areas of study: thermal fluid systems (with an emphasis on applications) and thermal fluid sciences (with an emphasis on fundamentals). They equip students with astrong foundation to analyze and design thermal fluid systems. Emerging global challenges such as climate change, sustainable energy, and water resources call for creative solutions within the constraints of fundamental physical principles. The Thermal Fluid concentration plays an active and crucial role in the broad discipline of mechanical engineering.

To complete the requirements of the area of concentration in Thermal Fluid, students must complete:

- ME 401 Foundations of Fluid Mechanics

and 4 more courses from the following two areas (with at least one course from each area):

Area 1: Thermal Fluid Systems

- ME 408 Renewable Energy
- ME 410 Internal Combustion Engines
- ME 411 Propulsion Systems
- ME 426 Turbomachinery

Area 2: Thermal Fluid Sciences

- ME 405 Theoretical Aerodynamics
- ME 427 Introduction to Computational Fluid Dynamics
- ME 450 Combustion
- ME 510 Gas Dynamics

Minor in Mechanical Engineering

The goal of the minor in Mechanical Engineering is to give students a broad understanding of mechanical engineering beyond what would normally be obtained in and denoted by their major. The minor consists of required and elective courses, totaling 26 or 28 credits depending on the student's major. The distribution of required and elective courses also depends on the student's major, as detailed in the lists below. Students with more than one major should consult the ME department head to create an appropriate ME minor.

Elective courses must be selected from approved required or elective courses with an ME/ES/EM prefix taught by the ME faculty. These elective courses must be listed explicitly on the minor declaration form for approval BEFORE completing the courses. Guidance on what might constitute acceptable and unacceptable courses for the minor is available on the ME advising resources page on my.rose-hulman.edu. There is no guarantee that courses completed before formal declaration and approval will count towards the minor.

ME Minor for Electrical Engineering or Computer Engineering students (26 credits total)

Required: EM104, EM121, ES201, ES212 or ES214, ME317
Electives: 8 credits
Not Allowed: ME123, EM103, ME430, ME406

ME Minor for Mathematics, Biomathematics, Biology, Computer Science, or Software Engineering students (28 credits total)

Required: EM104, EM103, EM121, ES201, ES212 or ES214, ME317
Electives: 8 credits
Not Allowed: ME123
Note that Biology students must select "math sequence 2 – modeling focus" as their math sequence

ME Minor for Chemistry students and Biochemistry and Molecular Biology students (28 credits total)

Required: EM104, EM103, EM121, ME123, ES201, ES212 or ES214, ME317
Electives: 4 credits
Not allowed: None

ME Minor for Chemical Engineering students (26 credits total)

Required: EM104, EM121, ES214, ME317
Electives: 12 credits
Not Allowed: ME123, EM103, ES201, ME406

ME Minor for Civil Engineering students (26 credits total)

Required: EM104, ME123, ME317
Electives: 16 credits
Not Allowed: EM121, EM103, ES201, ES212, ES214, EM204

ME Minor for Engineering Design and Biomedical Engineering students (28 credits total)

Required: ES212, ES214, ES205
Electives: 16 credits
Not Allowed: EM104, EM121, ME123, EM103, ES201, EM204, ME317

ME Minor for Optical Engineering and NanoEngineering students (28 credits total)

Required: EM121, ES201, ME317
Electives: 16 credits
Not Allowed: EM104, ME123, EM103

ME Minor for Physics students (26 credits total)

Required: EM103, EM121, ES201, ME317
Electives: 12 credits
Not Allowed: EM104, ME123, EM103
Physics students must choose BE100 or CSSE120 or ME123 for their computing elective

The mechanical engineering program is accredited by the Engineering Accreditation Commission of ABET,www.abet.org

Plan of Study

Freshman

Fall

Course	Credit
MA 111 Calculus I	5
Foundational Science* (PH 111)	4
RHIT 100 Foundations for Rose-Hulman Success	1
EM 104 Graphical Communications	2
HUM H190 First-Year Writing Seminar or HSSA Elective	4

	Total Credits: 16

Winter

Course	Credit
MA 112 Calculus II	5
Foundational Science* (PH 112)	4
EM 121 Statics & Mechanics of Materials I	4
HUM H190 First-Year Writing Seminar or HSSA Elective	4
	Total Credits: 17

Spring

Course	Credit
MA 113 Calculus III	5
Foundational Science* (CHEM111 or BIO101)	4
EM 103 Introduction to Design	2
ME 123 Computer Applications I	4
	Total Credits: 15

Sophomore

Fall

Course	Credit
MA 221 Matrix Algebra and Differential Equations I	4
ES 201 Conservation & Accounting Principles	4
ES 213 Electrical Systems	3
ES 213L Electrical Systems Lab	1
Foundational Science* (BIO101 or CHEM111)	4
	Total Credits: 16

Winter

Course	Credit
MA 222 Matrix Algebra and Differential Equations II	4
ES 212 Fluid Systems	4
ES 214 Mechanical Systems	4
HSSA Elective	4

	Total Credits: 16

Spring

Course	Credit
MA 223 Statistics for Engineers	4
ES 205 Analysis & Design of Engineering Systems	4
Math/Science Elective**	4
HSSA Elective	4
	Total Credits: 16

Junior

Fall

Course	Credit
ME 301 Applications of Thermodynamics	4
EM 204 Statics & Mechanics of Materials II	4
ME406 Control Systems or EM 406 Vibration Analysis	4
Free Elective**	4
	Total Credits: 16

Winter

Course	Credit
ME 317 Design for Manufacturing	4
ME 327 Numerical Methods in Engineering Analysis or ME 321 Measurement Systems	4
ME 328 Materials Engineering	4
ENGL H290 Technical Communications split winter or spring with HSSA Elective	4
	Total Credits: 16

Spring

Course	Credit
ME 302 Heat Transfer	4
ME 321 Measurement Systems or ME 327 Numerical Methods in Engineering Analysis	4
ME 480 Machine Component Design	4

HSSA Elective split winter or spring with ENGL H290 Technical Communications	4
	Total Credits: 16

Senior

Fall

Course	Credit
ME 470 Capstone Design I	4
ME 421 Lab or ME 430 Mechatronic Systems	2
HSSA Elective	4
Tech Elective**	4
Tech Elective**	4
	Total Credits: 18

Winter

Course	Credit
ME 471 Capstone Design II	4
ME 430 Mechatronic Systems or ME 421 Lab	4
HSSA Elective	4
Free Elective**	4
	Total Credits: 16

Spring

Course	Credit
ME 472 Capstone Design III	4
Tech Elective**	4
Tech Elective**	4
HSSA Elective	4
	Total Credits: 16

NOTES:

*Students must complete four foundational science classes, one in Biology (BIO101 or BIO110 or BIO120 or BIO130), two in Physics (PH111 and PH112), and one in Chemistry (CHEM111). All foundational science classes have a laboratory component.

28 credit hours in electives composed of 16 credit hours in technical electives, 8 credit hours in free electives, and 4 credit hours of a math elective or a science elective. A **technical elective is any course (at the 200 level or above) in biomathematics, chemistry, computer science, engineering, engineering management, geology, mathematics, or physics that is not cross-listed with HSSA or similar in content to a required course. A **math elective** is at the 200-level or higher and has an MA or BMTH prefix. A **science elective** is any course in biology, chemistry, geology, or physics except those courses that are cross-listed with an engineering course.

Mechanical Engineering - Course Descriptions

ME 123 Computer Programming 4R-0L-4C F,W,S
Prerequisites: ME/PHOE major or permission of instructor
Corequisites: There are no corequisites for this course.
Software tools and engineering processes for mechanical engineers. Topics may include: structured programming (Matlab), simulation of rigid body motion, presentation software, and spreadsheets. Introduction to teaming and creativity.

ME 193 Selected Topics in Design Hours as assigned. Maximum 4 credits per term. See Department
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Selected student design projects. May include testing and/or computer aided design.

ME 199 Professional Experience 1R-0L-1C See Department
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

ME 293 Selected Topics in Design Hours as assigned. Maximum 4 credits per term. See Department
Prerequisites: Sophomore class standing
Corequisites: There are no corequisites for this course.
Selected student design projects. May include testing and/or computer aided design.

ME 301 Applications of Thermodynamics 4R-0L-4C F,W
Prerequisites: ES 201F,W* or CE 205F *With a grade of C or better
Corequisites: There are no corequisites for this course.
Extend the conservation and accounting framework to examine energy-conversion systems. Topics include thermodynamic properties of pure substances, gas mixtures, exergy analyses, power and refrigeration cycles, psychrometric processes, combustion, and propulsion.

ME 302 Heat Transfer 4R-0L-4C S,F
Prerequisites: ES 212W,S or CHE 301F,S or EM 301S, and MA 222F,W,S
Corequisites: There are no corequisites for this course.
Introduces the basic modes of heat transfer, heat transfer properties, steady and unsteady one-dimensional heat conduction, free and forced convection, radiation and heat exchangers. Other topics may include numerical methods and boiling and condensation.

ME 304 Introduction to the Design of Mechanisms 4R-0L-4C W
Prerequisites: ME 123F,W,S or ENGD 120S or CSSE 120F,W,S or BE 100F
Corequisites: There are no corequisites for this course.

This course will cover a set of computational tools to design and analyze mechanisms to achieve specific goals. The specific focus of this course is to study kinematics (study of motion without regards to forces) of a mechanism. Students learn how to model and solve for the position, velocity, acceleration of linkages using vectors. They also study the kinematics of gear trains and specifically, planetary gear trains.

ME 305 Introduction to Aerospace Engineering 4R-0L-4C S

Prerequisites: ES 212W,S

Corequisites: There are no corequisites for this course.

Application of fundamental engineering concepts to aerospace systems. Aircraft performance and stability. Physical properties of the standard atmosphere. Aerodynamics of the airplane including lift, drag and pitching moment estimation. Introduction to orbital mechanics.

ME 317 Design for Manufacturing 4R-0L-4C W

Prerequisites: EM 104F

Corequisites: There are no corequisites for this course.

This is an introductory course that examines the interactions between design and manufacturing from the designer's point of view. Common manufacturing processes will be introduced and design guidelines will be developed for each process. The successful student will leave this class with an appreciation that a designer must consider the method of manufacture during the design process to ensure that a product is functional, economically viable, and safe.

ME 318 Material Processing in Manufacturing 4R-0L-4C Not Offered

Prerequisites: ME 328W

Corequisites: There are no corequisites for this course.

An introductory course in the control of the properties of materials during manufacturing. Covers the interrelationship between material properties and the principal manufacturing processes like hot and cold working, casting, welding, heat treating and machining. Emphasizes the importance of considering manufacturability when making material selection decisions in design.

ME 321 Measurement Systems 3R-3L-4C W,S

Prerequisites: EM 103S, and ES 205S,F, and MA 223F,W,S

Corequisites: There are no corequisites for this course.

Fundamentals of measurement systems in mechanical engineering including transducer operation, signal conditioning, data reduction, and presentation of results. Transducer and measurement system characteristics including resolution, sensitivity, loading, time response, and frequency response. Operating principles of basic instrumentation for measurement of mechanical quantities such as force, torque, pressure, temperature, and flow. Topics include uncertainty analysis, data analysis, calibration, data acquisition, presentation of results, and an introduction to experiment design.

ME 323 Numerical Methods in Engineering 1R-3L-2C W,S

Prerequisites: ME 123F,W,S or CSSE 120F,W,S

Corequisites: There are no corequisites for this course.

Engineering problems often lead to analytically intractable equations. This course combines structured programming and applied numerical methods to obtain approximate engineering solutions. Strategies include root finding, numerical integration, finite difference, initial value and boundary value problems. Matlab is used as the programming language for solving iterative problems numerically.

ME 327 Numerical Methods of Engineering Analysis 3R-3L-4C W,S

Prerequisites: ME 123F,W,S or BE 100F or CSSE 120F,W,S, and MA 222F,W,S
Corequisites: There are no corequisites for this course.
This is an inter-disciplinary course focusing on the generation and interpretation of numerical solutions and the processing of numerical data for engineering problems. Topics include approximate solutions to nonlinear algebraic and differential equations, initial and boundary value problems, numerical integration and differentiation, optimization, data conditioning, and regression analysis. Trade-offs between accuracy and cost are emphasized. Matlab is used as the programming language.

ME 328 Materials Engineering 4R-0L-4C W
Prerequisites: CHEM 111F,W,S
Corequisites: There are no corequisites for this course.
Introduces properties of metals, ceramics, polymers, and composites. Relates material processing to properties through underlying material structure. Overviews the materials available to engineers and discusses applications and material selection.

ME 359 Vehicle System Modeling 4R-0L-4C F
Prerequisites: ES 201F,W
Corequisites: There are no corequisites for this course.
Excel and Simulink are used to create reactive and predictive models of vehicle powertrains, both electric and internal combustion. Drive cycles are introduced, the powertrains are iteratively refined, and insightful observations are made with respect to vehicle performance. The course concludes with modeling a vehicle of the student's choosing.

ME 380 Creative Design 4R-0L-4C See Department
Prerequisites: Permission of instructor
Corequisites: There are no corequisites for this course.
Emphasis on the creative process in engineering design. Students will develop their design capability by exploring various conceptual blocks, using creative enhancement techniques and participating in on-the-spot design.

ME 393 Selected Topics in Design As assigned. Maximum 4 credits per term. See Department
Prerequisites: Junior class standing
Corequisites: There are no corequisites for this course.
Selected student design projects. May include testing and/or computer aided design.

ME 397 Special Topics in Mechanical Engineering 4R-0L-4C See Department
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Topics of current interest in mechanical engineering at the 300-level.

ME 401 Foundations of Fluid Mechanics 4R-0L-4C SeeDept
Prerequisites: ES 212W,S or EM 301S, and MA 222F,W,S
Corequisites: There are no corequisites for this course.
Covers the fundamental concepts of fluid dynamics with an emphasis on physical understanding. Topics include fluid kinematics, control-volume and differential analyses of fluid motion, similitude, potential flow, vorticity transport, low Reynolds number flow, boundary-layer physics, stability of laminar flow, and turbulent transport. Topics may be added or deleted as needed.

ME 402 Advanced Heat Transfer 4R-0L-4C See Department
Prerequisites: ME 302S,F

Corequisites: There are no corequisites for this course.
This course covers additional topics in conduction, convection and radiation heat transfer as well as an introduction to mass transfer, phase change and numerical methods.

ME 404 Advanced Design of Mechanisms 4R-0L-4C F

Prerequisites: ME 304W, and either ES 201F,W or ENGD 215S or BE 132S
Corequisites: There are no corequisites for this course.
This course will cover some intermediate topics in the design of mechanisms including position analysis of three, four, five and sixbar linkages, cam analysis and design, including motion of the cam/follower system, the method of constraints in kinematics, and velocity, acceleration and force analysis using the method of constraints. The method of virtual work will be used to conduct force analysis for the inverse dynamic problem. Extensive use will be made of MATLAB (or similar software) for plotting and animating solutions to mechanism design problems.

ME 405 Theoretical Aerodynamics 4R-0L-4C W

Prerequisites: ES 212W,S
Corequisites: There are no corequisites for this course.
Introduction to aerodynamics theory. Development of equations of conservation of mass and momentum. Vorticity, induced velocity and irrotational flow. Stream function, velocity potential, Laplace's equation and the principle of superposition. Flow about a body, the Kutta-Joukowski Theorem. Concepts of thin airfoil and finite wing theory. Exact solutions to elementary viscous flow problems.

ME 406 Control Systems 3R-3L-4C F

Prerequisites: ES 205S,F
Corequisites: There are no corequisites for this course.
Basic principles of feedback control theory. Mathematical modeling and performance analysis of dynamical systems. Includes stability analysis, root locus compensation and design, frequency response analysis. Implementation of control system analysis and design is gained with several laboratory experiences.

ME 407 Power Plants 4R-0L-4C See Department

Prerequisites: ME 301F,W
Corequisites: There are no corequisites for this course.
Steam, cogeneration and combined cycles are studied with the aid of property software. Various components of the cycles are studied in detail. A survey of alternative power sources is presented. Tours of power plants are taken when available.

ME 408 Renewable Energy 4R-0L-4C W

Prerequisites: ES 212W,S or equivalent
Corequisites: There are no corequisites for this course.
Covers renewable energy sources such as solar heating and cooling, wind energy, biomass, and photovoltaic energy. Surveys the energy availability of these sources and life cycle cost and present value used to evaluate the system. Students will design a system which utilizes a renewable energy source and economically evaluate the system.

ME 409 Air Conditioning 4R-0L-4C See Department

Prerequisites: ES 212W,S, and ME 302S,F
Corequisites: There are no corequisites for this course.
Human comfort and the properties of air. Air conditioning in residences, public and industrial buildings using vapor compression and absorption units. Cooling loads,

psychrometry, fans, duct sizing and layout, automatic control, and acoustic design considerations.

ME 410 Internal Combustion Engines 4R-0L-4C F

Prerequisites: ES 212W,S or CHE 301F,S

Corequisites: There are no corequisites for this course.

Study of spark ignition and compression ignition engines. Influences of engine design features on performance, economy, and air pollution. Influence of the combustion process, carburetion, fuel injection and ignition characteristics on engine operation.

ME 411 Propulsion Systems 4R-0L-4C S

Prerequisites: ME 301F,W

Corequisites: There are no corequisites for this course.

Application of basic principles in the study of the performance characteristics of air and space vehicles. Aerodynamics of steady one dimensional isentropic compressible flow. Shock waves, gas turbines, turbojet, turbofan, turboprop, turboshaft, ram jet, rocket, nuclear propulsion and space propulsion systems are discussed and compared.

ME 412 Lean Manufacturing 4R-0L-4C S

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

This course introduces students to lean manufacturing - the identification of value and elimination of waste in a manufacturing process. The course will feature frequent assigned reading and discussion as well as factory simulations, factory tours, and projects. Students will develop a fundamental understanding of lean principles and will be able to apply their knowledge in any profession.

ME 414 Materials Selection in Mechanical Design 4R-0L-4C See Department

Prerequisites: EM 204F, S

Corequisites: There are no corequisites for this course.

Introduces the Ashby approach to materials selection, a systematic method for choosing materials for applications based on design constraints, design objectives, and combinations of relevant materials properties. All classes of materials are considered, including metals, ceramics, polymers, and composites. The CES EduPack software is used extensively throughout the course. Project work is emphasized.

ME 415 Corrosion & Engineering Materials 4R-0L-4C Not Offered

Prerequisites: ME 328W or CHE 315F,S

Corequisites: There are no corequisites for this course.

Presents fundamentals of metallurgy and corrosion mechanisms in engineering metals. Discusses various classes of corrosion and methods of mitigating corrosion with emphasis on practical situations.

ME 416 Introduction to MEMS: Fabrication & Applications 3R-3L-4C S

Prerequisites: Junior or Senior standing

Corequisites: There are no corequisites for this course.

Properties of silicon wafers; wafer-level processes, surface and bulk micromachining, thin-film deposition, dry and wet etching, photolithography, process integration, simple actuators. Introduction to microfluidic systems. MEMS applications: capacitive accelerometer, cantilever and pressure sensor. Cross-listed with EP 410, ECE 416, and CHE 405.

ME 417 Advanced Materials Engineering 4R-0L-4C See Department

Prerequisites: ME 328W, and EM 203W or EM 204F, S

Corequisites: There are no corequisites for this course.
Fundamentals of deformation and fracture in metals, polymers, and ceramics with application to design. Emphasis on time-temperature dependence of polymers, brittle behavior of advanced ceramics, and the fracture mechanics approach to design of high strength and critical application materials.

ME 419 Advanced MEMS: Modeling & Packaging 3R-3L-4C F

Prerequisites: EP 410S or equivalent

Corequisites: There are no corequisites for this course.
Design process, modeling; analytical and numerical. Actuators; dynamics and thermal issues. Use of software for layout and simulation. Characterization and reliability of MEMS devices. Electrical interfacing and packaging of MEMS. Microsensors, microfluidic systems, applications in engineering, biology, chemistry, and physics.

ME 421 Mechanical Engineering Laboratory 0R-6L-2C F,W

Prerequisites: ME 321W,S, and ENGL H290F, W, S

Corequisites: There are no corequisites for this course.
Introduction to engineering experimentation, centered on an experimental project planned and executed by students. Uncertainty analysis, instrumentation systems, and statistical design of experiments. Emphasis on project on project planning and execution, developing a scope of work, interim deliverables, and reporting engineering results.

ME 422 Finite Elements for Engineering Applications 4R-0L-4C W

Prerequisites: EM 204F, S

Corequisites: There are no corequisites for this course.
Introduces finite element methodology from a strongly theoretical perspective. Emphasizes solving various 1D and 2D static, transient, and modal problem statements including trusses, beams, plane stress, plane strain, and axisymmetric models. Problems of interest similar to those found in Statics I and II, as well as Machine Component Design. Also assesses higher order bases, time stepping procedures, and iterative solvers. Utilizes Matlab and ANSYS for computational work. Upon completion of this class you should be “useful” to a Computer Aided Engineering group from both a theory and implementation standpoint.

ME 423 Fatigue 4R-0L-4C See Department

Prerequisites: EM 204F, S

Corequisites: There are no corequisites for this course.
Introduces modern methods in fatigue analysis and testing, with a focus on metal fatigue. Covers the stress-life approach, the strain-life approach, and crack growth analysis based on fracture mechanics.

ME 424 Mechanics of Composites 4R-0L-4C F

Prerequisites: EM 204F, S, and ME 328W

Corequisites: There are no corequisites for this course.
Introduction to the basic mechanical aspects of composite materials such as: types / classification of composites, micro and macro-mechanical models for material properties, stress/strain analysis, and the manufacturing or composites. Specific focus is given to fiber-reinforced composite materials. Project work is emphasized.

ME 425 Aerospace Engineering Laboratory 1R-3L-2C See Department

Prerequisites: ES 212W,S

Corequisites: There are no corequisites for this course.

Introduction to experiment planning and execution. Projects involve wind tunnel testing including measurement of forces and moments and flow visualization. Student organized and executed with direct faculty consultation. Emphasis on written presentation.

ME 426 Turbomachinery 4R-0L-4C See Department

Prerequisites: ES 205S,F

Corequisites: There are no corequisites for this course.

Introduces the theory and issues related to the design of axial and radial flow turbines, compressors and pumps. Euler's equation and vector diagrams are used to evaluate energy transfer and efficiency.

ME 427 Introduction to Computational Fluid Dynamics 3R-3L-4C S

Prerequisites: ES 212W,S, and ME 323W,S or ME 327W,S

Corequisites: There are no corequisites for this course.

Covers the key components of a CFD calculation: mesh generation, numerical algorithm and turbulence modeling. Survey of solution strategy includes both the finite volume and the finite difference methods. Issues on formal order of accuracy, dissipation, dispersion, stability and space-time coupling are discussed in detail. Both structured programs and commercial software will be used as vehicles in obtaining a CFD solution.

ME 428 Materials Research and Instrumentation 4R-0L-4C See Department

Prerequisites: CHEM 111F,W,S junior standing.

Corequisites: There are no corequisites for this course.

Introduces students to small scale manufacturing methods (deposition, lithography, and etching techniques) and instrumentation for probing these materials (scanning electron microscopy, x-ray diffraction, Raman spectroscopy, and profilometry). Electronic, magnetic, and optical properties are also discussed including (semi-conductivity, dielectric behavior, ferroelectricity, piezoelectricity, types of magnetism, and quantum dots). Students are expected to read journal articles throughout the course related to these topics and to conduct research in an area of interest in a small team.

ME 429 Experimental Fluid Mechanics 2R-6L-4C W

Prerequisites: ES 212W,S

Corequisites: There are no corequisites for this course.

An introduction to experimental methods used to study thermal/fluid phenomena. Techniques studied include pressure and force measurement, particle image velocimetry (PIV), laser-induced fluorescence (LIF), laser Doppler velocimetry (LDV), constant temperature/constant current hot-wire anemometry (CTA/CCA), and schlieren/ shadowgraph imaging. Focus is placed on understanding the comparative strengths and weaknesses of techniques in a variety of situations.

ME 430 Mechatronic Systems 3R-3L-4C F,W

Prerequisites: ME 123F,W,S or CSSE 120F,W,S or BE 100F or ENGD 120S, and ES 213S, and ES 213LS or ECE 203S, F or ENGD 120S or BE 131S

Corequisites: There are no corequisites for this course.

Applications of microprocessors and microcontrollers and digital electronics to the design and utilizations of embedded control systems in smart systems and products. Topics include Boolean logic and algebra, system hardware and software development, and interfacing for mechanical applications.

ME 435 Robotics Engineering 3R-3L-4C S

Prerequisites: ME 430F,W or ECE 230W,S

Corequisites: There are no corequisites for this course.

Interdisciplinary course in robotics focusing on communication, software development, kinematics, robot GUI design, sensing, control, and system integration. Labs in the course cover MATLAB GUI development with GUIDE, Denavit-Hartenberg parameters, Arduino programming, Arduino to Android communication, Android app development, and OpenCV4Android image recognition. Students in the course will program an Android + Arduino, 6-wheeled mobile robot with 5 DOF servo arm to participate in an outdoor GPS robotics challenge. Cross-listed with CSSE 435.

ME 441 Advanced Modeling and Simulation Techniques 4R-0L-4C S

Prerequisites: ES 205S,F

Corequisites: There are no corequisites for this course.

Covers cross-disciplinary system analysis, modeling, simulation, and control using specialized techniques. Systems to be investigated include linear mechanical, rotational mechanical, electrical, thermal, pneumatic, electro-magnetic, and combinations thereof. Bond graph method for modeling. System simulation and controller design using MATLAB and Simulink. Discussion of modeling, simulation, and control of nonlinear systems. Special topics may be added if time permits.

ME 445 Robot Dynamics and Control 4R-0L-4C W

Prerequisites: ME 406F or ECE 320W,S or BE 350W,S

Corequisites: There are no corequisites for this course.

This course introduces students to the basics of kinematic and dynamic modeling of serial manipulators. Students will also learn joint-space position control and gain familiarity with Cartesian-space control.

ME 447 Visualizing Data 4R-0L-4C Not Offered

Prerequisites: Junior class standing

Corequisites: There are no corequisites for this course.

The course is about creating truthful and compelling data visuals. We study elements of statistical analysis, programming in R, human perception, graphic design, and visual rhetoric and ethics. After successfully completing this course, students should be able to design effective and truthful data displays, credibly explain their design rationale, produce publication-quality visuals, and credibly critique a data display. Prior experience with R is not required.

ME 450 Combustion 4R-0L-4C S

Prerequisites: ME 301F,W or CHE 303F,S

Corequisites: There are no corequisites for this course.

Study of the thermodynamics and kinetics of combustion processes and the underlying chemical processes. Topics covered include deflagration and detonation waves, combustion of solid, liquid, and gaseous fuels, and environmental impacts of combustion. Laboratory experience via in-class, hands-on exercises.

ME 461 Aircraft Design 4R-0L-4C F

Prerequisites: ME 305S

Corequisites: There are no corequisites for this course.

Fundamentals of conceptual aircraft design. Aerodynamic analysis, design constraints based on customer requirements, mission profiles, aircraft sizing, optimization, and presentation of performance capabilities. Oral and written communication emphasized. Design teams.

ME 462 Thermal Design 4R-0L-4C See Department

Prerequisites: ES 212W,S, and ME 302S,F

Corequisites: There are no corequisites for this course.

Applications of the thermodynamic, heat transfer, and fluid flow principles to the modeling and design of thermal systems. These systems include pumps, fans, and heat and mass exchangers. A team project which includes the design, construction and testing of a fluid or thermal device or system provides the focus for the course.

ME 470 Capstone Design I 2R-3L-4C F,S

Prerequisites: ES 205S,F, and EM 204F, S, and ME 301F,W, and ME 480S,F (or concurrent registration), and Junior standing.

Corequisites: There are no corequisites for this course.

Students work in teams with three to five members on design projects furnished from clients. The emphasis is on creating design solutions, with appropriate analyses, to meet stakeholders' needs. In addition to regular meetings with their faculty advisors, the teams are expected to maintain close and continuous communications with their clients during the quarter. The ten week projects culminate in interim reports which are submitted to the clients.

ME 471 Capstone Design II 1R-4L-4C F,W

Prerequisites: ME 470F,S, and ME 480S,F

Corequisites: There are no corequisites for this course.

This course is a continuation of ME470. Students continue work in teams with three to five members developing the project started in ME470. The emphasis is on detailing design solutions identified in the first quarter. In addition to regular meetings with their faculty advisors, the teams are expected to maintain close and continuous communications with their clients during the quarter. The ten week projects culminate in interim reports which are submitted to the clients. This course is intended to be taken in the quarter immediately following ME470.

ME 472 Capstone Design III 1R-4L-4C W,S

Prerequisites: ME 471F,W

Corequisites: There are no corequisites for this course.

This course is a continuation of ME 471. The student teams test their prototype solutions and transfer the project results to their client. Continuous and regular communication with the outside clients, as well as with the faculty advisors, is expected. The course culminates with a final report that documents the design process. This course is intended to be taken in the quarter immediately following ME471.

ME 480 Machine Component Design 4R-0L-4C S,F

Prerequisites: EM 204F, S or BE 222W or EM 203W

Corequisites: There are no corequisites for this course.

Applications of fundamentals of engineering mechanics in analysis and synthesis of machine components and systems. Special emphases placed on stress/strength analyses and fatigue failures. Design of mechanical components and systems including threaded fasteners, springs, bearings, gears, shafts, clutches, brakes, belts, chains, and couplings.

ME 490 Directed Research As assigned. Maximum 4 credits per term. See Department

Prerequisites: Completion of freshman and sophomore course requirements and approval of adviser and course instructor

Corequisites: There are no corequisites for this course.

Selected projects for student research.

ME 491 Directed Research As assigned. Maximum 4 credits per term. See Department

Prerequisites: Completion of freshman and sophomore course requirements and approval of adviser and course instructor
Corequisites: There are no corequisites for this course.
Selected projects for student research.

ME 493 Selected Topics in Design Hours as assigned. Maximum 4 credits per term. See Department

Prerequisites: Senior class standing
Corequisites: There are no corequisites for this course.
Selected student design projects. May include testing and/or computer aided design.

ME 497 Special Topics in Mechanical Engineering 4R-0L-4C Arranged See Department

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Topics of current interests in mechanical engineering.

ME 501 Advanced Thermodynamics 4R-0L-4C See Department

Prerequisites: ME 301F,W or equivalent
Corequisites: There are no corequisites for this course.
Study of advanced thermodynamic topics: modeling of transient systems, exergy (availability) analysis, equations of state and thermodynamics relationships for simple, compressible substances.

ME 502 Topics in Heat Transfer 4R-0L-4C See Department

Prerequisites: ME 302S,F
Corequisites: There are no corequisites for this course.
Course may be repeated for different heat transfer topics.

ME 503 Viscous Fluid Flow 4R-0L-4C See Department

Prerequisites: ME 401SeeDept
Corequisites: There are no corequisites for this course.
Material and spatial descriptions of fluid motion. The Reynolds transport equation. The stress tensor and governing equations for the motion of viscous fluids. Newtonian fluids, the Navier-Stokes equations. Asymptotic solutions including fully developed channel flow, oscillating flat plate, wakes and jets. Introduction to boundary layers and turbulent flow including Reynolds averaging.

ME 505 Modeling & Simulation of Dynamic Systems 4R-0L-4C Not Offered

Prerequisites: ES 205S,F, and MA 222F,W,S
Corequisites: There are no corequisites for this course.
Modeling and simulation of engineering components and systems. Emphasis on a unified work-energy approach to modeling physical systems, model formulation using a differential-algebraic form of Lagrange's equation, and the numerical solution of the resulting initial-value problem. Applications are explored using modeling and simulation projects.

ME 506 Advanced Control Systems 4R-0L-4C See Department

Prerequisites: ME 406F or equivalent or consent of instructor
Corequisites: There are no corequisites for this course.
Physical models for control; system response, analysis and design. Time domain; system response, analysis and design. Frequency domain; state variable representation/description; stability, controllability, observability; linear quadratic regulator, pole-placement, state estimation/observers.

ME 507 Applied Nonlinear Control Systems 4R-0L-4C Not Offered
Prerequisites: ME 406F or equivalent or consent of instructor
Corequisites: There are no corequisites for this course.
Analysis and design of controls for inherently nonlinear systems and the use of nonlinear elements in design. Techniques for analysis and design include, stability by Liaqunov, describing functions, phase plane analysis, sliding control, adaptive control and control of multi-input systems.

ME 510 Gas Dynamics 4R-0L-4C F
Prerequisites: ES 212W,S
Corequisites: There are no corequisites for this course.
Introduction to the dynamics of a compressible flow. Equations of motion for subsonic and supersonic flow. Nozzle flow. Normal and oblique shock waves, Prandtl-Meyer flow. Steady and unsteady, one dimensional gas flow with friction and heat transfer.

ME 511 Numerical Methods for Dynamic Systems Analysis 4R-0L-4C Not Offered
Prerequisites: ES 205S,F, and ME 323W,S or ME 327W,S
Corequisites: There are no corequisites for this course.
Applications of approximate numerical solution techniques, including the finite element method, to the analysis of dynamic, continuous systems. Introduction to variational principles in mechanics for purposes of formulating governing equations of motion.

ME 512 Light Weight Structures 4R-0L-4C See Department
Prerequisites: MA 222F,W,S, and EM 203W or EM 204F, S
Corequisites: There are no corequisites for this course.
Applies the principles of mechanics to the structural analysis of mechanical and aerospace components. Covers stress tensors, shear flow in open and closed sections, beam columns, unsym-metrical bending. Castigliano's theorem, statically indeterminate structures , thin walled pressure vessels, introduction to elasticity.

ME 513 Environmental Noise 4R-0L-4C See Department
Prerequisites: Senior class standing
Corequisites: There are no corequisites for this course.
Introduces noise and its sources as a potential public health hazard. Covers the basics of sound propagation relating to noise measurement and analysis. Emphasizes effects on humans and the environment. Covers methods of noise and vibration control and abatement including absorption, enclosures, vibration isolation, damping, and mufflers. Team projects involving noise measurement and reduction are required.

ME 514 Materials Selection in Mechanical Design 4R-0L-4C See Department
Prerequisites: Graduate standing or permission of instructor.
Corequisites: There are no corequisites for this course.
Same as ME414, with the requirement that ME514 is only open to graduate students having a graduate project or thesis that the instructor agrees would benefit from the materials selection approach taught in ME414. Students enrolled in ME 514 must complete an experimental, computational, and/or theoretical project related to their graduate work that includes complexities not covered in ME414. Students may not receive credit for both ME414 and ME514.

ME 516 Introduction to MEMS: Fabrication & Applications 3R-3L-4C S
Prerequisites: Junior or Senior class standing
Corequisites: There are no corequisites for this course.
Properties of silicon wafers; wafer-level processes, surface and bulk micromachining, thin-film deposition, dry and wet etching, photolithography, process integration,

simple actuators. Introduction to microfluidic systems. MEMS applications: capacitive accelerometer, cantilever and pressure sensor. Cross-listed with EP 510, ECE 516, CHE 505, and BE 516.

ME 517 Mechanics of Metal Forming 4R-0L-4C See Department

Prerequisites: EM 204F, S

Corequisites: There are no corequisites for this course.

Fundamentals of plasticity, 2D and 3D stress and strain tensors, characteristics of yield surfaces, flow rules and constitutive relations for elasto-plastic materials. Modelling of metal forming processes using work balance, slab and upper bound analysis techniques. Friction in metal forming. The mechanics of bulk metal forming processes such as extrusion, sheet metal forming, stamping, rolling, drawing, and stretching. Design forming tool dies.

ME 518 Advanced Kinematics 4R-0L-4C Not Offered

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

Considers the analysis, design, and simulation of planar and spatial mechanisms. The mechanisms examined are parallel manipulators, serial manipulators, and compliant mechanisms. These mechanisms are analyzed for position, velocity, acceleration, and workspace. The techniques used for the analysis include vector approaches, homogeneous transformations, and dual number techniques.

ME 519 Advanced MEMS: Modeling & Packaging 3R-3L-4C F

Prerequisites: EP 410S or equivalent

Corequisites: There are no corequisites for this course.

Design process, modeling; analytical and numerical. Actuators; dynamics and thermal issues. Use of software for layout and simulation. Characterization and reliability of MEMS devices. Electrical interfacing and packaging of MEMS. Microsensors, microfluidic systems, applications in engineering, biology, chemistry, and physics. Cross-listed with ECE 519, EP 511, and CHE 519.

ME 520 Computer-Aided Design & Manufacturing (CAD/CAM) 4R-0L-4C S

Prerequisites: EM 104F and Senior class standing

Corequisites: There are no corequisites for this course.

Use and management of computer in engineering for drafting, design management, documentation, and manufacturing. Covers drafting methods and standards, design data management, CNC operations and implementation.

ME 522 Advanced Finite Element Analysis 4R-1L-4C S

Prerequisites: ME 422W

Corequisites: There are no corequisites for this course.

A continuation of ME 422. Includes multi-dimensional extensions of 2-D theory for transient, nonlinear problem statements in engineering. Utilizes Matlab and Ansys for developing and assessing FEA solutions to real world problems via theory developed in ME 422.

ME 523 Fatigue 4R-0L-4C See Department

Prerequisites: Permission of instructor.

Corequisites: There are no corequisites for this course.

Same as ME 423, with the additional requirement that students enrolled in ME 523 must complete an experimental, computational, and/or theoretical project including complexities not covered in ME 423. Students may not receive credit for both ME 423 and ME 523.

ME 524 Mechanics of Composites 4R-0L-4C F

Prerequisites: EM 204F, S, and ME 328W and graduate standing, or permission of instructor.
Corequisites: There are no corequisites for this course.
Same as ME 424 with the requirement that ME 524 is only open to graduate students. Students enrolled in ME 524 must complete an additional laboratory project in the course extending the principles developed in the course beyond what is directly covered during the course itself. Students may not receive credit for both ME 424 and ME 524.

ME 526 Turbomachinery 4R-0L-4C See Department

Prerequisites: ES 205S,F or equivalent, or permission of instructor
Corequisites: There are no corequisites for this course.
Introduces the theory and issues related to the design of axial and radial flow turbines, compressors and pumps. Euler's equation and vector diagrams are used to evaluate energy transfer and efficiency. Students enrolled in ME 526 must complete a design project including complexities not covered in ME 426. Students may not receive credit for both ME 426 and ME 526

ME 527 Computational Fluid Dynamics 3R-3L-4C S

Prerequisites: ES 212W,S, and ME 323W,S or ME 327W,S
Corequisites: There are no corequisites for this course.
Covers the key components of a CFD calculation: mesh generation, numerical algorithm and turbulence modeling. Survey of solution strategy includes both the finite volume and the finite difference methods. Issues on formal order of accuracy, dissipation, dispersion, stability and space-time coupling are discussed in detail. Both structured programs and commercial software will be used as vehicles in obtaining a CFD solution. Students enrolled in ME527 must complete a design project not covered in ME 427. Students may not receive credit for both ME 427 and ME 527.

ME 528 Materials Research and Instrumentation 4R-0L-4C See Department

Prerequisites: CHEM 111F,W,S graduate standing, or permission of instructor.
Corequisites: There are no corequisites for this course.
Same as ME 428 with the additional requirement that students enrolled in ME 528 must work individually on their research topic. The research topic must also be multifaceted requiring use of several of the instruments discussed during class. Students may not receive credit for both ME 428 and ME 528.

ME 536 Computational Intelligence in Control Engineering 4R-0L-4C See Department

Prerequisites: ME 406F or equivalent, or consent of instructor
Corequisites: There are no corequisites for this course.
Machine learning and adaptation applied to feedback control, guidance and navigation. Neural Networks for pattern recognition, modeling and control. Radial basis function model identification by recursive least squares. Fuzzy logic controllers. Genetic algorithm for optimization and turning of controllers including fuzzy logic control.

ME 541 Advanced Modeling and Simulation Techniques 4R-0L-4C S

Prerequisites: ES 205S,F
Corequisites: There are no corequisites for this course.
This course is the same as ME 441 with the addition of greater depth on modeling, simulation, and control of nonlinear systems. ME 541 students will also complete a course project not part of ME 441. Students may not receive credit for both ME 441 and ME 541.

ME 545 Robot Dynamics and Control 4R-0L-4C W

Prerequisites: ME 406F or ECE 320W,S or BE 350W,S graduate standing, or permission of instructor.
Corequisites: There are no corequisites for this course.
This course is the same as ME445 with the additional topic of orientation representation and greater depth on dynamic modeling. ME545 students will also complete a course project. Students may not receive credit for both ME445 and ME545.

ME 547 Visualizing Data 4R-0L-4C Not Offered

Prerequisites: Graduate standing and instructor consent.
Corequisites: There are no corequisites for this course.
Same as ME 447 with the added requirement that the course is open only to graduate students having a graduate project or thesis generating quantitative data that the course instructor has agreed meets the 500-level course objectives.

ME 550 Combustion 4R-0L-4C S

Prerequisites: ME 301F,W or CHE 303F,S
Corequisites: There are no corequisites for this course.
Study of the thermodynamics and kinetics of combustion processes and the underlying chemical processes. Topics covered include deflagration and detonation waves, combustion of solid, liquid, and gaseous fuels, and environmental impacts of combustion. Laboratory experience via in-class, hands-on exercises. Students enrolled in ME 550 must complete a design project not covered in ME 450. Students may not receive credit for both ME 450 and ME 550.

ME 590 Thesis Research As assigned See Department

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Credits as assigned; however, not more than 12 credits will be applied toward the requirements of an M.S. degree.

ME 597 Selected Topics for Graduate Students As assigned. Maximum 4 credits per term. See Department

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Topics arranged by instructor.

ME 699 Professional Experience 1R-0L-1C See Department

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The work experiences should be informative or integral to the advancement or completion of the student's program requirements. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

Optical Engineering

The science of light, once confined to research labs and science fiction novels, has found its way into our everyday lives. The applications of optics can be seen everywhere. A list of more common examples of these applications include laser printers, fiber optic communication, internet switches, fiber optic telephone lines, compact disc players, credit cards bearing holograms, grocery checkout scanners, computers and eye surgery. The field of optics is an enabling technology and is growing at a rapid pace. Optical techniques are found in a wide range of areas such as surveying and construction, measurements of material parameters and deformation, flow measurements, communications, machine vision, laser cutting, drilling and welding, data storage, internet switches, optical computers and sensors etc. Surveys show that there is a growing demand for optical designers/scientists/ engineers every year. Opportunities for graduates in Optical Engineering are available in many industries, including automated inspection, consumer electronics, fiber optic communications, optical instrumentation, laser devices, radar systems, data storage etc.

The Optical Engineering bachelor's degree program is one of the few in the country. This program provides a firm foundation for those interested in continuing thier studies in optics at the graduate level, as well as for those going into industry. The curriculum was developed by the faculty with input from industrial representatives as well as from renowned national and international optics educators. Because of the diverse applications of optics, the curriculum contains a mix of courses in physics and mathematics as well as humanities and social sciences. The Optical Engineering program at Rose-Hulman stresses laboratory instruction. We also encourage students to look at options for a double major, especially Optical Engineering with electrical, computer or mechanical engineering.

Students majoring in degree programs other than Optical Engineering are eligible to obtain an area minor in Optical Engineering.

The Department of Physics and Optical Engineering also offers an M.S. (Optical Engineering) degree. The masters level degree program complements the B.S. (Optical Engineering) degree program. Highly motivated students may obtain both a B.S. and an M.S. in Optical Engineering in a five-year period. A plan of study for this program must be approved by the end of the student's junior year.

You may view all information regarding Physics and Optical Engineering at our website: https://www.rose-hulman.edu/academics/academic-departments/physics-and-optical-engineering/index.html

Current Students should visit the POE page under the Academics section of My Rose-Hulman for additional information.

OE Program Educational Objectives

1. Our graduates will set their career path and advance beyond their entry-level position or progress toward the completion of an advanced degree.
2. Our graduates will make a positive impact on society.
3. Our graduates will behave ethically and act as responsible members of the engineering and science community.
4. Our graduates will continue to develop professionally

OE Student Learning Outcomes

Outcome 1:	An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

Outcome 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
Outcome 3:	An ability to communicate effectively with a range of audiences
Outcome 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
Outcome 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
Outcome 6:	An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
Outcome 7:	An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

The optical engineering program is accredited by the Engineering Accreditation Commission of ABET, https://www.abet.org, under the commission's General Criteria and Program Criteria for Optical, *Photonic*, and Similarly Named Engineering Programs.

Optical Engineering graduation data http://www.rose-hulman.edu/media/1262267/oe.pdf

OPTICAL ENGINEERING

SUMMARY OF GRADUATION REQUIREMENTS FOR OPTICAL ENGINEERING

1.	All the courses listed above by the number.
2.	The program must be approved by the advisor.
3.	A technical elective is any RHIT course in biology, biomathematics, chemistry, computer science, engineering, mathematics, or physics

Classes by subjects	**Hours**
Optics Coursework	50
Physics Coursework	16
Freshmen Physics, Chemistry and Mathematics Coursework	47

Humanities and Social Science (Standard requirement)	36
Electives (8 credits engineering electives, and 12 credits of free electives; cannot include ECE 340)	20
Miscellaneous	25
Total	**194**

Physics Classes

Course	**Description**	**Hours**
PH235	Many particle physics	4
PH255	Foundations of Modern Physics	4
PH292	Physical Optics	4
PH316	Elec & Mag Fields	4
Total		**16**

Freshman Physics, Math and Chemistry Classes

Course	**Description**	**Hours**
PH111	Physics I	4
PH112	Physics II	4
PH113	Physics III	4
MA111	Calculus I	5
MA112	Calculus II	5
MA113	Calculus III	5
MA221	Matrix Algebra & Differential Equations I	4
MA222	Matrix Algebra & Differential Equations II	4
MA381	Introduction to Probability with Appilcations to Statistics	4
CHEM111	Engineering Chemistry I	4
CHEM113	Engineering Chemistry II	4

Course	Description	Hours
Total		**47**

Miscellaneous and Engineering Classes

Course	Description	Hours
RHIT 100	Foundations for Rose-Hulman Success	1
EM 104	Graphical Communication	2
ME 123	Computer Programming	4
EM 103	Introduction to Design	2
ES 213	Electrical Systems	3
ES 213L	Electrical Systems Lab	1
Total		**13**

Minor

The course requirements and advisors for Minors in Optical Engineering, Solid State Physics/Materials Science, and Electronics are listed below. Successful completion of a Minor is indicated on the student's grade transcript. A student interested in pursuing a minor should consult with the appropriate advisor.

Minor in Optical Engineering

(Eligibility: students in any degree program, except programs where Optical Engineering is designated as one of the majors.)

Advisors: Drs. Alisafaee, Duree, Granieri, Joenathan, Reza, Siahmakoun, and Wagner.

Required Courses (12 hours)

Course	Hours	Course Description
OE 280	4	Geometrical Optics
PH 292	4	Physical Optics
OE 295	4	Photonic Devices and Systems

Plus at least two courses (8 hours) from the list below:

Course	Hours	Course Description
OE 360	4	Optical Materials

OE 392	4	Linear Optical Systems
OE 393	4	Fiber Optics and Applications
OE 395	4	Optomechanics & Optical Engineering Lab
OE 434	4	Non-Imaging Optics
OE 435	4	Biomedical Optics
OE 437	4	Introduction to Image Processing
OE 450	4	Laser Systems and Applications
OE 470	4	Special Topics in Optical Engineering
OE 480	4	Optical System Design
OE 493	4	Fundamentals of Optical Fiber Communications
OE 495	4	Optical Metrology

Also see Certificate Program in Semiconductor Materials and Devices

Optical Communications Certificate

Faculty advisors: Drs. Alisafaee, Duree, Joenathan, Reza, Siahmakoun, and Granieri

Rose-Hulman has become a leader in providing opportunities for students to choose a great mainstream degree program with flexibility to specialize in other areas of interest. This leadership is in no way limited to only traditional areas of study. One of these new areas that had a high impact in technology is optical communications. It is a rapidly growing field requiring investment beyond the traditional program structure, and is well suited to the students at Rose-Hulman All these topics are closely related to well established disciplines as optics and electronics. Considerable R&D efforts are allocated in both university and industrial laboratories enhancing the demand for both researchers and engineers with expertise in the field.

We propose the creation of a new certificate program in Optical Communications to enhance the programs currently offered. Combining expertise in Optical and Electrical Engineering, this program requires an interdisciplinary emphasis that is beyond the traditional content of either of its parent programs. This program is more than just the creation of the certificate program Optical Communications. This program will be critical to help developing a more interdisciplinary interaction for students and faculty. The creation of a workgroup within the faculty of both departments will coordinate current courses and resources, create new courses of interest for the field, and develop a showcase testbed education and research laboratory. Primary objectives include the removal of redundancy from existing courses, increasing interaction between the PHOE and ECE Departments, and improving opportunities for students in the field.

This certificate is designed to give the student a firm theoretical and practical working knowledge in the area of fiber optic devices, optical communications, networks and its applications. The main purpose is to couch these fundamentals in a context that serves as the backbone for device, components and sub-system development for use in high-speed optical data and information links and networks. At the end of the program the student will be expected to:

1. Understand the fundamental operation characteristics of high-speed optoelectronic components, such as laser transmitters, light modulators and receivers and passive fiber optic components as connectors, couplers, filters, and switches.
2. Understand the technology and performance of analog and digital fiber optic links, optical amplification and optical wavelength division multiplexing and optical time division multiplexing networks.
3. Have hands-on working knowledge of the use of fiber optic test equipment and techniques used by industry and telecommunication companies to test the performance of optical fiber links and components, such as, optical time domain reflectometry, optical spectrum analyzers and optical bit error testing equipment.

The Certificate will consist of 20 credit hours of which 12 credit hours will be required courses. Students interested in pursuing this Certificate should contact an ECE/PHOE certificate advisor (Professors Duree, Granieri, Alisafaee, Reza, Joenathan, Siahmakoun).

Required Courses

- ECE 310 Communication Systems
- OE 393 Fiber Optics and Applications
- OE 493 Fundamentals of Optical Fiber Communications

Elective Courses (two from the list)
Only courses not required for the student’s major will count for electives in the certificate.

- ECE 380 Discrete Time & Continuous Systems
- ECE 410 Communication Networks
- ECE 414 Wireless Systems
- OE 360 Optical Materials
- OE 435 Biomedical Optics
- OE 450 Laser Systems and Applications

Plan of Study

Freshman

Fall

Course	Credit
MA 111 Calculus I	5
PH 111 Physics I	4
RHIT 100 Foundations for Rose-Hulman Success	1
CHEM 111 General Chemistry I	4

EM 104 Graph Comm	2	
		Total Credits: 16

Winter

Course	Credit	
PH 112 Physics II	4	
MA 112 Calculus II	5	
CHEM 113 General Chemistry II	4	
HUM H190 First-Year Writing Seminar	4	
		Total Credits: 17

Spring

Course	Credit	
PH 113 Physics III	4	
MA 113 Calculus III	5	
ME 123 Computer Applications I or CSSE 120 Intro to Soft Dev	4	
OE 172 Lasers & Fiber Optics *	2	
EM 103 Intro Eng. Design	2	
		Total Credits: 17

Sophomore

Fall

Course	Credit	
PH 235 Many-Particle Physics	4	
PH 292 Physical Optics	4	
MA 221 Matrix Algebra and Differential Equations I	4	
ES 213 Electrical Systems	3	
ES 213L Electrical Systems Lab	1	
		Total Credits: 16

Winter

Course	Credit	
HSSA Elective	4	
PH 255 Fnd. of Mod. Phys.	4	
MA 222 Matrix Algebra and Differential Equations II	4	
OE 280 Geometrical Optics	4	
		Total Credits: 16

Spring

Course	Credit
OE 295 Photonic Devices & Systems	4
ECON S151 Introduction to Microeconomics -or- ECON S152 Introduction to Macroeconomics	4
MA 381 Intro to Probability with Applications to Statistics	4
Free Elective	4
	Total Credits: 16

Junior

Fall

Course	Credit
OE 480 Optical Systems Design	4
OE 395 Opto-Mech & Optical Eng Lab	4
PH 316 Elec & Mag Fields	4
HSSA Elective	4
	Total Credits: 16

Winter

Course	Credit
OE 392 Linear Optical Systems or OE 360 Optical Materials	4
ENGL H290 Tech & Prof Communications	4
Free Elective	4
Engineering Elective**	4
	Total Credits: 16

Spring

Course	Credit
OE 415 Opt Eng Des I	4
OE 450 Laser Systems & Applications	4
HSSA Elective	4
OE 393 Fiber Optics & Applications	4
	Total Credits: 16

Senior

Fall

Course	Credit
OE 416 Optical Eng Design II	4
OE 460 Silicon Photonics	4
PH/OE/EP Elective***	4
HSSA Elective	4
	Total Credits: 16

Winter

Course	Credit
OE 417 Optical Engineering Design III	4
OE 495 Optical Metrology	4
OE 392 Linear Optical Systems or OE 360 Optical Materials	4
Engineering Elective**	4
	Total Credits: 16

Spring

Course	Credit
HSSA Elective	4
HSSA Elective	4
Engineering Elective**	4
Free Elective	4
	Total Credits: 16

NOTES:

*If OE 172 is not taken during the freshman or sophomore year, the requirement must be replaced with a 300 or 400-level OE course of at least 2 credits.
**An engineering elective is any 200, 300,or 400-level course listed as OE, EP, ECE, ME, CE, BE, EM or ES.
***A PH/OE/EP elective is any 200, 300,or 400-level course listed as OE, EP or PH.

Optical Engineering - Course Descriptions

OE 171 Photography and Holography 2R-0L-2C F

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Introduce students to basic knowledge of optics, principles and operation of a camera, shutters, films, and film development, color photography. Basic understanding of interference of waves, concept of holography, properties of various holograms, application of holography, and each student makes an individual hologram that can be seen in sunlight.

OE 172 Lasers and Fiber Optics 2R-0L-2C S

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.

Light, optics, image formation, and optical instruments. Introduction to the properties, physics of operation, types, and applications of lasers. Characteristics of optical fibers and optical communication systems. Applications of lasers and fibers in industry, medicine, and consumer products. Laser safety.

OE 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

OE 280 Geometrical Optics 3.5R-1.5L-4C W

Prerequisites: PH 113S,F,W

Corequisites: There are no corequisites for this course.

First-order optics including graphical ray tracing, Gaussian methods, y-nu ray tracing, cardinal points, apertures, stops, pupils, vignetting, and obscuration. Optical invariant, dispersion, chromatic aberrations, glass selection, exact ray tracing, third-order monochromatic aberrations, introduction to computer-aided design and analysis. Relevant laboratory experiments.

OE 290 Directed Research Arranged

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

Research for freshmen and sophomore students under the direction of a physics and optical engineering faculty member. May earn up to a maximum of 2 credits for meeting the graduation requirements. The student must make arrangements with the faculty member for the research project prior to registering for this course.

OE 295 Photonic Devices & Systems 3.5R-1.5L-4C S

Prerequisites: PH 113S,F,W, and MA 221F,W,S

Corequisites: There are no corequisites for this course.

Optical radiation, radiometry, and photometry. Blackbody radiation and thermal sources. Introduction to optoelectronic devices. Light emitting diodes and other optical sources. Optical detectors (thermal, photoemissive, and semiconductor detectors). Sources/effects of noise and SNR. Flux transfer in optical systems. Relevant laboratory experiments.

OE 360 Optical Materials 4R-0L-4C W (every other year)

Prerequisites: PH 255W, and PH 316F

Corequisites: There are no corequisites for this course.

Electromagnetic waves in dielectrics/metals and complex refractive index. Optical, thermal, and mechanical properties of materials. Thin film interference, optical coatings, and design of multilayer films. Optical characterization of materials. Electromagnetic waves in anisotropic materials, double refraction, optical activity, and polarization devices.

OE 392 Linear Optical Systems 4R-0L-4C W (every other year)

Prerequisites: PH 292F, and MA 222F,W,S

Corequisites: There are no corequisites for this course.

Propagation of light and scalar diffraction theory. Fraunhofer and Fresnel diffraction, coherence, Fourier series and transforms, convolution and correlation. Linear system theory, impulse and step response, transfer functions. Coherent and incoherent image formation, optical transfer function (OTF), modulation transfer function (MTF). Image quality assessment methods. Optical information processing applications.

OE 393 Fiber Optics & Applications 3.5R-1.5L-4C S

Prerequisites: PH 113S,F,W, and either PH 316F or ECE 340F,W

Corequisites: There are no corequisites for this course.

Step-index and graded-index fibers; single-mode and multi-mode fibers; numerical aperture; attenuation and dispersion; fabrication of optical fibers and cables; fiber measurements; source coupling, splices and connectors; point-to-point links; selected applications such as fiber optic sensors and fiber optic system components. Slab and cylindrical dielectric waveguides, silicon waveguides, mode cutoff conditions; effective index of propagating mode, examples of silicon passive and active devices. Relevant laboratory experiments.

OE 395 Optomechanics & Optical Engineering Lab 2R-6L-4C F

Prerequisites: PH 292F, and OE 280W, and OE 295S

Corequisites: There are no corequisites for this course.

Design, assembly, and alignment of bench top optical systems. Introduction to experimental techniques in optics. Data collection and analysis. Relevant lecture topics including principles of opto-mechanical design, fold mirrors and prisms, lens and mirror mounting, kinematic mounts, precision adjustments and control.

OE 415 Optical Engineering Design I 2R-6L-4C S

Prerequisites: OE 280W and Junior/Senior standing

Corequisites: ENGL H290 4R-OL-4C F, W, S *Prerequisite or concurrent registration

Principles of design. Codes of ethics appropriate to engineers. Case studies related to optical engineering and engineering physics professional practice, teamwork, contemporary issues, patents and intellectual property. Team-oriented design project work on selected topics in optical engineering and engineering physics. Introduction to product development practices, product research, planning and project management. Preliminary design of a product and product specifications. Deliver a design document specific to customer needs and constraints. Cross-listed with EP 415.

OE 416 Optical Engineering Design II 2R-6L-4C F

Prerequisites: OE 415S

Corequisites: There are no corequisites for this course.

Team-based capstone design project following structured design processes and utilizing knowledge gained from prior coursework. Project planning and budgeting, development of product/process specifications, application of engineering standards, system design and prototyping subject to multiple realistic constraints (cost, schedule, and performance). Formal midterm design review. Deliver initial statement of work and interim technical report. Laboratory activities supporting the formal design process. Cross-listed with EP 416.

OE 417 Optical Engineering Design III 2R-6L-4C W

Prerequisites: OE 416F

Corequisites: There are no corequisites for this course.

Continuation of OE 416. System design and prototyping, performance testing, and data analysis. Formal midterm design review. Demonstration of a functional prototype. Deliver oral presentation and final technical report. Cross-listed with EP 417.

OE 434 Non-Imaging Optics 4R-0L-4C S (every other year)

Prerequisites: OE 295S

Corequisites: There are no corequisites for this course.
Lighting, illumination, and solar concentration systems. Radiometry and photometry for illumination, etendue, and concentration. Color coordinates, color vision, and color measurements. Sources, light transfer components, and systems evaluation. Introduction to design methods (edge-ray, compound parabolic concentrator, tailored reflector). Design examples and case studies.

OE 435 Biomedical Optics 4R-0L-4C W

Prerequisites: PH 113S,F,W, and MA 222F,W,S
Corequisites: There are no corequisites for this course.
Optical techniques for biomedical applications and health care; imaging modalities; laser fundamentals, laser interaction with biological cells, organelles and nanostructures; laser diagnostics and therapy, laser surgery; microscopes; optics-based clinical applications; imaging and spectroscopy; biophotonics. Cross-listed with BE 435.

OE 437 Introduction to Image Processing 3R-3L-4C W

Prerequisites: MA 222F,W,S
Corequisites: There are no corequisites for this course.
Basic techniques of image processing. Discrete and continuous two dimensional transforms such as Fourier and Hotelling. Image enhancement through filtering and histogram modification. Image restoration through inverse filtering. Image segmentation including edge detection and thresholding. Introduction to image encoding. Relevant laboratory experiments.

OE 450 Laser Systems & Applications 3.5R-1.5L-4C S

Prerequisites: PH 292F, and MA 222F,W,S
Corequisites: There are no corequisites for this course.
Ray transfer matrix methods, Gaussian beam propagation, and beam quality. Optical resonators and stability, longitudinal and transverse modes. Stimulated emission, population inversion, rate equations, gain and threshold. Q-switching and mode-locking. Applications and types of lasers. Laser safety and relevant laboratory experiments.

OE 460 SILICON PHOTONIC DEVICES AND APPLICATIONS 3.5R-1.5L-4C F

Prerequisites: PH 292F
Corequisites: There are no corequisites for this course.
Energy bands in semiconductors, minority and majority carriers and n/p-type doping. PN-junction in semiconductors, free-carrier absorption and recombination, forward and reverse bias pn-junction diodes. Thermo-optic effect, Franz-Keldysh effect, and plasma dispersion effect in semiconductors. TE/TM-mode propagation in semiconductor waveguides. Modeling passive and active silicon photonic (SiPh) devices. Examples of photonic integrated circuits (PICs) and applications. Fabrication of passive and active SiPh devices and PICs. Laboratory experiments will cover performance characterization of passive and active SiPh devices and PIC systems.

OE 470 Special Topics in Optical Engineering 2-4C

Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
Lectures on special topics in optics.

OE 480 Optical System Design 4R-0L-4C F

Prerequisites: OE 280W
Corequisites: There are no corequisites for this course.
Review of geometrical optics and exact ray tracing. Chromatic and monochromatic aberrations. Image quality assessment, spot size, point spread function, Strehl ratio,

and modulation transfer function. Classical lens design and design of various imaging, non-imaging, and diffractive optical systems. First-order layout, computer-based optimization, tolerancing, and manufacturing considerations.

OE 490 Directed Research 1-4C

Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.

Research for junior and senior students under the direction of a physics and optical engineering faculty member. May earn a maximum of 8 credits between PH/OE 290 and PH/OE 490 for meeting graduation requirements. Maximum of 4 credits per term. The student must make arrangements with the faculty member for the research project prior to registering for this course.

OE 493 Fundamentals of Optical Fiber Communications 3.5R-1.5L-4C S (every other year)

Prerequisites: OE 393S

Corequisites: There are no corequisites for this course.

Analysis and design of common fiber optic communication systems and optical networks. Transmission penalties: dispersion, attenuation. Optical transmitters and receivers: fundamental operation and noise. Intensity and phase modulation. Optical amplification: types of amplifiers, noise and system integration. Point-to-point links: power budget and rise-time analysis. Performance analysis: BER and eye diagrams. WDM concepts and components: multiplexers, filters, common network topologies. Non-linear effects in fibers. Relevant laboratory experiments.

OE 495 Optical Metrology 3.5R-1.5L-4C W

Prerequisites: OE 280W, and PH 292F

Corequisites: There are no corequisites for this course.

Geometrical test methods (refractometers, knife edge, Ronchi, Wire, Hartmann). Review of interference and coherence. Third-order aberrations, Zernike polynomials, and fringe analysis. Interferometers (Newton, Fizeau, Twyman-Green, and shearing), fringe localization, and phase shifting. Holographic, Moire, photoelastic and speckle interferometry. Applications of optical metrology. Relevant laboratory experiments.

OE 497 Senior Thesis 1-2C F

Prerequisites: Consent of PHOE faculty

Corequisites: There are no corequisites for this course.

Literature search, research proposal preparation, and laboratory project work. This sequence is designed to result in a completed senior thesis or initiation of research to be completed in an MSOE degree at Rose-Hulman.

OE 498 Senior Thesis 1-2C W

Prerequisites: Consent of PHOE faculty

Corequisites: There are no corequisites for this course.

Literature search, research proposal preparation, and laboratory project work. This sequence is designed to result in a completed senior thesis or initiation of research to be completed in an MSOE degree at Rose-Hulman.

OE 499 Senior Thesis 1-2C S

Prerequisites: Consent of PHOE faculty

Corequisites: There are no corequisites for this course.

Literature search, research proposal preparation, and laboratory project work. This sequence is designed to result in a completed senior thesis or initiation of research to be completed in an MSOE degree at Rose-Hulman.

OE 520 Principles of Optics 2R-0L-2C F
Prerequisites: Graduate standing
Corequisites: There are no corequisites for this course.
Introduction to optics for incoming graduate students. Geometric optics; wave optics; sources and detectors. Students progressing towards or holding a bachelor's degree in Optical Engineering may not receive credit for OE 520.

OE 535 Biomedical Optics 4R-0L-4C W
Prerequisites: PH 113S,F,W and Senior or Graduate standing
Corequisites: There are no corequisites for this course.
Optical techniques for biomedical applications and health care; imaging modalities; laser fundamentals, laser interaction with biological cells, organelles and nanostructures; laser diagnostics and therapy, laser surgery; microscopes; optics-based clinical applications; imaging and spectroscopy; biophotonics. Students must do additional project work on a topic selected by the instructor. Students may not receive credit for both OE 435 and OE 535. Cross-listed with BE 535.

OE 537 Advanced Image Processing 3R-3L-4C S
Prerequisites: CSSE 120F,W,S or ME 123F,W,S and Senior or Graduate standing
Corequisites: There are no corequisites for this course.
Introduction to image segmentation and recognition. Use of neural networks, fuzzy logic and morphological methods for feature extraction. Advanced segmentation, detection, recognition and interpretation. Relevant laboratory experiments and required project. Cross-listed with ECE 582.

OE 570 Special Topics in Optics 2 or 4C F,W,S
Prerequisites: Consent of instructor and Senior or Graduate standing
Corequisites: There are no corequisites for this course.
Lectures on contemporary topics in optical science, optical engineering, and photonics.

OE 580 Optical System Design 4R-0L-4C F
Prerequisites: OE 280W and Senior or Graduate standing
Corequisites: There are no corequisites for this course.
Review of geometrical optics and exact ray tracing. Chromatic and monochromatic aberrations. Image quality assessment, spot size, point spread function, Strehl ratio, and modulation transfer function. Classical lens design and design of various imaging, non-imaging, and diffractive optical systems. First-order layout, computer-based optimization, tolerancing, and manufacturing considerations. Students must do additional project work on a topic selected by the instructor. Students may not receive credit for both OE 480 and OE 580.

OE 584 Medical Imaging Systems 4R-0L-4C S
Prerequisites: OE 392W (every other year)* or ECE 300F, S * with a grade of B or better or Graduate standing or consent of instructor
Corequisites: There are no corequisites for this course.
Engineering principles of major imaging techniques/modalities for biomedical applications and health care including diagnostic x-ray, computed tomography, nuclear techniques, ultrasound, and magnetic resonance imaging. Topics include general characteristics of medical images; physical principles, signal processing to generate an image, and instrumentation of imaging modalities. Clinical applications of these technologies are also discussed. Cross-listed with ECE 584 and BE 541.

OE 585 Electro-Optics and Applications 3R-3L-4C F
Prerequisites: PH 292F, and PH 316F and Senior or Graduate standing

Corequisites: There are no corequisites for this course.
Optical wave propagation in anisotropic media. Normal surface and the index ellipsoid. Double refraction. Optical activity and Faraday rotation. Pockels and Kerr effects. Electrooptic modulators. Acousto-optic effect. Modulators and scanners. Introduction to nonlinear optics. Second-harmonic generation and frequency doubling. Relevant laboratory experiments.

OE 592 Fourier Optics & Applications 3.5R-1.5L-4C S

Prerequisites: OE 392W (every other year) and Senior or Graduate standing
Corequisites: There are no corequisites for this course.
Two-dimensional linear systems. Scalar diffraction theory, Fresnel & Fraunhofer diffraction. Coherent optical systems analysis. Frequency analysis of optical imaging systems. Spatial filtering and analog optical information processing. Wavefront reconstruction and holography. Relevant laboratory experiments.

OE 593 Fundamentals of Optical Fiber Communications 3.5R-1.5L-4C S (every other year)

Prerequisites: OE 393S Senior or Graduate Standing
Corequisites: There are no corequisites for this course.
Analysis and design of common fiber optic communication systems and optical networks. Transmission penalties, dispersion, attenuation. Optical transmitters and receivers: fundamental operation and noise. Intensity and phase modulation. Optical amplification: types of amplifiers, noise and system integration. Point-to-point links: power budget and rise-time analysis. Performance analysis: BER and eye diagrams. WDM concepts and components: multiplexers, filters, common network topologies. Non-linear effects in fibers. Relevant laboratory experiments. Students must do additional project work on a topic selected by the instructor. Students may not receive credit for both OE 493 and OE 593.

OE 594 Integrated Silicon Photonics 3.5R-1.5L-4C W

Prerequisites: OE 393S and Senior or Graduate standing
Corequisites: There are no corequisites for this course.
Dispersion properties of silicon waveguides, coupled-mode theory, mode propagation and confinement, effective index of TE and TM modes. Modeling silicon passive devices: directional coupler, Y-branch, Mach-Zehnder interferometer, ring resonators, I/O grating couplers. Modeling silicon active devices: thermo-optic phase-shifters, pn-junction modulators, electro-absorption modulators, and photodetectors. Modeling and simulation of integrated silicon photonics circuits and applications. Laboratory experiments: Fabrication and characterization of a silicon passive device.

OE 595 Optical Metrology 3.5R-1.5L-4C W

Prerequisites: OE 280W, OE 392W (every other year) Senior or Graduate standing or consent of instructor
Corequisites: OE 480 4R-0L-4C F
Geometrical test methods (refractometers, knife edge, Ronchi, Wire, Hartmann). Review of interference and coherence. Third-order aberrations, Zernike polynomials, and fringe analysis. Interferometers (Newton, Fizeau, Twyman-Green, and shearing), fringe localization, and phase shifting. Holographic, Moire, photoelastic and speckle interferometry. Applications of optical metrology. Relevant laboratory experiments. Students must do additional project work on a topic selected by the instructor. Students may not receive credit for both OE 495 and OE 595.

OE 599 Thesis Research 1-4C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Graduate students only. Credits as arranged; however not more than 12 credits will be applied toward the requirements for the MS (OE) degree.

OE 699 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The work experiences should be informative or integral to the advancement or completion of the student's program requirements. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

Physics

The physics curriculum is designed to develop a strong foundation in classical and modern physics, which will serve as a basis for future specialization, for additional study at the graduate level, and for design and development work in industrial laboratories. The curriculum emphasizes basic physical concepts, and includes extensive work in mathematics and related areas. Laboratory facilities are available for work in optics, acoustics, X-ray diffraction, nuclear physics, and solid-state physics. Course topics included in the curriculum are Many Particle Physics, Physical Optics, Biophysics, Biomedical Optics, Theoretical Mechanics, Electromagnetism, Celestial Mechanics, Acoustics, Microsensors, Semiconductor Materials and Devices, X-rays and Crystalline Materials, Electro-Optics, and Laser Physics.

The Physics program places an emphasis on laboratory courses with a hands-on approach. The students have the opportunity to take a variety of courses in disciplines such as math and chemistry allowing them to tailor their education. The Physics curriculum is flexible enough that one can double major in computer science, mathematics, electrical engineering, and mechanical engineering. National interest in our program has been generated by our basic physics courses that use new methodologies of teaching such as studio format lectures.

We have a wide range of research programs accessible to undergraduates including areas such as: Astronomy, Solid State Devices, Electro-optics, Non-linear Optics, X-ray absorption, Semiconductor Materials and Devices, Magnetics, Chaos, Lasers, Fiber Optics, Holography, Microsensors. In addition, we are very successful in placing our students in summer internship positions with various research facilities such as NASA, Argonne National Laboratory, Sandia National Laboratory, National Radio Astronomy Observatory, and CSPAAR.

Physics Student Learning Outcomes

Fundamental Knowledge: Demonstrate a broad working knowledge base in physics.

Problem Solving: Demonstrate competency in applying the skills and knowledge necessary for scientific solutions to mathematical, scientific, and engineering problems.

Experiments: Design and conduct experiments and interpret and analyze acquired data while demonstrating understanding of the underlying scientific theory, method, and process.

Modeling: Formulate questions and produce an appropriate physical model to represent and describe real-world physics problems.

Ethics: Explain professional and ethical responsibility to the field and public and behave with integrity and accountability.

Communication: Communicate effectively, accurately, and succinctly scientific problems and solutions to a range of audiences via appropriate methods.

PHYSICS

SUMMARY OF GRADUATION REQUIREMENTS FOR PHYSICS MAJORS

1. All the courses listed above by the number.
2. The program must be approved by the advisor.
3. Eleven credits of physics courses, besides those listed by number. At least one of these credits must be directed research (PH290 or PH490).
4. Twenty credits of technical electives of which at least eight must be in courses other than physics courses (cannot include ECE340).
5. Cross reference for the following courses:
   ECE340 and ECE341 for PH316 and PH317
   ES202 and ES204 for PH235
6. Sixteen credits of free electives (cannot include ECE340).
7. Thirty-six credits of humanities or social sciences courses. The distribution of these courses must meet the requirements of the Department of Humanities, Social Sciences, and the Arts.
8. A technical elective is any RHIT course in biology, biomathematics, chemistry, computer science, engineering, mathematics, or physics.
9. A free elective is any course offered at RHIT.

Course by Subjects	Hours
Physics Course work	57
Physics Electives*	11
Chemistry and Mathematics Course work**	43
Humanities, Social Sciences, and the Arts (Standard	36
requirement)	20
Technical Electives†	16
Free Electives††	9
Miscellaneous and OE450†††	**192**
Total	

*Listed below are the PH elective courses, from which a physics major is required to take 11 hours.

Course	Course Title	Hours
PH 215	Introduction to Chaos	2

PH 231	Observational Astronomy	4
PH 241	Physics of Stars	4
PH 250	Planets and Galaxies	4
PH 265	Fundamentals of Nuclear	4
PH 270	Physics	Arranged
PH 290	Special Topics in Physics	Arranged
PH 302	Directed Research	4
PH 310	Biophysics	2
PH 315	Intro to Relativity	4
PH 322	Theoretical Mechanics II	4
PH 402	Celestial Mechanics and	4
PH 404	Solar	4
PH 407	Introduction to Atomic	4
PH 410	Physics	4
PH 440	Acoustics	4
PH 460	Solid State Physics	Arranged
PH 470	General Relativity	Arranged
PH 480	X-rays and Crystalline	Arranged
PH 490	Materials	Arranged
PH 496+	Directed Study	Arranged
PH 497+	Directed Research	Arranged
PH 498+	Seminar	Arranged
PH 499	Directed Research	4
PH 512	Senior Thesis	4
PH 514	Senior Thesis	4
PH 530	Senior Thesis	4
PH 537	Physics Ethics and	4
PH 538	Communication	4
	Methods of Mathematical	
	Physics	
	Quantum Mechanics	
	Advanced Acoustics	
	Advanced Image	
	Processing	
	Introduction to Neural	
	Networks	

+Students wanting to pursue the Senior Thesis option must find a faculty advisor (from the Physics and Optical Engineering Faculty) by the Fall Term of their Senior Year. At that time, the thesis topic should be decided and the research plan developed. Students in the thesis option should enroll in Senior Thesis courses for each of the three terms of their Senior Year for a total number of 8 credit hours over the three quarter sequence. Students working on a Senior Thesis will present their thesis near the end of the Spring Term of their Senior Year.

**Math and Chemistry Courses:

Course	**Course Title**	**Hours**
MA 111	Calculus I	5

MA 112	Calculus II	5
MA 113	Calculus III	5
MA 221	Matrix Algebra and	4
MA 222	Differential Equations I	4
MA 330	Matrix Algebra and	4
MA 336	Differential Equations II	4
MA 371	Vector Calculus	4
CHEM 111	Boundary Value Problems	4
CHEM 113	Linear Algebra	4
Total	General Chemistry I	**43**
	General Chemistry II	

†Twenty credits of technical electives are required for a physics major, of which at least eight must be in courses other than physics courses (cannot include ECE340).

††A physics major may take sixteen credit hours of free electives, which may include any of the electives mentioned above or any other course offered at RHIT.

†††Miscellaneous Courses

Course	**Course Title**	**Hours**
RHIT 100	Foundations for Rose-	1
EM 104	Hulman Success	2
OE 450	Graph Comm.	4
	Laser System and	2
Total	Applications	**9**
	Computing Elective	

Physics Thesis Option:
The Physics thesis option is intended for students who complete a substantive research project in this field. To complete this thesis option, a student must:
- Pass a minimum of 8 combined credit hours of PH496, PH497, and PH498.
- Perform research in the above classes that involves the same research project and is completed under the direction of a departmental faculty mentor.
- Write and submit the thesis to the department and perform an oral research presentation as part of PH499. Successful completion of the Physics thesis will be noted on the student's transcript.
- Upon successful completion of the thesis in PH499, 4 of the thesis credits can be used for a course substitution for PH425 and up to 4 thesis credits may be used for one Physics elective.

The course requirements and advisors for Minors in Physics, Astronomy, Solid State Physics/Materials Science, and Optical Engineering are listed below. Successful completion of a minor is indicated on the student's grade transcript. A student interested in pursuing a minor should consult with the appropriate advisor.

Minor in Physics

Eligibility: Students in any major degree program except for Physics and NanoEngineering

Advisors: all Physics and Optical Engineering faculty members.

Required courses:

Course	**Course Title**	**Prerequisite Course(s)**	**Hours**
PH 325	Advanced Laboratory I	PH 113	4
Plus 4 credit hours from the following courses:			
PH 235	Many-Particle Physics		4
PH 255	Foundations of Modern Physics		4

Plus 12 credit hours from the following courses:

Course	**Course Title**		**Hours**
PH 270/470*	Special Topics in Physics		ARR
PH 290/490*	Directed Research		ARR
PH 310	Introduction to Relativity	PH 113	2
PH 314	Theoretical Mechanics I	PH 112 and MA 222	4
PH 316	Electric and Magnetic Fields	PH 113 and MA 221 or MA 222	4
PH 327	Thermodynamics and Statistical Mechanics	PH 235	4
PH 401	Quantum Mechanics	PH 255 or PH 265	4
PH 405	Semiconductor Materials & Applications	PH 255	4
PH 425	Advanced Physics Lab II	PH 325	4
PH 460*	Directed Study		ARR

*A maximum of 4 credit hours can be taken from these categories.

Suggested Pathways (These involve no "unused" prerequisite PH credit hours):

- Experimental Physics: PH255, PH325, PH401, PH405, PH425
- Modern Physics: PH255, PH270/470/290/490 (2cr), PH310, PH325, PH401, PH405
- Classical Physics: PH235, PH314, PH316, PH325, PH327

Minor in Astronomy

Eligibility: Students in any major degree program

Advisors: Drs. Ditteon, Duree, Kirkpatrick, McInerney and Syed

Required Courses

Course	Course Title	Hours
PH 231	Observational Astronomy	2
PH 241	Physics of Stars	4
PH 250	Planets and Galaxies	4
PH 431 or PH 490	Adv. Observational Astronomy or Directed Study	2
It is recommended, but not required, that the required courses be taken in the order listed above.		
Plus eight hours of:		
PH 270	Special Topics in Physics	2
PH 310	Introduction to Special Relativity	2
PH 322	Celestial Mechanics	4
PH 410	General Relativity	4
PH 460	Directed Study	1
PH 470	Special Topics in Physics	2
PH 290/490	Directed Research	1

The optional courses must be on a topic approved by one of the astronomy advisors.

Normally, only one credit of directed research or directed study is taken each quarter. Directed study and directed research may be repeated (4 hours maximum) and must be on a topic approved by one of the astronomy advisors.

Minor in Solid State Physics/Materials Science

Eligibility: Students in any degree program, except students who are working for the Semiconductor Materials and Devices Certificate.

Advisors: Dr. Bunch, Dr. McInerney, Dr. Moloney, Dr. Siahmakoun, Dr. Syed, Dr. Wagner

Required courses:

Course	Description	Hours
PH 405	Semiconductor Materials and Applications	4
EP 406	Semiconductor Devices and Fabrication	4
ME 328/CHE 315	Materials Engineering/ Material Science & Engineering	4

Plus at least two of:

Course	Description	Hours
OE 360	Opto-mechanics and Optical Materials	4
EP 330	Material Failure	4
PH 407	Solid State Physics	4
EP 408	Microsensors	4
PH 440	X-Rays and Crystalline Materials	4
PH 490/ME 490	Directed Research	4
ME 302	Heat Transfer	4
ME 417	Advanced Materials Engineering	4

Minor in Optical Engineering

Eligibility: Students in any degree program, except Optical Engineering.

Advisors: Drs. Bunch, Ditteon, Duree, Granieri, Joenathan, Lepkowicz, Siahmakoun, Wagner, F. Berry, and Black.

Required courses:

Course	Description	Hours
OE 280	Paraxial Optics	4
PH 292	Physical Optics	4
OE 295	Optical Systems	4

Plus at least two* courses from one of the areas listed below:

Lens Design Area

OE 360	Optical Materials and	4
OE 415	Opto-mechanics	4
OE 480	Optical Engineering	4
OE 490	Design I	4
	Lens Design and	
	Aberrations	
	Directed Research (4	
	Credits Only)	

Photonics/Electro-optics Area

Course	Description	Hours
OE 360	Optical Materials and	4
OE 415	Opto-mechanics	4
OE 450	Optical Engineering	4
OE 485	Design I	4
OE 490	Laser Systems and	4
OE 493	Applications	4
	Electro-optics and	
	Applications	
	Directed Research (4	
	Credits Only)	
	Fundamentals of Optical	
	Fiber Communications	

Image Processing Area

Course	Description	Hours
OE 360	Optical Materials and Opto-mechanics	
OE 415	Optical Engineering	4
OE 490	Design I	4
	Directed Research (4 Credits Only)	
OE 437/ECE 480	Introduction to Image Processing	4
PH 537/ECE 582	Advanced Image Processing	4

Minor in Theoretical Physics

Eligibility: Students in any major degree program, except Physics and NanoEngineering.

Advisors: all Physics and Optical Engineering faculty members.

Required Courses:

Course	Course Title	Prerequisite Course(s)	Hours
PH 314	Theoretical Mechanics I	PH 112 and MA 222	4

PH 316	Electirc and Magnetic Fields	PH 113 and MA 222	4
PH 401	Quantum Mechanics	PH 255 or PH 113 and PH 265	4

Plus 8 credit hours from the following courses:

Course	**Course Title**	**Prerequisite Course(s)**	**Hours**
MA 421	Tensor Calculus & Riemannian Geometry	MA 330	4
PH 270/470	Special Topics in Physics*		ARR
PH 290/490	Directed Research*		ARR
PH 310	Introduction to Special Relativity	PH 113	2
PH 315	Theoretical Mechanics II	PH 314	4
PH 317	Electromagnetism	PH 316	4
PH 327	Thermodynamics & Statistical Mechanics	PH 235	4
PH 402	Introduction to Atomic Physics	PH 401	4
PH 410	General Relativity	PH 310 and MA 421	4
PH 460	Directed Study*		ARR

*This is restricted to a maximum of 4 credit hours across the 4 categories.

Students intending to complete this minor should plan for accommodating the prerequisite of the upper-division classes they choose to include int he minor plan of study.

CERTIFICATE IN SEMICONDUCTOR MATERIALS AND DEVICES

The Certificate will consist of 20 credit hours of which 12 credit hours will be required courses. Students interested in pursuing this Certificate should see a PHOE certificate advisor (S. Kirkpatrick, Liptak, McInerney, Siahmakoun, Syed and Wagner). Students taking solid state/material science minor cannot take this certificate.

Required Courses

1. PH405 Semiconductor Materials and Applications -- 3R-3L-4C F Pre: PH113 or PH255 or PH265 or consent of instructor.

2. EP406 Semiconductor Devices and Fabrication -- 3R-3L-4C W Pre: PH405 or consent of instructor.
3. EP410 Intro to MEMS: Fabrication and Applications -- 3R-3L-4C S Pre: JR or SR standing or consent of the instructor.
   or:
   CHE440 Process Control 4R-0L-4C W Pre: CHE202

Electives

Course	Hours	Course Title
OE 450	4	Laser Systems and Applications
OE 485	4	Electro-Optics and Applications
PH 330	4	Material Failure
PH 401	4	Introduction to Quantum Mechanics
PH 440	4	X-rays and Crystalline Materials
EP 408	4	Microsensors
EP 411	4	Advanced Topics in MEMS
ECE 351	4	Analog Electronics
ECE 551	4	Digital Integrated Circuit Design
ECE 552	4	Analog Integrated Circuit Design
ME 302	4	Heat Transfer
ME 328	4	Materials Engineering
ME 424	4	Composite Materials & Mechanics
ME 415	4	Corrosion and Engineering Materials
CHE 314	4	Heat Transfer
CHE 315	4	Material Science and Engineering
CHE 440	4	Process Control
CHE 441	4	Polymer Engineering
CHEM 441	4	Inorganic Chemistry I
CHEM 451	4	Organic Structure Determination
CHEM 457	4	Synthetic Polymer Chemistry

Course	Hours	Course Title
CHEM 462	4	Physical Polymer Chemistry
MA 381	4	Intro to Probability with Applications to Statistics
MA 385	4	Quality Methods
MA 487	4	Design of Experiments

Overall aim of the Certificate

A certificate holder will understand how semiconductor devices work, have practical experience in the main stages of device production, have practical experience in the more common forms of device testing and characterization, and have broad understanding of the mechanical and chemical properties of the material used.

A Certificate holder will be well suited for jobs requiring an understanding of semiconductor devices and their production. These jobs include not only those directly related to device fabrication, but also those involved with testing and trouble-shooting electronic equipment and the design of machines that contain electronic equipment. The experience in simple device fabrication that the Certificate provides is particularly useful for future engineers in “process” industries.

Plan of Study

Freshman

Fall

Course	Credit
EM 104 Graphical Communications	2
MA 111 Calculus I	5
PH 111 Physics I	4
HUM H190 First-Year Writing Seminar	4
RHIT 100 Foundations for Rose-Hulman Success	1
	Total Credits: 16

Winter

Course	Credit
CHEM 111 General Chemistry I	4
MA 112 Calculus II	5
PH 112 Physics II	4
Computing Elective*	2 or 4
	Total Credits: 15, or 17

Spring

Course	Credit
CHEM 113 General Chemistry II	4
MA 113 Calculus III	5
PH 113 Physics III	4
HSSA Elective	4
	Total Credits: 17

Sophomore

Fall

Course	Credit
MA 221 Matrix Algebra & Differential Equations I	4
PH 235 Many Particle Physics	4
PH 292 Physical Optics	4
Free Elective†	4
	Total Credits: 16

Winter

Course	Credit
MA 222 Matrix Algebra and Differential Equations II	4
PH 255 Fund. of Modern Physics	4
HSSA Elective	4
MA 373 Applied Linear Algebra or MA 371**	4
	Total Credits: 16

Spring

Course	Credit
MA 330 Vector Calculus	4
Tech Elective	4
PH 314 Theoretical Mechanics I	4
HSSA Elective	4
	Total Credits: 16

Junior

Fall

Course	Credit
MA 336 Boundary Value Problems	4

PH 316 Electric & Magnetic Fields	4
Physics Elective	4
HSSA Elective	4
PH 290 or 490 Directed Study	1
	Total Credits: 17

Winter

Course	Credit
PH 317 Electromagnetism	4
PH 401 Intro Quantum Mechanics	4
ENGL H290 Technical & Professional Communication	4
Technical Elective†	4
	Total Credits: 16

Spring

Course	Credit
OE 450 or Physics Elective	4
PH 325 Advanced Physics Lab I	4
PH 327 Thermodynamics & Statistical Mechanics	4
HSSA Elective	4
	Total Credits: 16

Senior

Fall

Course	Credit
HSSA Elective	4
PH 405 Semiconductor Materials & Applications	4
Technical Elective†	4
Free Elective	4
	Total Credits: 16

Winter

Course	Credit
PH 425 Advanced Physics Lab II	4
HSSA Elective	4
Technical Elective†	4
Free Elective†	4

	Total Credits: 16

Spring

Course	Credit
OE 450 Laser Sys & App or Physics Elective	4
Physics Elective†	4
Technical Elective†	4
PH 499 Physics Ethics and Communication	1
	Total Credits: 13

NOTES:

* Computing elective: 2 or 4 credit course on computing from the following course: BE 100, CHE 110, CSSE 120, and ME 123. CSSE 120 is required for physics majors who are planning to double major with CSSE, CPE, EE, MA, and ME

**MA 371 (F or S) can be substituted for MA 373 (W)

†Free, Math and technical electives are only suggestions and can change subject to offering. Electives must be approved by PHOE advisor.

Physics - Course Descriptions

PH 090 College Preparatory Physics 4R-0L-4C
Prerequisites: College Algebra II
Corequisites: There are no corequisites for this course.
Topics covered include: Units, significant figures, vectors, 1 and 2 dimensional motion; kinematic equations, objects in free-fall, motion in a circle, projectile motion, Newton's Laws, contact forces, non-contact forces: gravity, Coulomb's Law, magnetic force; centripetal force; collisions, linear momentum, rotational kinematics, torques, angular momentum, mechanical equilibrium - static equilibrium. The credits from this course cannot be counted toward any degree completion at Rose-Hulman.

PH 111 Physics I 3.5R-1.5L-4C F,W
Prerequisites: There are no prerequisites for this course.
Corequisites: MA 111 5R-0L-5C F,W or MA 105 5R-0L-5C F
Kinematics, Newton's laws of motion, gravitation, Coulomb's law, Lorentz force law, strong and weak nuclear forces, conservation of energy and momentum, relevant laboratory experiments.

PH 112 Physics II 3.5R-1.5L-4C W,S,F
Prerequisites: PH 111F,W, and MA 111F,W or MA 105F*
Corequisites: MA 112 5R-0L-5C F,W,S or MA 106 4R-0L-4C W
Torque and angular momentum, oscillations, one-dimensional waves, electric fields and potentials, electric current and resistance, DC circuits, capacitance, relevant laboratory experiments.

PH 113 Physics III 3.5R-1.5L-4C S,F,W
Prerequisites: PH 112W,S,F, and MA 112F,W,S
Corequisites: MA 113 5R-0L-5C F,W,S

Sources of magnetic fields, Faraday's law, inductance electromagnetic waves, reflection and polarization, geometric and physical optics, introduction to relativity, relevant laboratory experiments.

PH 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

PH 200 Career Preparation 1R-0L-1C W,S

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

This course is for physics majors to be taken in the second year. The course addresses career choices, summer opportunities, employment and graduate school preparation, and curriculum vitae and resumes preparation. This course is cross-listed with CHEM200, MA200 and SV200.

PH 215 Introduction to CHAOS 2R-0L-2C W

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

What constitutes chaotic behavior, detection of chaos in real systems using phase space plots, Poincare sections, bifurcation plots, power spectra, Lyupunov exponents, and computer simulation of chaotic systems.

PH 231 Observational Astronomy 1R-3L-2C F

Prerequisites: MA 111F,W, and PH 111F,W or EM 120F, S

Corequisites: There are no corequisites for this course.

Celestial coordinates; basics of celestial mechanics; electromagnetic radiation, atomic structure, spectra, blackbody radiation; telescopes and detectors; quantitative observational work using modern telescopes and detectors.

PH 235 Many-Particle Physics 3.5R-1.5L-4C F

Prerequisites: PH 111F,W

Corequisites: MA 112 5R-0L-5C F,W,S

Dynamics of rigid body, harmonic motion; mechanics of fluids; heat, kinetic theory, thermodynamics. Alternate week laboratories.

PH 241 Physics of Stars 4R-0L-4C W

Prerequisites: MA 111F,W, and PH 111F,W or EM 120F, S

Corequisites: There are no corequisites for this course.

Binary stars and stellar parameters; stellar spectra; stellar atmospheres; stellar interiors; star formation; stellar evolution; star death; stellar remnants; black holes and binary stars.

PH 250 Planets and Galaxies 4R-0L-4C S

Prerequisites: MA 111F,W, and PH 111F,W or EM 120F, S

Corequisites: There are no corequisites for this course.

Overview of planets and planetary science; origin and evolution of the solar system; structure and evolution of galaxies; origin and evolution of the universe; introduction to cosmology.

PH 255 Foundations of Modern Physics 3.5R-1.5L-4C W

Prerequisites: PH 113S,F,W
Corequisites: MA 221 4R-0L-4C F,W,S
Wave-particle nature of matter and radiation, Bohr model, Schrodinger equation, quantum description of the hydrogen atom, atomic and molecular spectra, and introduction to statistical physics.

PH 265 Fundamentals of Nuclear Physics & Radiation 3R-3L-4C S

Prerequisites: PH 112W,S,F, and MA 221F,W,S
Corequisites: There are no corequisites for this course.
Relativity, black-body radiation, the Bohr model, physics of the nucleus, fission and fusion, reactors, nuclear radiation, radiation damage, medical applications.

PH 270 Special Topics in Physics 1-4C

Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
Lectures on special topics in physics. Maximum of 4 credits per term.

PH 290 Directed Research 1-4C

Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
Research for freshmen and sophomore students under the direction of a physics and optical engineering faculty member. May earn up to a maximum of 2 credits for meeting the graduation requirements. The student must make arrangements with a faculty member for the research project prior to registering for this course.

PH 292 Physical Optics 3.5R-1.5L-4C F

Prerequisites: PH 113S,F,W
Corequisites: There are no corequisites for this course.
The wave equation; electromagnetic waves; phase and group velocities; complex refractive index; dispersion, interference; interferometers and applications, optical interferometry; coherence; polarized light; Jones vectors/matrices; production of polarized light; birefringence, Fraunhoffer diffraction; diffraction gratings.

PH 302 Biophysics 4R-0L-4C F

Prerequisites: PH 113S,F,W or consent of instructor
Corequisites: There are no corequisites for this course.
Biological examples of the interaction of radiation and matter; medical uses of x-rays, nuclear medicine, magnetic resonance imaging, and current applications in biophysics.

PH 310 Introduction to Special Relativity 2R-0L-2C F

Prerequisites: PH 113S,F,W Consent of instructor
Corequisites: There are no corequisites for this course.
Experimental background of the special theory of relativity, the structure of the theory and its consequences in measurements involving space, time and motion. Relativistic mechanics, relativity and electromagnetism, and applications in modern physics.

PH 314 Theoretical Mechanics I 4R-0L-4C S

Prerequisites: PH 112W,S,F, and MA 222F,W,S
Corequisites: There are no corequisites for this course.
Statics and dynamics of particles and systems of particles, including rigid bodies. Conservation of energy, linear and angular momentum. Central forces. Lagrangian and Hamiltonian equations of motion. Vibrations.

PH 315 Theoretical Mechanics II 4R-0L-4C W

Prerequisites: PH 314S
Corequisites: There are no corequisites for this course.
Statics and dynamics of rigid bodies. Lagrangian treatment of rigid body dynamics. Euler method of rigid body dynamics. Small oscillations about positions of equilibrium and about steady motion. Statics and dynamics of deformable bodies. Computational analysis of mechanical systems.

PH 316 Electric & Magnetic Fields 4R-0L-4C F
Prerequisites: PH 113S,F,W, and MA 222F,W,S
Corequisites: There are no corequisites for this course.
Maxwell's equations in integral and point form, vector calculus; electric field and potential, electric fields in matter, boundary conditions; the magnetic field.

PH 317 Electromagnetism 4R-0L-4C W
Prerequisites: PH 316F
Corequisites: There are no corequisites for this course.
Further methods in electrostatics, Poisson's equation; magnetostatics, the vector potential; electromagnetic induction; magnetic properties of matter; further applications of Maxwell's equations, properties of electromagnetic radiation.

PH 322 Celestial Mechanics 4R-0L-4C S
Prerequisites: PH 112W,S,F or MA 221F,W,S
Corequisites: There are no corequisites for this course.
Dynamics of point masses; the two-body problem; the restricted three-body problem; orbital position as a function of time; orbits in three dimensions; preliminary orbit determination; orbital maneuvers; interplanetary trajectories.

PH 325 Advanced Physics Laboratory I 2R-6L-4C S
Prerequisites: PH 113S,F,W
Corequisites: There are no corequisites for this course.
Introduction to the methods of experimental physics; topics may include error analysis, component fabrication, transducers, ac circuits, operational amplifiers, electrical signal conditioning, and automated data acquisition.

PH 327 Thermodynamics & Statistical Mechanics 4R-0L-4C S
Prerequisites: PH 235F or consent of instructor
Corequisites: There are no corequisites for this course.
First, second, and third laws of thermodynamics. Ideal gases, real gases, liquids, solids, change of phase. The Joule-Thompson effect, adiabatic demagnetization. Kinetic theory of gases, classical and quantum statistical mechanics.

PH 401 Introduction to Quantum Mechanics 4R-0L-4C W
Prerequisites: PH 255W or PH 113S,F,W, and PH 265S
Corequisites: There are no corequisites for this course.
Review of wave-particle experiments, atomic model, Bohr theory, deBroglie's hypothesis. Uncertainty principle, Schroedinger equation, quantum mechanical operators and stationary states, quantization and role of angular momentum.

PH 402 Introduction to Atomic Physics 4R-0L-4C S (odd years)
Prerequisites: PH 401W
Corequisites: There are no corequisites for this course.
Solutions of Schroedinger equation, perturbation theory, applications to one electron system. Quantum numbers, spin and magnetic moments, multi-electron systems including LS coupling. Zeeman effect, transition rates, hyperfine structure, X-rays.

PH 404 Acoustics 4R-0L-4C W (odd years)
Prerequisites: PH 113S,F,W, and MA 222F,W,S
Corequisites: There are no corequisites for this course.
Harmonic motion, waves on strings, membranes, eigenfunctions and eigenvalues; waves in rods and fluids; behavior of waves at interfaces; radiation from vibrating piston; resonators, absorption.

PH 405 Semiconductor Materials & Applications 3R-3L-4C F
Prerequisites: PH 113S,F,W or PH 255W or PH 265S
Corequisites: There are no corequisites for this course.
Material structure electronic levels and energy bands; semiconductor doping; optical and electronic material characteristics; p-n junction and diode characteristics; bipolar junction transistor; basics of device fabrication. Laboratories on X-ray and Scanning Electron Microscope investigations, device characteristics and a three-week design project on production and testing of thin films. Cross-listed with PH 505.

PH 407 Solid State Physics 4R-0L-4C S (even years)
Prerequisites: PH 255W or PH 265S
Corequisites: There are no corequisites for this course.
Selected topics in the field are discussed in detail; e.g., crystal structures, lattice vibrations and electronic band structure; electrical, optical and thermal properties of solids and semi-conductors; and the properties of materials at very low temperatures.

PH 410 General Relativity 4R-0L-4C W (odd years)
Prerequisites: PH 310F, and MA 421Fall (Odd years)
Corequisites: There are no corequisites for this course.
An in-depth study of Einstein’s theory of General Relativity. Gravity as geometry and curved space-time, metrics, and geodesics. Orbits and light paths around spherical masses. Detailed study of Einstein’s equation in vacuum and with sources of space-time curvature.

PH 425 Advanced Physics Laboratory II 0R-8L-4C W
Prerequisites: PH 325S
Corequisites: There are no corequisites for this course.
Selected experiments in various areas of physics, with primary emphasis on nuclear physics and a significant independent student project

PH 431 Advanced Observational Astronomy 1R-3L-2C S
Prerequisites: PH 231F, and either PH 241W or PH 250S
Corequisites: There are no corequisites for this course.
Students will conduct astronomical observations with telescopes and learn to process and interpret astronomical data. They will learn astronomical data processing, statistical analysis, image processing, observational bias, data interpretation, and scientific writing skills.

PH 440 X-rays and Crystalline Materials 2R-6L-4C S (even years)
Prerequisites: PH 255W or PH 265S
Corequisites: There are no corequisites for this course.
X-ray emission, absorption, fluorescence, and diffraction. Methods of analyzing crystalline solid materials. Applications in solid-state physics, materials science, chemistry, metallurgy, and biology.

PH 460 Directed Study 1-4C
Prerequisites: Consent of instructor

Corequisites: There are no corequisites for this course.
Permits study in an area of physics not available in regular course offerings. Maximum of 4 credits per term.

PH 470 Special Topics in Physics 2-4C

Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
Lectures on special topics in physics.

PH 480 Seminar 0C

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Lectures by staff, students, and outside speakers on topics of special interest.

PH 490 Directed Research 1-2 C

Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
Research for junior and senior students under the direction of a physics and optical engineering faculty member. May earn a maximum of 8 credits between PH 290 and PH 490 for meeting graduation requirements. Maximum of 2 credits per term. The student must make arrangements with a physics and optical engineering faculty member for the research project prior to registering for this course.

PH 496 Senior Thesis 2-4C

Prerequisites: Consent of PHOE faculty
Corequisites: There are no corequisites for this course.
Literature search, research proposal preparation, and laboratory project work with a total number of 8 credit hours over the three quarter sequence. This sequence is designed to result in a completed senior thesis.

PH 497 Senior Thesis 2-4C F

Prerequisites: Consent of PHOE faculty
Corequisites: There are no corequisites for this course.
Literature search, research proposal preparation, and laboratory project work with a total number of 8 credit hours over the three quarter sequence. This sequence is designed to result in a completed senior thesis.

PH 498 Senior Thesis 2-4C W

Prerequisites: Consent of PHOE faculty
Corequisites: There are no corequisites for this course.
Literature search, research proposal preparation, and laboratory project work with a total number of 8 credit hours over the three quarter sequence. This sequence is designed to result in a completed senior thesis.

PH 499 Physics Ethics and Communication 1R-0L-1C S

Prerequisites: PH 497F, PH 498W or PH 425W
Corequisites: There are no corequisites for this course.
Guidelines will be discussed to encourage ethical reporting and conduct of research performed by individuals. Situations in physics research and publication will be presented and discussed in regards to ethical reporting and conduct. As the final component of the students' Senior Thesis, students will prepare oral and written presentations of their research and present them at a public forum held near the end of the spring term. Students not in the thesis track will present (in both oral and written form) the projects conducted in PH425 Advanced Physics Lab II.

PH 505 Semiconductor Materials & Devices I 3R-3L-4C F
Prerequisites: PH 113S,F,W or PH 255W or PH 265S
Corequisites: There are no corequisites for this course.
Material structure electronic levels and energy bands; semiconductor doping; optical and electronic material characteristics; p-n junction and diode characteristics; bipolar junction transistor; basics of device fabrication. Laboratories on X-ray and Scanning Electron Microscope investigations, device characteristics and a three-week design project on production and testing of thin films. Students must do additional project work on a topic selected by the instructor. Cross-listed with PH 405.

PH 512 Methods of Mathematical Physics 4R-0L-4C
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Ordinary and partial differential equations, linear vector spaces, matrices, tensors. Strum-Liouville theory and eigenvalue problems, special functions, function of a complex variable, theory of groups, linear integral equations.

PH 514 Quantum Mechanics 4R-0L-4C
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Development of quantum mechanical theory to the present time. Examples from spectroscopy, chemistry, nuclear physics.

PH 530 Advanced Acoustics 4R-0L-4C
Prerequisites: PH 404W (odd years)
Corequisites: There are no corequisites for this course.
Waves in solids, electrodynamics and piezoelectric sound transducers, ultrasonics. Architectural acoustics. Underwater sound.

PH 538 Introduction to Neural Networks 3R-3L-4C
Prerequisites: Senior or Graduate Standing
Corequisites: There are no corequisites for this course.
Classifiers, linear separability. Supervised and unsupervised learning. Perceptrons. Back-propagation. Feedback networks. Hopfield networks. Associative memories. Fuzzy neural networks. Integral laboratory.

PH 540 Computer Physics 3R-3L-4C
Prerequisites: Consent of instructor
Corequisites: There are no corequisites for this course.
Exploration of physics by simulation including planetary motion, waves, chaos, cellular automata and fractals; application of numerical methods of differentiation and integration; computer hardware and machine language as it affects laboratory use; curve fitting and smoothing of data.

Pre-Professional Programs & Advising

Many graduates of Rose-Hulman choose to pursue professional or graduate studies after completion of their undergraduate studies. Engineering and science curricula provide excellent backgrounds for careers in business, law, and medicine. A student planning to enter a professional or graduate school should seek information as to the requirements for entrance into the institution of their choice and should arrange their undergraduate program accordingly. Advisors are available on the campus to advise and assist students interested in pursuing such studies after graduation.

Pre-business Courses

Any of the prescribed curricula at Rose-Hulman are satisfactory for entrance into a professional school of business administration. Students interested in this area will find courses in economics, statistics, operations research, and computer sciences particularly helpful.

Pre-law Advising

Law schools accept superior students from a wide variety of undergraduate backgrounds. The analytical training and problem-solving techniques inherent in engineering and science programs are particularly helpful to students interested in pursuing law careers. Law schools require that the Law School Admission Test (LSAT) be taken prior to consideration for admission. Contact the Pre-Law Adviser for more information.

Pre-medicine Advising

Because of the increased importance of engineering and instrumentation technology in modern medicine, medical schools are very interested in attracting superior students with engineering and science backgrounds. The various curricula at Rose-Hulman, when supplemented with elective courses available, enable the student to meet all course requirements for admission to medical school.

Each medical school has its own specific minimum academic requirements but the generally include basic courses in general chemistry, physics, organic chemistry, and biology. Programs in biology, biomedical engineering, biochemistry, chemistry and chemical engineering provide especially helpful backgrounds for this purpose, but many Rose-Hulman graduates from a variety of disciplines such as mathematics, physics, mechanical engineering, and electrical engineering, have completed medical school and are successful practicing physicians.

Application to a medical school should be made between May and October of the year previous to that in which the applicant expects to enter. The Medical College Admissions Test (MCAT) is required for consideration for admission. Interested students should contact the Health Professions Adviser for additional information.

ROTC: Air Force

Air Force ROTC is designed as a four year training program that culminates in a student's becoming an Officer in the United States Air Force. This program is designed to run concurrently with the four year college curriculum and is open to all college students at no obligation.*

We also offer modified programs which can be completed in three or two years which also earn a commission in the Air Force. Once students have completed Air Force ROTC and college requirements they are off to serve at least the next four years in leadership positions throughout the Air Force.

*Based on individual situations, Air Force ROTC will ask for an obligation before more advanced training or monies are paid to a student. Until such time, the classes are free and at no obligation-contact Air Force ROTC for more details.

SCHOLARSHIPS

The Air Force is looking for the best and brightest students the country has to offer. To assist these students with their college education, a variety of scholarships are offered on a nationwide competitive basis. Scholarship winners attending Rose-Hulman can receive up to the full cost of tuition, plus payment of most school fees. Scholarships also pay for books along with a monthly tax-free stipend, during the school year. In addition, Rose-Hulman offers financial incentives to students bringing their ROTC scholarship to Rose-Hulman. For more information on Air Force scholarships, contact Rose-Hulman Admissions or Air Force ROTC Detachment 218 at Indiana State University, Technology Center Room 203, Terre Haute, IN 47809-2245. Phone (812) 237-2657.

The Air Force ROTC courses are designed to develop the leadership and management skills required to be an effective Air Force officer. Topics range from Air Force history to ethics and values. The curriculum is separated into four (4) major areas:

Profession of Arms Designed specifically for the continued development of professional knowledge and skills unique to the Air Force profession. Subject areas include officership, military law, laws of armed conflict, military customs and courtesies, and the individual's role in supporting organizational and Air Force policies.

Communications Skills Designed specifically to enhance professional development, which is integrated throughout the AFROTC curriculum. Emphasis is on a progressive study of the various communication skills required of Air Force junior officers. The curriculum is designed to provide both instruction and application of principles and concepts in written communications, staff communication instruments, oral communication, and the nature and art of effective listening.

Leadership Studies Designed to examine aspects of military leadership and management functions as a part of the overall concept of leadership. An examination of leader variables and characteristics provides a lead-in to a protracted study of leadership theory. Leadership and management skills are developed and applied in Leadership Laboratory and cadet corps activities. Leadership training is emphasized at Field Training where team sports, military drill, and special leadership problems are mandatory.

Military Studies/International Security Studies Designed to develop an understanding of the nature of conflict and how the United States military forces, particularly aerospace forces, are developed, organized, and employed. Subjects include the need for national security, the evolution and formulation of American defense policy and strategy, regional security issues, and joint doctrine.

Benefits
Air Force ROTC classes, text books, and uniforms are free to all fully-enrolled cadets. Once enrolled as a full member of the program, cadets are eligible to attend a variety of professional development programs during the summer months. Successful completion of the Air Force ROTC program results in a commission as a Second Lieutenant in the active duty US Air Force.

Plan of Study

Freshman

Fall

Course	Credit
AS 101 Found. of the US Air Force I	1
AS 101L Leadership Laboratory	0

AS 102 Found.of the US Air Force II	1
AS 102L Leadership Laboratory	0
AS 103 Found.of the US Air Force III	1
AS 103L Leadership Laboratory	0
	Total Credits: 3

Sophomore

Fall

Course	Credit
AS 201 Evol. of Air & Space Power I	2
AS 201L Leadership Laboratory	0
AS 202 Evol. of Air & Space Power II	2
AS 202L Leadership Laboratory	0
AS 203 Evol. of Air & Space Power III	2
AS 203L Leadership Laboratory	0
	Total Credits: 6

Junior

Fall

Course	Credit
AS 301 Air Force Lead. Studies I	4
AS 301L Leadership Laboratory	0
AS 302 Air Force Lead. Studies II	4
AS 302L Leadership Laboratory	0
AS 303 Air Force Lead. Studies III	4
AS 303L Leadership Laboratory	0
	Total Credits: 12

Senior

Fall

Course	Credit
AS 401 Nat.Sec.Aff./Prep. for Active Duty I	4
AS 401L Leadership Laboratory	0
AS 402 Nat.Sec.Aff./Prep. for Active Duty II	4
AS 402L Leadership Laboratory	0

AS 403 Nat.Sec.Aff./Prep. for Active Duty III	4	
AS 403L Leadership Laboratory	0	
		Total Credits: 12

NOTES:

Leadership Laboratory is part of the curriculum for all four years of study. This lab is designed to give students hands-on application of the skills taught in the classes. In addition, students practice the various customs and courtesies and leadership skills they will be use once they enter active duty.

ROTC-Air Force - Course Descriptions

AS 101 Heritage and Values I 1R-2L-1C F
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
This is a survey course designed to introduce students to the Department of the Air Force (DAF) and provides an overview of the basic characteristics, missions, communications and organization of the Air and Space Forces

AS 101L Leadership Laboratory - F,W,S
Prerequisites: AS 101F* or AS 102W* or AS 103W* *Enrollment in one of the three courses
Corequisites: There are no corequisites for this course.
Meets one day a week for 2 hours. This class is mandatory for cadets who apply for membership in the AFROTC program and who are pursuing a commission in the United States Air Force. Cadets apply leadership concepts and principles, and practice critical skills needed to be an effective Air Force officer. Activities include physical fitness training, communication exercises, drill and ceremonies, and active duty Air Force experiences.

AS 102 Heritage and Values II 1R-2L-1C W
Prerequisites: AS 101F or consent of instructor
Corequisites: There are no corequisites for this course.
This is a survey course designed to introduce students to the Department of the Air Force (DAF) and provides an overview of the basic characteristics, missions, communications and organization of the Air and Space Forces

AS 102L Leadership Laboratory - F,W,S
Prerequisites: AS 101F* or AS 102W* or AS 103W* *Enrollment in one of the three courses
Corequisites: There are no corequisites for this course.
Meets one day a week for 2 hours. This class is mandatory for cadets who apply for membership in the AFROTC program and who are pursuing a commission in the United States Air Force. Cadets apply leadership concepts and principles, and practice critical skills needed to be an effective Air Force officer. Activities include physical fitness training, communication exercises, drill and ceremonies, and active duty Air Force experiences.

AS 103 Heritage and Values III 1R-2L-1C W
Prerequisites: AS 102W or consent of instructor
Corequisites: There are no corequisites for this course.

This is a survey course designed to introduce students to the Department of the Air Force (DAF) and provides an overview of the basic characteristics, missions, communications and organization of the Air and Space Forces

AS 103L Leadership Laboratory - F,W,S

Prerequisites: AS 101F* or AS 102W* or AS 103W* *Enrollment in one of the three courses

Corequisites: There are no corequisites for this course.

Meets one day a week for 2 hours. This class is mandatory for cadets who apply for membership in the AFROTC program and who are pursuing a commission in the United States Air Force. Cadets apply leadership concepts and principles, and practice critical skills needed to be an effective Air Force officer. Activities include physical fitness training, communication exercises, drill and ceremonies, and active duty Air Force experiences.

AS 201 The Evolution of Air and Space Power I 2R-3L-2C F

Prerequisites: AS 103W or consent of instructor

Corequisites: There are no corequisites for this course.

This course designed to examine the general aspects of air and space power through a historical perspective. Utilizing this perspective, the course covers a time period from the first balloons and dirigibles to the space-age global positioning systems of the Persian Gulf War. Historical examples are provided to extrapolate the development of Air Force capabilities (competencies), and missions (functions) to demonstrate the evolution of what has become today's USAF air and space power. Furthermore, the course examines several fundamental truths associated with war in the third dimension: e.g. Principles of War and Tenets of Air and Space Power. As a whole, this course provides the cadets with a knowledge level understanding for the general element and employment of air and space power, from an institutional doctrinal and historical perspective. In addition, the students will continue to discuss the importance of the Air Force Core Values, through the use of operational examples and historical Air Force leaders, and will continue to develop their communication skills. Leadership Laboratory is mandatory for AFROTC cadets and complements this course by providing cadets with followership experiences.

AS 201L Leadership Laboratory 0 F,W,S

Prerequisites: AS 201F* or AS 202W* or AS 203S* *Enrollment in one of the three courses

Corequisites: There are no corequisites for this course.

Meets one day a week for 3 hours. This class is mandatory for cadets who apply for membership in the AFROTC program and who are pursuing a commission in the United States Air Force. Cadets apply leadership concepts and principles, and practice critical skills needed to be an effective Air Force officer. Activities include physical fitness training, communication exercises, drill and ceremonies, and active duty Air Force experiences.

AS 202 The Evolution of Air and Space Power II 2R-3L-2C W

Prerequisites: AS 201F or consent of instructor

Corequisites: There are no corequisites for this course.

This course is a continuation of the fall quarter course designed to examine the general aspects of air and space power through a historical perspective.

AS 202L Leadership Laboratory 0 F,W,S

Prerequisites: AS 201F* or AS 202W* or AS 203S* *Enrollment in one of the three courses
Corequisites: There are no corequisites for this course.
Meets one day a week for 3 hours. This class is mandatory for cadets who apply for membership in the AFROTC program and who are pursuing a commission in the United States Air Force. Cadets apply leadership concepts and principles, and practice critical skills needed to be an effective Air Force officer. Activities include physical fitness training, communication exercises, drill and ceremonies, and active duty Air Force experiences.

AS 203 The Evolution of Air and Space Power III 2R-3L-2C S

Prerequisites: AS 202W or consent of instructor
Corequisites: There are no corequisites for this course.
This course is a continuation of the winter quarter course designed to examine the general aspects of air and space power through a historical perspective.

AS 203L Leadership Laboratory 0 F,W,S

Prerequisites: AS 201F* or AS 202W* or AS 203S* *Enrollment in one of the three courses
Corequisites: There are no corequisites for this course.
Meets one day a week for 3 hours. This class is mandatory for cadets who apply for membership in the AFROTC program and who are pursuing a commission in the United States Air Force. Cadets apply leadership concepts and principles, and practice critical skills needed to be an effective Air Force officer. Activities include physical fitness training, communication exercises, drill and ceremonies, and active duty Air Force experiences.

AS 301 Leading People and Effective Communication I 3R-3L-4C F

Prerequisites: Enrollment in Professional Officer Corps
Corequisites: There are no corequisites for this course.
This course utilizes student's field training experience to take a more in-depth look at leadership. Special emphasis is placed on enhancing communication skills, and why that is important as a leader. Students have an opportunity to try out these leadership and management skills techniques in a supervised environment as juniors and seniors.

AS 301L Leadership Laborator - F,W,S

Prerequisites: AS 301F* or AS 302W* or AS 303S* *Enrollment in one of the three courses
Corequisites: There are no corequisites for this course.
Meets one day a week for 3 hours. This class is mandatory for cadets who apply for membership in the AFROTC program and who are pursuing a commission in the United States Air Force. Cadets apply leadership concepts and principles, and practice critical skills needed to be an effective Air Force officer. Activities include physical fitness training, communication exercises, drill and ceremonies, and active duty Air Force experiences.

AS 302 Leading People and Effective Communication II 3R-3L-4C W

Prerequisites: AS 301F
Corequisites: There are no corequisites for this course.
This course utilizes student's field training experience to take a more in-depth look at leadership. Special emphasis is placed on enhancing communication skills, and why that is important as a leader. Students have an opportunity to try out these leadership and management skills techniques in a supervised environment as juniors and seniors.

AS 302L Leadership Laborator - F,W,S

Prerequisites: AS 301F* or AS 302W* or AS 303S* *Enrollment in one of the three courses

Corequisites: There are no corequisites for this course.

Meets one day a week for 3 hours. This class is mandatory for cadets who apply for membership in the AFROTC program and who are pursuing a commission in the United States Air Force. Cadets apply leadership concepts and principles, and practice critical skills needed to be an effective Air Force officer. Activities include physical fitness training, communication exercises, drill and ceremonies, and active duty Air Force experiences.

AS 303 Leading People and Effective Communication III 3R-3L-4C S

Prerequisites: AS 302W

Corequisites: There are no corequisites for this course.

This course utilizes student's field training experience to take a more in-depth look at leadership. Special emphasis is placed on enhancing communication skills, and why that is important as a leader. Students have an opportunity to try out these leadership and management skills techniques in a supervised environment as juniors and seniors.

AS 303L Leadership Laborator - F,W,S

Prerequisites: AS 301F* or AS 302W* or AS 303S* *Enrollment in one of the three courses

Corequisites: There are no corequisites for this course.

Meets one day a week for 3 hours. This class is mandatory for cadets who apply for membership in the AFROTC program and who are pursuing a commission in the United States Air Force. Cadets apply leadership concepts and principles, and practice critical skills needed to be an effective Air Force officer. Activities include physical fitness training, communication exercises, drill and ceremonies, and active duty Air Force experiences.

AS 401 National Security Affairs and Preparation for Active Duty I 3R-3L-4C F

Prerequisites: AS 303S

Corequisites: There are no corequisites for this course.

This course is designed for college seniors and provides them the foundation to understand their role as military officers and how they are directly tied to our National Security Strategy. It is an overview of the complex social and political issues facing the military profession and requires a measure of sophistication commensurate with the senior college level.

AS 401L Leadership Laboratory - F,W,S

Prerequisites: AS 401F* or AS 402W* or AS 403S* *Enrollment in one of the three courses

Corequisites: There are no corequisites for this course.

Meets one day a week for 3 hours. This class is mandatory for cadets who apply for membership in the AFROTC program and who are pursuing a commission in the United States Air Force. Cadets apply leadership concepts and principles, and practice critical skills needed to be an effective Air Force officer. Activities include physical fitness training, communication exercises, drill and ceremonies, and active duty Air Force experiences.

AS 402 National Security Affairs and Preparation for Active Duty II 3R-3L-4C W

Prerequisites: AS 401F

Corequisites: There are no corequisites for this course.

This course is designed for college seniors and provides them the foundation to understand their role as military officers and how they are directly tied to our National Security Strategy. It is an overview of the complex social and political issues facing the military profession and requires a measure of sophistication commensurate with the senior college level.

AS 402L Leadership Laboratory - F,W,S

Prerequisites: AS 401F* or AS 402W* or AS 403S* *Enrollment in one of the three courses

Corequisites: There are no corequisites for this course.

Meets one day a week for 3 hours. This class is mandatory for cadets who apply for membership in the AFROTC program and who are pursuing a commission in the United States Air Force. Cadets apply leadership concepts and principles, and practice critical skills needed to be an effective Air Force officer. Activities include physical fitness training, communication exercises, drill and ceremonies, and active duty Air Force experiences.

AS 403 National Security Affairs & Preparation for Active Duty III 3R-3L-4C S

Prerequisites: AS 402W

Corequisites: There are no corequisites for this course.

This course is designed for college seniors and provides them the foundation to understand their role as military officers and how they are directly tied to our National Security Strategy. It is an overview of the complex social and political issues facing the military profession and requires a measure of sophistication commensurate with the senior college level.

AS 403L Leadership Laboratory - F,W,S

Prerequisites: AS 401F* or AS 402W* or AS 403S* *Enrollment in one of the three courses

Corequisites: There are no corequisites for this course.

Meets one day a week for 3 hours. This class is mandatory for cadets who apply for membership in the AFROTC program and who are pursuing a commission in the United States Air Force. Cadets apply leadership concepts and principles, and practice critical skills needed to be an effective Air Force officer. Activities include physical fitness training, communication exercises, drill and ceremonies, and active duty Air Force experiences.

ROTC: Army

The completion of the Army ROTC program leads to a commission as a Second Lieutenant in the Active Army, Army Reserve or Army National Guard. Students completing the program receive their commissions upon graduation and serve a specified period of active duty ranging from three months to four years, depending upon the student’s choice of commissioning program and Army requirements.

CURRICULUM

The ROTC program specializes in teaching leadership and management skills required by the military and sought by civilian employers. ROTC cadets learn how to motivate co-workers and how to plan, organize and implement large projects and tasks. They also learn skills in demand in civilian businesses, such as teamwork, tact problem solving, decision making, and effective communication. The program includes the Basic Course for freshmen and sophomores and the Advanced Course for juniors and seniors. Students incur active duty and reserve commitments only upon enrollment in the Advanced Course or through the ROTC scholarship program and successful completion of the curriculum.

Students who miss out on the basic ROTC Freshman and Sophomore curriculum can attend a four-week (LTC) leadership training course at Fort Knox, KY., during the summer between their sophomore and junior years.

In the Advanced Course, students must complete 18 credit hours of Military Science and the 5-week ROTC Leadership Development and Assessment Course (MS 304) at Fort Lewis, WA. Qualified students may also participate in Army Airborne, Air Assault, Northern Warfare, or Mountain Warfare training.

Veterans and students who received ROTC training in high school should contact the Department concerning possible constructive credit for part or all of the Basic Course. Graduate students, transfer students and students who expect to complete degree requirements in less than four years should contact the Department concerning an accelerated program if they desire to obtain a commission. Other programs are available for selected students to complete the program in 2 years or less.

Allowances
Uniforms are furnished, when appropriate, to all students without charge. Students on scholarship and/or enrolled in the Advanced Course receive a monthly subsistence allowance that ranges from $250-400 per month during the school year and approximately $20 per day during the ROTC Advanced Camp, plus free room and board (meals).

Scholarships
ROTC awards Full-Tuition scholarships plus free Room/Board per year, providing money for tuition and educational fees. Scholarships are awarded strictly on merit, although the Institute provides an additional financial incentive. Scholarship winners also receive a designated textbook allowance of $900 per year and a tax-free stipend allowance from $300-500 per month for up to 10 months for each year the scholarship is in effect. Four-year scholarships are open to high school graduates prior to entering Army ROTC as freshmen. The three and two year scholarships are available to students enrolled in ROTC at Rose-Hulman. Full details on the scholarship program may be obtained by contacting the ROTC office at 1 (800)-248-7448, extension 8348 or 8236, or by visiting the Army ROTC home page at http://www.rose-hulman.edu/AROTC/

Partnership Institutions
Through a cooperative agreement, students at Indiana State University, Saint Mary-of-the-Woods College, University of Southern Indiana (USI) and DePauw University may participate in the Rose-Hulman Military Science program.

*All contracted cadets must attend Leadership Laboratories and Physical Training..

Plan of Study

Freshman

Full Year

Course	Credit
MS 101 Leadership & Personal Development	1
MS 102 Introduction to Tactical Leadership	1
MS 103 Basic Tactical Leadership	1
	Total Credits: 3

Sophomore

Full Year

Course	Credit
MS 201 Innovative Team Leadership	2
MS 202 Foundations of Tactical Leadership	2
MS 203 Foundations of Tactical Leadership II	2
	Total Credits: 6

Junior

Full Year

Course	Credit
MS 301 Adaptive Team Leadership	4
MS 302 Leadership Under Fire	4
MS 303 Leadership Under Fire II	4
	Total Credits: 12

Senior

Full Year

Course	Credit
MS 401 Developing Adaptive Leaders	4
MS 402 Leadership in a Complex World	4
MS 403 Leadership in a Complex World II	4
	Total Credits: 12

NOTES:

*All contracted cadets must attend Leadership Laboratories and Physical Training..

SUMMER COURSE:

MS 206 ROTC Basic Camp - no credits

ROTC-Army - Course Descriptions

MS 101 Introduction to the Army and Critical Thinking 1R-3L-1C F

Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
MS 101 introduces Cadets to the personal challenges and competencies that are critical for effective leadership. Cadets learn how the personal development of life skills such as critical thinking, time management, goal setting, stress management, and comprehensive fitness relate to leadership, and the Army profession.

MS 102 Adaptive Leadership & Professional Competence 1R-3L-1C W

Prerequisites: MS 101F or consent of instructor
Corequisites: There are no corequisites for this course.
MS 102 introduces Cadets to the personal challenges and competencies that are critical for adaptive leadership. Cadets learn the basics of the communications process and the importance for leaders to develop the essential skills to effectively communicate in the Army. Students will examine the Army Profession and what it means to be a professional in the U.S. Army.

MS 103 Basic Tactical leadership 1R-3L-1C S

Prerequisites: MS 101F, and MS 102W or consent of instructor
Corequisites: There are no corequisites for this course.
MS 103 continues the exploration of leadership fundamentals and examines the leadership process as affected by individual differences and styles, group dynamics, and personality behavior of leaders. Students will experience an introduction of fundamental leadership concepts, and examine factors that influence leader and group effectiveness. Students will fully explore the basic soldier skills and squad level tactical operations. Students participate in briefings and hands-on practical exercises. Attention is devoted to development of leadership potential through practical exercises both in and out of the classroom.

MS 201 Leadership and Decision Making 2R-3L-2C F

Prerequisites: MS 101F, and MS 102W, and MS 103S or consent of instructor
Corequisites: There are no corequisites for this course.
MS 201 explores the dimensions of creative and innovative tactical leadership strategies and styles by examining team dynamics and two historical leadership theories that form the basis of the Army leadership framework. Aspects of personal motivation and team building are practiced planning, executing and assessing team exercises.

MS 202 Army Doctrine & Team Development 2R-3L-2C W

Prerequisites: MS 201F or consent of instructor
Corequisites: There are no corequisites for this course.
MS 202 examines the challenges of leading teams in the complex operational environment. The course highlights dimensions of terrain analysis, patrolling, and operation orders. Further study of the theoretical basis of the Army Leadership Requirements Model explores the dynamics of adaptive leadership in the context of military operations. Cadets develop greater self awareness as they assess their own leadership styles and practice communication and team building skills.

MS 203 Foundations of Tactical Leadership II 2R-3L-2C S

Prerequisites: MS 201F, and MS 202W or consent of instructor
Corequisites: There are no corequisites for this course.
MS203 continues the examination of the challenge of leading tactical teams in the complex contemporary operational environments. Dimensions of the cross-cultural challenges of leadership in a constantly changing world are highlighted and applied to practical Army leadership tasks and situations. Cadets develop greater self-awareness as they practice communication and team building skills. Contemporary Operational Environment case studies give insight into the importance and practice of teamwork and tactics in real world scenarios.

MS 206 ROTC Cadet Initial Entry Training Course -
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
Covering a training period of approximately thirty days, the Department of Military Science ROTC battalion provides travel to and from Fort Knox. Students may attend to access their desire to continue and contract into the ROTC Advanced Course. While in the course, you will meet students from all over the nation while earning $700 in pay and receive free room and board. You may apply for a two-year Full-tuition scholarship and receive up to $1200 annually for books and earn a monthly stipend of over $450 per month for 10 months per year. The Cadet Initial Entry Training Course is a way to catch up on missed Military Science courses in order to qualify the student for progression as a contracted Advanced Course ROTC cadet.

MS 301 Training Management and the Warfighting Functions 3R-3L-4C F
Prerequisites: MS 206W or completion of Basic Course requirements, or prior military service (contact Military Science Department for specific requirements established in Army Regulations)
Corequisites: There are no corequisites for this course.
MS 301 Cadets will study, practice, and apply the fundamentals of Army Leadership, Officership, Army Values and Ethics, Personal Development, and small unit tactics at the platoon level. At the conclusion of this course, Cadets will be capable of planning, coordinating, navigating, motivating and leading a squad and platoon in the execution of a mission during a classroom PE, a Leadership Lab, or during a Leader Training Exercise (LTX).

MS 302 Applied Leadership in Small Unit Operations 3R-3L-4C W
Prerequisites: MS 301F
Corequisites: There are no corequisites for this course.
MS 302 uses increasingly intense situational leadership challenges to build cadet awareness and skills in leading small units. Skills in decision-making, persuading and motivating team members when under fire are explored, evaluated, and developed. Aspects of military operations are reviewed as a means of preparing for the ROTC Cadet Leader Course (CLC). Cadets are expected to apply basic principles of the Law of Land Warfare, Army training, and motivation to troop leading procedures. Emphasis is also placed on conducting military briefings and developing proficiency in garrison operation orders. Cadets are evaluated on what they know and do as leaders.

MS 303 Leadership under Fire II 3R-3L-4C S
Prerequisites: MS 302W
Corequisites: There are no corequisites for this course.
MS 303 continues development in decision making, persuading, and motivating team members in operational situations are explored, evaluated and developed. Aspects of

military operations are reviewed as a means of preparing for CLC. Cadets are expected to apply basic principles of Law of the Land Warfare, Army training, and motivation to troop leading procedures. Emphasis is also placed on conducting military briefings and developing proficiency in garrison operations orders. Cadets are evaluated on what they know and do as leaders.

MS 401 Mission Command & Ethics 3R-3L-4C F

Prerequisites: MS 303S

Corequisites: There are no corequisites for this course.

MS 401 is an advanced course that places primary emphasis on Officership with our MS IV cadets who are our educational main effort; MS 401 and 402 together refine and ultimately completes the Cadet-tocommissioned officer transition. In MS 401 Mission Command and ethics is stressed in order to assist the Cadet in further embracing their future role as an Army officer.

MS 402 Mission Command and the Army 3R-3L-4C W

Prerequisites: MS 401F

Corequisites: There are no corequisites for this course.

MS 402 and MS 403 are the culmination of a four-year sequential, progressive, challenging developmental leadership experience. It is during this quarter and MSL 403 that the Cadet is undergoing final preparation for the duties and responsibilities of a commissioned officer along with their integration into the Army. The emphasis is placed on critical knowledge, skills, abilities and competencies skills newly commissioned officers will need to succeed in their first unit of assignment, and the modern operating environment where they will be expected to plan, prepare, execute, and assess platoon-level training strategies and more to enable mission accomplishment.

MS 403 Leadership in a Complex World II 3R-3L-4C S

Prerequisites: MS 401F

Corequisites: There are no corequisites for this course.

MS 403 continues the exploration of the dynamics of leading in the complex situations of current military operations from MS 402. Cadets examine differences in customs and courtesies, military law, principles of war, and rules of engagement in the face of international terrorism. Aspects of interacting with non-government organizations, civilians on the battlefield, and host nation support are examined and evaluated. Significant emphasis is placed on preparing cadets for their first unit of assignment as Second Lieutenants.

MS 497 Military Science Independent Study Variable Credit

Prerequisites: MS 301F, and MS 302W, and MS 303S and consent of instructor

Corequisites: There are no corequisites for this course.

MS 497 provides ROTC cadets who have completed their Cadet Leader Course the opportunity to conduct detailed research and independent study on a current problem or topic associated with the military. Program of study will be arranged individually with the Professor of Military Science.

Overview of CLC Cadet Leader Course - S

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

The purpose of the course is to train U.S. Army ROTC Cadets to Army standards, to develop their leadership skills, and to evaluate their officer potential. The 29-day course starts with individual training and leads to collective training, building from simple to complex tasks. This building-block approach permits integration of previouslylearned skills into follow-on training. This logical, common-sense training sequence is maintained for each training cycle. Every day at CLC is a day of training.

Software Engineering

Software engineering is the creation of software using a process similar to other engineering disciplines. It allows for software to be reliable and developed within time and cost estimates. The software engineering curriculum prepares students for a career in reliable, economical software development.

Programming is only one phase (construction) of software engineering. There are many other aspects of the software engineering process, such as requirements definition, architectural design, and quality assurance, which need to be applied in order to develop reliable software on time and within budget constraints. The software engineering curriculum provides students a solid background in both the theory and practice of all phases in the software engineering process, beginning with their first course of study in the Department of Computer Science and Software Engineering, and continuing to the end of the senior year.

Since software is a non-physical product developed and executed on computers, the software engineering curriculum has computer science as its primary engineering science. The computer science courses taken by software engineering majors include the study of algorithms, data structures, database concepts, computer architecture, programming languages and operating systems. Software engineering majors also complete important courses in other closely related fields, such as discrete mathematics, digital logic design, and engineering statistics.

Coverage of software engineering topics begins in a three-term introduction to software development during the freshman and sophomore years. This study continues with coverage of core software engineering areas in the junior year, including software requirements, software architecture, software design, software project management, software construction, software maintenance, software evolution, software quality assurance, and formal methods in software specification and design. All of these courses include individual and team projects relevant to that particular area of software engineering. These projects generally include both written and oral presentations, building upon a technical communication course which introduces the student to the skills necessary for this important aspect of being a software professional. Throughout the senior year, a capstone team project develops and delivers software for a “real-world” client, which is put on display locally at a public exposition.

Throughout society, software exists for a wide variety of application domain areas. Each student is required to take at least three courses in a particular application domain, so that RHIT software engineering graduates can more effectively apply the software engineering principles they learn to that domain area. Students can choose from a variety of domain areas, including engineering, scientific and commercial applications.

Courses in various computer science topics such as computer graphics, artificial intelligence, computer networks, computer vision, web-based information systems, and cryptography are among those available as advanced electives. In addition, free elective courses allow students to tailor their undergraduate education to their specific goals.

The department has its own local area network. This network is connected to the campus-wide network and the Internet. Laboratory machines are mostly Sun Ultra workstations. Software engineering majors have unlimited access to the department's laboratories. Software engineering students are frequently employed by the computing center as user consultants and by the department as system managers and course assistants.

The student chapter of the Association for Computing Machinery provides seminars and other technical activities throughout the year. The national honor society in the computing and engineering disciplines, Upsilon Pi Epsilon and Tau Beta Pi, both have chapters at Rose-Hulman. Software engineering majors are also eligible to join the Order of the Engineer, which focuses on the ethical and professional responsibilities of an engineer, during the spring of their last year of study.

Software Engineering Program Educational Objectives

The software engineering program prepares its graduates for many types of careers in the computing industry as well as for graduate study in software engineering and in closely related disciplines. Within a few years after completing the software engineering degree program, our graduates will:

1. Advance beyond their entry-level position to more responsible roles, or progress towards completion of advanced degree(s).
2. Continue to keep pace with advancements in their disciplines, and develop professionally in response to changes in roles and responsibilities.
3. Demonstrate that they can collaborate professionally within or outside of their disciplines at local, regional, national, or international levels.
4. Contribute to the body of computing products, services, or knowledge.

Software Engineering Student Outcomes

By the time students graduate with a Software Engineering degree from Rose-Hulman, they will be able to:

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.

The Computer Science and Software Engineering faculty strives to maintain an open atmosphere that encourages mutual respect and support as well as learning and sharing of knowledge.

The software engineering program is accredited by the Engineering Accreditation Commission of ABET, https://www.abet.org, under the commission's General Criteria and Program Criteria for Software and Similarly Named Engineering Programs.

SOFTWARE ENGINEERING

Summary of graduation requirements for the software engineering major

To complete the major in software engineering a student must complete the following:

1. All required courses listed by number in the schedule of courses above: CSSE120, CSSE132, CSSE220, CSSE230, CSSE232, CSSE280, CSSE304, CSSE332, CSSE333, CSSE371, CSSE372, CSSE373, CSSE374, CSSE375, CSSE376, CSSE477, CSSE497, CSSE498, CSSE499; ECE233, MA111, MA112, MA113, MA221, MA276, MA374, MA381; PH111, PH112, CHEM111; HUMH190, ENGLH290; RHIT100.
2. Eight credits of additional software engineering courses numbered between 300 and 492 and designated as software engineering electives. The student's academic advisor must approve the course used to satisfy this requirement. Use of software engineering courses numbered 490 through 492 to fulfill this requirement must be approved by the department head. Credits used to satisfy any requirements for a minor or secondary major pursued by a student cannot also be used to satisfy SE elective requirements for the student's primary or secondary major in Software Engineering. Credits used by a student pursuing a secondary major in SE that are intended to satisfy the SE elective requirement can only be used to satisfy technical or free elective requirements within the student's primary major or not used towards any requirements within the primary major.
3. Four additional credits of technical electives, consisting of any courses in biology, chemistry, engineering (except software engineering and engineering management), geology, mathematics, biomathematics, or physics.
4. Four additional credits of courses offered by the Department of Mathematics excluding MA351 MA356. The student's academic advisor must approve the coursesused to satisfy this requirement.
5. Four credits of science electives, which can be any CHEM, GEOL, PH, or BIO courses not already required for the software engineering major.
6. Twenty-eight credits of additional courses offered by the Department of Humanities and Social Sciences; the distribution of these courses must meet the requirements of that department.
7. Twelve credits of free elective courses.These courses must have the approval of the student's academic advisor. Free electives may be selected from any Rose-Hulman course.
8. A total of 192 credits.

DATA SCIENCE MAJOR (SECOND MAJOR ONLY)

Data Science is open to all students as a second major; this means that the student will have some other discipline as their primary major. Students whose primary major is in Computer Science, Software Engineering or Mathematics will find the Data Science program the easiest since there is considerable overlap between those programs and the Data Science requirements Students from other disciplines are also encouraged to participate, but will have to take more courses. All students are encouraged to take the individual courses in the program, regardless of whether they wish to fulfill the second major requirements. Learn more about Data Science requirements.

Minor in Software Engineering

Advisor: CSSE Department Head

Students majoring in Computer Science may not receive a Software Engineering minor.

Required Courses

CSSE 120, Introduction to Software Development
CSSE 220, Object-Oriented Software Development
CSSE 230, Data Structures and Algorithm Analysis
CSSE 371, Software Requirements Engineering
CSSE 374, Software Design

Two additional courses in software engineering chosen from CSSE 372, 373, 375, 376, and 477, and courses identified as Software Engineering (SE) electives.

Plan of Study

Freshman

Fall

Course	Credit
CSSE 120 Introduction to Software Development	4
MA 111 Calculus I	5
PH 111 Physics I	4
HUM H190 First-Year Writing Seminar	4
RHIT 100 Foundations for Rose-Hulman Success	1
	Total Credits: 18

Winter

Course	Credit
CSSE 220 Object-Oriented Software Development	4
MA 112 Calculus II	5
PH 112 Physics II	4
HSSA Elective	4
	Total Credits: 17

Spring

Course	Credit
CSSE 132 Introduction to Computer Systems Design	4
MA 113 Calculus III	5
ECE 233 Introduction to Digital Systems	4

Science Elective	4	
		Total Credits: 17

Sophomore

Fall

Course	Credit	
CSSE 232 Computer Architecture I	4	
CSSE 280 Introduction to Web Programming	4	
MA 221 Matrix Algebra & Differential Equations I	4	
MA 276 Introduction to Proofs	4	
		Total Credits: 16

Winter

Course	Credit	
CSSE 230 Data Structures & Algorithm Analysis	4	
MA 374 Combinatorics	4	
ENGL H290 Technical & Professional Communication	4	
CSSE 332 Operating Systems	4	
		Total Credits: 16

Spring

Course	Credit	
CSSE 376 Software Quality Assurance	4	
MA Elective	4	
CSSE 333 Database Systems	4	
HSSA Elective	4	
		Total Credits: 16

Junior

Fall

Course	Credit	
CSSE 371 Software Requirements Engineering	4	
CSSE 372 Software Project Management	4	

Course	Credit
MA 381 Introduction to Probability with Statistical Applications	4
CHEM 111 General Chemistry I	3
CHEM 111L Gen Chemistry I Lab	1
	Total Credits: 16

Winter

Course	Credit
CSSE 374 Software Design	4
CSSE 304 Programming Lang. Concepts	4
Tech Elective	4
HSSA Elective	4
	Total Credits: 16

Spring

Course	Credit
CSSE 373 Formal Methods in Specification & Design	4
CSSE 375 Software Construction & Evolution	4
HSSA Elective	4
Free elective	4
	Total Credits: 16

Senior

Fall

Course	Credit
CSSE 477 Software Architecture	4
CSSE 497 Senior Capstone Project I	4
HSSA Elective	4
SE elective	4
	Total Credits: 16

Winter

Course	Credit
CSSE 498 Senior Capstone Project II	4
HSSA Elective	4
Free Elective	4
SE Elective	4
	Total Credits: 16

Spring

Course	Credit
CSSE 499 Senior Capstone Project III	4
HSSA Elective	4
Free Elective	4
	Total Credits: 12

Software Engineering Course Descriptions

CSSE 120 Introduction to Software Development 3R-3L-4C F,W,S
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
An introduction to programming with an emphasis on problem solving. Problems may include visualizing data, interfacing with external hardware or solving problems from a variety of engineering disciplines. Programming concepts covered include data types, variables, control structures, arrays, and data I/O. Software development concepts covered include testing, debugging, incremental development, understanding requirements, and version control systems.

CSSE 132 Introduction to Systems Programming 3R-3L-4C F,S
Prerequisites: CSSE 120
Corequisites: There are no corequisites for this course.
Provides students with understanding of computer system level issues and their impact on the design and use of computer systems. Students will study low-level programming (assembly) and memory operations, representation of various types of data and programs in memory, and resource/efficiency trade-offs. System requirements such as resource management, security, communication and synchronization are studied and basic systems tools for these tasks are implemented. Course topics will be explored using a variety of hands-on assignments and projects.

CSSE 140 Practical Security I 0R-1L-1C F
Prerequisites: There are no prerequisites for this course.
Corequisites: There are no corequisites for this course.
This is an entry-level introduction to exploiting and securing computer systems, networks, and web sites. This shallow introduction exposes students to various applied cybersecurity topics including Firewalls, SSH, passwords, web security, and basic unix system administration. Through a series of hands-on exercises, students will relate these topics to practical ways to secure computers.

CSSE 141 Practical Security II 0R-1L-1C W
Prerequisites: CSSE 140
Corequisites: There are no corequisites for this course.
A second-level introduction to exploiting and securing computer systems, networks, and web sites. This class continues the introduction to applied cybersecurity topics including basic Cryptography, network protocol analysis, reverse engineering, steganography, forensics, and more unix system administration. Students are also introduced to capture-the-flag exercises, which are widely practiced cybersecurity skill competitions.

CSSE 142 Practical Security III 2L-2C Term F
Prerequisites: CSSE 141
Corequisites: There are no corequisites for this course.

A third-level class on exploiting and securing computer systems, networks, and web sites. This class continues the introduction to applied cybersecurity topics and focus on applying concepts learned in CSSE140/141 to security competitions such as capture-the-flag events. This class exposes students to strategy used in security competitions, teamwork skills for effective competition, and construction of set of exercises used for running a CTF event. Students will work in teams to solve security-oriented problems, apply their skills to create competition challenges/exercises for use in CSSE 141 and for competition training, practice for security competitions, and participate in or run a few security competitions.

CSSE 145 Cybersecurity Seminar 2R-0L-2C Varies

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

This course provides exposure to leading-edge industrial and academic experts in Cybersecurity and Digital Privacy. Topics including the societal, economic, scientific, and psychological impacts of modern areas of cybersecurity and privacy are examined from both practical and theoretical points of view. Students in this class will attend live and view remote or recorded talks from industry/academic experts, read emergent papers on Cybersecurity and Digital Privacy, participate in discussions or debate about the topics, and reflect on the impacts these topics have on their major area of study. May be repeated for credit with approval from the course instructor when topics are different.

CSSE 199 Professional Experience 1R-0L-1C

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

The professional experiences course captures the practical work experiences related to the student's academic discipline. Students are required to submit a formal document of their reflections, which communicates how their employment opportunity reinforced and enhanced their academic studies. The course will be graded as "S" satisfactory, or "U" unsatisfactory based on the written report of the professional experience.

CSSE 212 Hardware-oriented Programming 3R-3L-4C

Prerequisites: ICS major

Corequisites: There are no corequisites for this course.

Simple computer architecture. Special hardware-oriented programming. Introduction to the C programming language, especially the use of pointers. Interrupt programming. This course is taught as part of the International Computer Science dual degree program at Hochschule Ulm, Germany.

CSSE 220 Object-Oriented Software Development 3R-3L-4C F,W,S

Prerequisites: CSSE 120

Corequisites: There are no corequisites for this course.

Object-oriented programming concepts, including the use of inheritance, interfaces, polymorphism, abstract data types, and encapsulation to enable software reuse and assist in software maintenance. Recursion, GUIs and event handing. Use of common object-based data structures, including stacks, queues, lists, trees, sets, maps, and hash tables. Space/time efficiency analysis. Testing. Introduction to UML.

CSSE 221 Fundamentals of Software Development Honors 3R-3L-4C

Prerequisites: A score of 4 or 5 on the APCS A exam or permission of instructor

Corequisites: There are no corequisites for this course.

This course is intended for students who have sufficient programming experience to warrant placement in an accelerated course covering the topics from CSSE 120 and

CSSE 220. This course will satisfy the prerequisite requirements for courses that have CSSE 220 as a prerequisite.

CSSE 225 Programming 3 3R-3L-4C

Prerequisites: ICS major

Corequisites: There are no corequisites for this course.

Differences between Java and C++. C++ concepts of object-oriented programming (classes, objects, inheritance, polymorphism). Storage management. Multiple inheritance, operator overloading, friend-concept, exception handling, I/O. Error analysis of programs. Generic programming and introduction to C++ - standard library. This course is taught as part of the International Computer Science dual degree program at Hochschule Ulm, Germany.

CSSE 230 Data Structures and Algorithm Analysis 3R-3L-4C F,W,S

Prerequisites: MA 112, and CSSE 220, with a grade of C or better

Corequisites: There are no corequisites for this course.

This course reinforces and extends students' ability to independently design, develop, and debug object-oriented software that uses correct, clear, and efficient algorithms and data structures. Students study and implement classical data structures such as list, stack, queue, tree, priority queue, hash table, graph, set, and dictionary. Formal efficiency analysis is used to evaluate the complexity of algorithms for these data structures. Students gain proficiency in writing recursive methods. Students design and implement software individually.

CSSE 232 Computer Architecture I 3R-3L-4C F,W

Prerequisites: ECE 233, and CSSE 120

Corequisites: There are no corequisites for this course.

Computer instruction set architecture and implementation. Specific topics include historical perspectives, performance evaluation, computer organization, instruction formats, addressing modes, computer arithmetic, ALU design, floating-point representation, single-cycle and multi-cycle data paths, and processor control. Assembly language programming is used as a means of exploring instruction set architectures. The final project involves the complete design and implementation of a miniscule instruction set processor.

CSSE 240 Principles of Cybersecurity 4R-0L-4C W

Prerequisites: CSSE 120, and HUM H190

Corequisites: There are no corequisites for this course.

This course introduces ethical, theoretical, and practical issues of information security in interconnected systems of computers. Implications of relevant professional codes of ethics are a recurring theme of the course, as are societal and human impacts on computer system security. Foundational topics include access control matrices and standard system models, as well as policies for security, confidentiality, and integrity. Implementation issues include key management, cipher techniques, authentication, principles of secure design, representation of identity, access control mechanisms, information flow, life cycle issues, and formal evaluation and certification techniques. Additional topics include malicious logic, vulnerability analysis, and auditing. Computer system attack techniques are observed and evaluated in a closed environment to motivate and inform discussion and exploration of computer network defense techniques.

CSSE 241 Computing in a Global Society 2R-6L-4C

Prerequisites: CSSE 220 or CSSE 221

Corequisites: There are no corequisites for this course.

The ability to work with colleagues from other cultures and to work on international projects are key assets in today's job market. The centerpiece of this course is a real-world computing project that students develop in cooperation with peers from an institution of higher education in a foreign country. Exposes students to the procedures and complexities of working on projects that span many time-zones and cultures. Additionally, students examine the use and impact of computing in a global community. International travel is required; students will be expected to incur additional expenses (will vary depending on the project, institution, and country). May be repeated once (for free elective credit only) if the country involved is different.

CSSE 242 Programming in the Community Variable Credit (1 or 2 credits) F, W, S

Prerequisites: There are no prerequisites for this course.

Corequisites: There are no corequisites for this course.

Programming in the Community is a unique course where Rose-Hulman students learn how to become teachers in Computer Science for younger students. As the name suggests, students will go teach CS material to K-12 students at their local school. Students will be assigned to a teaching team to take turns leading and helping follow along projects for the K-12 students. Students are expected to join a weekly instructor meeting on Teams, then take two teaching trips into the community per week (40 to 50 minute lessons). Transportation can be arranged for students unable to travel to the school. Students of any major are welcome to join. This class is a very real-world experience. It is a great way to learn leadership and teaching skills while doing great community service. May be repeated up to 12 credit hours.

CSSE 252 Computer Game Design 4R-OL-4C

Prerequisites: ENGL H290

Corequisites: There are no corequisites for this course.

An introduction to computer game design. Topics include game concepts, game settings and worlds, storytelling and narrative, character development, creating the user experience, gameplay, game balancing, and game genres. Working in teams, students will design their own game and produce several design documents for that game.

CSSE 280 Introduction to Web Programming 3R-3L-4C F, W

Prerequisites: CSSE 220 or CSSE 221

Corequisites: There are no corequisites for this course.

Introduction to the client-side and server-side mechanisms for creating dynamic web applications with persistent data storage. Browser-server interaction via HTTP. Static web page creation using current markup and styling languages. Client-side programming with modern scripting languages and the DOM. Server-side programming with emerging web programming languages and frameworks. Persistent data storage with a state-of-the-art database management system. Asynchronous client-server communication via HTTP requests. Development and consumption of REST APIs. Deployment of web applications to cloud platforms or platform as a service providers. Security considerations. This course provides breadth of knowledge of many tools/technologies rather than deep knowledge of any particular tool/technology. No previous experience with Web development is required.

CSSE 286 Introduction to Machine Learning 4R-0L-4C

Prerequisites: Prior programming experience

Corequisites: There are no corequisites for this course.

An introduction to machine learning (ML) systems, with a focus especially on Artificial Intelligence-based systems, versus statistical ones. The course is designed to be useful to students with a basic knowledge of programming and software systems, whether or not they are computer science majors. During the course, students try different machine learning algorithms on data from problems in a domain of interest to them, comparing results with that of other students taking the class, as well as comparing the outcomes of the different algorithms on their own data. A goal of the course is learning how to gain real predictive value from “big data.”

CSSE 290 Special Topics in Computer Science 4C

Prerequisites: Arranged prerequiste - permission of instructor

Corequisites: There are no corequisites for this course.

Selected topics of current interest. May be repeated for credit if topic is different.

CSSE 304 Programming Language Concepts 4R-0L-4C F,W

Prerequisites: CSSE 230, and CSSE 280

Corequisites: There are no corequisites for this course.

Syntax and semantics of programming languages. Grammars, parsing, data types, control flow, parameter passing, run-time storage management, binding times, functional programming and procedural abstraction, syntactic extensions, continuations, language design and evaluation. Students will explore several language features by writing an interpreter that implements them.

CSSE 332 Operating Systems 4R-0L-4C W,S

Prerequisites: CSSE 220 or CSSE 221, and CSSE 132 or CSSE 232

Corequisites: There are no corequisites for this course.

Students learn fundamental concepts of modern operating systems by studying how and why operating systems have evolved. Topics include CPU scheduling, process synchronization, memory management, file systems, I/O systems, privacy and security, and performance evaluation. Students implement parts of an operating system as a means of exploring the details of some of these topics.

CSSE 333 Database Systems 3R-3L-4C W,S

Prerequisites: CSSE 230

Corequisites: There are no corequisites for this course.

Relational database systems, with emphasis on entity relationship diagrams for data modeling. Properties and roles of transactions. SQL for data definition and data manipulation. Use of contemporary API's for access to the database. Enterprise examples provided from several application domains. The influence of design on the use of indexes, views, sequences, joins, and triggers. Physical level data structures: B+ trees and RAID. Survey of object databases.

CSSE 335 Introduction to Parallel Computing 4R-0L-4C S

Prerequisites: MA 221 and programming experience

Corequisites: There are no corequisites for this course.

Principles of scientific computation on parallel computers. Algorithms for the solution of linear systems and other scientific computing problems on parallel machines. Course includes a major project on RHIT's parallel cluster. Same as MA 335.

CSSE 340 Foundations of Cybersecurity 4R-0L-4C W

Prerequisites: CSSE 132, and CSSE 280

Corequisites: There are no corequisites for this course.

This course introduces ethical, theoretical, and practical issues of information security in interconnected systems of computers. Implications of relevant professional codes of ethics are a recurring theme of the course, as are societal and human impacts on computer system security. Foundational topics include access control matrices and standard system models, as well as policies for security, confidentiality, and integrity. Implementation issues include key management, cipher techniques, authentication, principles of secure design, representation of identity, access control mechanisms, information flow, life cycle issues, and formal evaluation and certification techniques.

Additional topics include malicious logic, vulnerability analysis, and auditing. Computer system attack techniques are discussed and explored in a closed environment to motivate and inform discussion and exploration of computer network defense techniques.

CSSE 343 Cybercrime and Digital Forensics 2R-2L-4C

Prerequisites: ENGL H100, and either CSSE 132, or Senior Class Standing

Corequisites: There are no corequisites for this course.

This course introduces students to "cybercrime," how police investigate these crimes, and what forensics techs use to uncover digital evidence. Students will examine the laws, technologies, tools, and procedures used in the investigation and prosecution of computer crimes through case studies, discussions, ethical debates, and hands-on laboratory exercises that uncover and analyze digital evidence. This class covers topics including: basics of criminal law, collection and chain of evidence, search & seizure procedures, digital trail discovery, data recovery, and smartphone investigation.

CSSE 351 Computer Graphics 4R-0L-4C F

Prerequisites: MA 221, and either CSSE 220 or CSSE 221

Corequisites: There are no corequisites for this course.

Computer graphics algorithms, hardware and software. Line generators, affine transformations, line and polygon clipping, interactive techniques, perspective projection, solid modeling, hidden surface algorithms, lighting models, shading, and graphics standards. Programming assignments and a final project are required.

CSSE 352 Computer Game Development 4R-0L-4C

Prerequisites: CSSE 230

Corequisites: There are no corequisites for this course.

An introduction to designing and developing computer games. Topics include game genres, game design, sprites, game physics, collisions, characters, scripting, graphics, and sound. Students will design and implement their own game using an available game engine.

CSSE 371 Software Requirements Engineering 3R-3L-4C F

Prerequisites: CSSE 230, and ENGL H290, and CSSE 333 and Junior standing

Corequisites: There are no corequisites for this course.

Basic concepts and principles of software requirements engineering, its tools and techniques, and methods for modeling software systems. Topics include requirements elicitation, prototyping, functional and non-functional requirements, object-oriented techniques, and requirements tracking.

CSSE 372 Software Project Management 4R-0L-4C F

Prerequisites: There are no prerequisites for this course.

Corequisites: CSSE 230

Major issues and techniques of project management. Project evaluation and selection, scope management, team building, stakeholder management, risk assessment, scheduling, quality, rework, negotiation, and conflict management. Professional issues including career planning, lifelong learning, software engineering ethics, and the licensing and certification of software professionals.

CSSE 373 Formal Methods in Specification and Design 4R-0L-4C S

Prerequisites: CSSE 230, and MA 276

Corequisites: There are no corequisites for this course.

Introduction to the use of mathematical models of software systems for their specification and validation. Topics include finite state machine models, models of concurrent systems, verification of models, and limitations of these techniques.

CSSE 374 Software Design 3R-3L-4C W

Prerequisites: CSSE 230 and Junior standing
Corequisites: There are no corequisites for this course.
Introduction to the architecture and design of complete software systems, building on components and patterns. Topics include architectural principles and alternatives, design documentation, and relationships between levels of abstraction.

CSSE 375 Software Construction and Evolution 3R-3L-4C S

Prerequisites: CSSE 374
Corequisites: There are no corequisites for this course.
Issues, methods and techniques associated with constructing software. Topics include detailed design methods and notations, implementation tools, coding standards and styles, peer review techniques, and maintenance issues.

CSSE 376 Software Quality Assurance 4R-0L-4C S

Prerequisites: CSSE 230
Corequisites: There are no corequisites for this course.
Theory and practice of determining whether a product conforms to its specification and intended use. Topics include software quality assurance methods, test plans and strategies, unit level and system level testing, software reliability, peer review methods, and configuration control responsibilities in quality assurance.

CSSE 386 Data Mining with Programming 4R-0L-4C

Prerequisites: CSSE 220, and CSSE 280, and MA 221, and either MA 223 or MA 381
Corequisites: There are no corequisites for this course.
An introduction to data mining for large data sets, including data preparation, exploration, aggregation/reduction, and visualization. Elementary methods for classification, association, and cluster analysis are covered. Significant attention will be given to presenting and reporting data mining results. Students may not get credit for both this course and also the MA 384 Data Mining course.

CSSE 400 CSSE Seminar 4R-0L-4C

Prerequisites: ICS major
Corequisites: There are no corequisites for this course.
This course presents an overview of current application areas within computer science and software engineering through the use of practical case studies. Students will undertake their own preparation of one or more case studies and present their results. This course is taught as part of the International Computer Science dual degree program at Hochschule Ulm, Germany.

CSSE 402 Theory and Practice of Garbage Collection 4R-0L-4C

Prerequisites: CSSE 332
Corequisites: There are no corequisites for this course.
Garbage collection (GC) is a method of automatically reclaiming dynamically allocated storage that anapplication no longer needs. In this course, students will explore the classical problems of garbagecollection such as detecting unused objects and reclaiming the space allocated to them. Students willsurvey the GC literature to become familiar with the current state of the art and future researchdirections. Students will explore techniques used to implement state-of-the-art garbage collectionalgorithms and will design and implement garbage collectors for a memory-managed language (e.g.,Java, C#, php, or Python).

CSSE 403 Programming Language Paradigms 4R-0L-4C F (even years)

Prerequisites: CSSE 304
Corequisites: There are no corequisites for this course.
A survey of some current and emerging programming languages, focusing on unique language paradigms-ways of structuring solutions or manipulating data. Examples of

paradigms include dynamic programming languages, object-oriented programming, highly parallelizable code, and functional programming. Emphasizes developing independent learning techniques that will allow students to acquire skills in new languages quickly. Students will develop basic skills in at least three different languages representing distinct paradigms. They will also be exposed to a selection of other languages. Includes a substantial team project.

CSSE 404 Compiler Construction 4R-0L-4C S (odd years)

Prerequisites: CSSE 232, and CSSE 304, and CSSE 474

Corequisites: There are no corequisites for this course.

Theory and practice of programming language translation. Lexical analysis, syntax analysis, parser generators, abstract syntax, symbol tables, semantic analysis, intermediate languages, code generation, code optimization, run-time storage management, error handling. Students will construct a complete compiler for a small language.

CSSE 413 Artificial Intelligence 4R-0L-4C F

Prerequisites: CSSE 230

Corequisites: There are no corequisites for this course.

Students investigate how to model and implement intelligent behavior using computers. Topics are chosen from how machines can: solve problems; reason and use knowledge; learn from experience; and perceive and act. Students explore these topics by implementing many of the ideas in software. Readings are drawn both from a textbook and from technical papers in recent conferences and journals.

CSSE 415 Machine Learning 4R-0L-4C S

Prerequisites: MA 221, and either MA 223 or MA 381, and either CHE 310 or CSSE 220 or ECE 230 or MA 332 or MA 386 or ME 323

Corequisites: There are no corequisites for this course.

An introduction to machine learning. Topics include: error metrics, accuracy vs interpretability trade-off, feature selection, feature engineering, bias-variance trade-off, under-fitting vs. overfitting, regularization, cross-validation, the bootstrap method, the curse of dimensionality and dimensionality reduction using the singular value decomposition. Both parametric and nonparametric methods are covered including: k-nearest neighbors, linear and logistic regression, decision trees and random forests, and support vector machines. Same as MA415.

Prerequisite Notes:

Prerequisite Clarification for CSSE415:

Junior Standing and MA221,

and either MA223 or MA381,

and one of CHE310, CSSE220, ECE230, MA332, MA386 (or ME323 or ME327).

CSSE 416 DEEP LEARNING 4R-0L-4C See Dept

Prerequisites: See below

Corequisites: There are no corequisites for this course.

An introduction to deep learning using both fully-connected and convolutional neural networks. Topics include: least squares estimation and mean square error, maximum likelihood estimation and cross-entropy, convexity, gradient descent and stochastic gradient descent algorithms, multivariate chain rule and gradient computation using back propagation, linear vs nonlinear operations, convolution, over-fitting vs under-fitting and hyper-parameter optimization, L2, early stopping and dropout regularization, data augmentation and transfer learning. Same as MA416.

Prerequisite Notes:

MA 212 or MA 221, and either MA 223 or MA 381, and either CHE 310 or CSSE 220 or ECE 230 or MA 332 or MA 386 or ME 327

CSSE 432 Computer Networks 4R-0L-4C S
Prerequisites: CSSE 220 or CSSE 221
Corequisites: There are no corequisites for this course.
Organization, design, and implementation of computer networks, especially the Internet. Network protocols, protocol layering, flow control, congestion control, error control, packet organization, routing, gateways, connection establishment and maintenance, machine and domain naming, security. Each of the top four layers of the Internet protocol stack: application (FTP, HTTP, SMTP), transport (TCP, UDP), network (IP), link (Ethernet).

CSSE 433 Advanced Database Systems 4R-0L-4C S
Prerequisites: CSSE 333
Corequisites: There are no corequisites for this course.
This course covers advanced topics in the design and development of database management systems and their modern applications. Topics to be covered include query processing and, in relational databases, transaction management and concurrency control, eventual consistency, and distributed data models. This course introduces students to NoSQL databases and provides students with experience in determining the right database system for the right feature. Students are also exposed to polyglot persistence and developing modern applications that keep the data consistent across many distributed database systems.

CSSE 434 Introduction to the Hadoop Ecosystem 4R-0L-4C
Prerequisites: CSSE 230 *Some Experience with SQL recommended
Corequisites: There are no corequisites for this course.
This advanced course examines emergent Big Data techniques through hands-on introductions to the various technologies and tools that make up the Hadoop ecosystem. Topics covered include internals of MapReduce and the Hadoop Distributed File system (HDFS), internals of the YARN distributed operating system, MapReduce for data processing, transformation & analysis tools for data at scale (processing terabytes and petabytes of information quickly), scheduling jobs using workflow engines, data transfer tools & real time engines for data processing.

CSSE 435 Robotics Engineering 3R-3L-4C S
Prerequisites: ME 430 or ECE 230
Corequisites: There are no corequisites for this course.
Interdisciplinary course in robotics focusing on communication, software development, kinematics, robot GUI design, sensing, control, and system integration. Labs in the course cover MATLAB GUI development with GUIDE, Denavit-Hartenberg parameters, Arduino programming, Arduino to Android communication, Android app development, and OpenCV4Android image recognition. Students in the course will program an Android + Arduino, 6-wheeled mobile robot with 5 DOF servo arm to participate in an outdoor GPS robotics challenge. Cross-listed with ME 435.

CSSE 443 Distributed Systems & IT Security 3R-3L-4C
Prerequisites: ICS major
Corequisites: There are no corequisites for this course.
Building complex distributed information systems requires a systematic approach. This course covers the analysis of existing distributed information systems and provides the ability to model simple new distributed applications with special attention to the

trustworthiness, reliability and security of information systems. Topics covered include the main architectural models of distributed systems, describing simple distributed applications according to architecture and function, defining simple communication protocols, the benefits of using middleware, the risks of using distributed systems, and safety measures. This course is taught as part of the International Computer Science dual degree program at Hochschule Ulm, Germany.

CSSE 444 Real-time Systems 3R-3L-4C

Prerequisites: ICS major

Corequisites: There are no corequisites for this course.

Students will learn the features and specifications of real-time systems. Topics covered include real-time operating systems and programming languages, design patterns for real-time systems, scheduling, synchronization, hybrid task sets, and applications of real-time systems. This course is taught as part of the International Computer Science dual degree program at Hochschule Ulm, Germany.

CSSE 451 Advanced Computer Graphics 4R-0L-4C W (even years)

Prerequisites: CSSE 351

Corequisites: There are no corequisites for this course.

Advanced topics in computer graphics. Topics will be drawn from current graphics research and will vary, but generally will include ray tracing, radiosity, physically-based modeling, animation, and stereoscopic viewing. Programming assignments and a research project are required.

CSSE 453 Topics in Artificial Intelligence 4R-0L-4C

Prerequisites: CSSE 413

Corequisites: There are no corequisites for this course.

Advanced topics in artificial intelligence. Topics will vary. Past topics have included machine game playing and machine learning. May be repeated for credit if topic is different.

CSSE 461 Computer Vision 4R-0L-4C S (odd years)

Prerequisites: MA 221, and either CSSE 220 or CSSE 221 *Also recommended (but not required) either MA371 or MA373.

Corequisites: There are no corequisites for this course.

An introduction to 3D computer vision techniques. Both theory and practical applications will be covered. Major topics include image features, camera calibration, stereopsis, motion, shape from x, and recognition.

CSSE 463 Image Recognition 4R-0L-4C W

Prerequisites: MA 221 Junior standing and programming experience

Corequisites: There are no corequisites for this course.

Introduces statistical pattern recognition of visual data; low-level visual feature extraction (color, shape, edges); clustering and classification techniques. Applies knowledge to various application domains through exercises, large programming projects in Matlab, and an independent research project. Familiarity with probability distributions will be helpful, but not required.

CSSE 473 Design and Analysis of Algorithms 4R-0L-4C W

Prerequisites: CSSE 230, and MA 276, and MA 374

Corequisites: There are no corequisites for this course.

Students study techniques for designing algorithms and for analyzing the time and space efficiency of algorithms. The algorithm design techniques include divide-and-conquer, greedy algorithms, dynamic programming, randomized algorithms and parallel algorithms. The algorithm analysis includes computational models, best/average/

worst case analysis, and computational complexity (including lower bounds and NP-completeness). Same as MA 473.

CSSE 474 Theory of Computation 4R-0L-4C S

Prerequisites: CSSE 230, and MA 276, and MA 374

Corequisites: There are no corequisites for this course.

Students study mathematical models by which to answer three questions: What is a computer? What limits exist on what problems computers can solve? What does it mean for a problem to be hard? Topics include models of computation (including Turing machines), undecidability (including the Halting Problem) and computational complexity (including NP-completeness). Same as MA 474.

CSSE 477 Software Architecture 4R-0L-4C F

Prerequisites: CSSE 374 or consent of instructor

Corequisites: There are no corequisites for this course.

This is a second course in the architecture and design of complete software systems, building on components and patterns. Topics include architectural principles and alternatives, design documentation, relationships between levels of abstraction, theory and practice of human interface design, creating systems which can evolve, choosing software sources and strategies, prototyping and documenting designs, and employing patterns for reuse. How to design systems which a team of developers can implement, and which will be successful in the real world.

CSSE 479 Cryptography 4R-0L-4C S

Prerequisites: MA 276, and either CSSE 220 or CSSE 221

Corequisites: There are no corequisites for this course.

Introduction to basic ideas of modern cryptography with emphasis on mathematical background and practical implementation. Topics include: the history of cryptography and cryptanalysis, public and private key cryptography, digital signatures, and limitations of modern cryptography. Touches upon some of the societal issues of cryptography. Same as MA 479.

CSSE 480 Cross-Platform Development 3R-3L-4C F

Prerequisites: CSSE 230

Corequisites: There are no corequisites for this course.

Programming cross-platform mobile applications that target Android, iOS, and web mobile devices using programmatic UIs, layouts, reusable components, and data persistence via cloud backends. Emphasis is on hands-on use of these components in application development. Includes a substantial team project including UI mockups, design, development, testing, and presentation.

CSSE 481 Web-Based Information Systems 4R-0L-4C F (odd years)

Prerequisites: CSSE 230

Corequisites: There are no corequisites for this course.

In this course, students learn about several aspects of research: thinking creatively about interesting research problems, researching existing work in a chosen area, and keeping current in a field. Students are exposed to the process of research by writing a pre-proposal for a project that advances the web. Projects either develop new web-technologies or applications or investigate a topic of importance. Based on feedback received, groups of students write a research proposal which goes through a formal peer review process. Approved projects are pursued for the remainder of the quarter. Students present current research as well as give a final presentation of their group project. Selected web-technologies are introduced; in the past, these have included CGI programming and XML technologies.

CSSE 483 Android Application Development 4R-0L-4C

Prerequisites: CSSE 230
Corequisites: There are no corequisites for this course.
An introduction to programming mobile applications using the Android stack. Topics include the activity lifecycle, resources, layouts, intents for multiple activities, menus, fragments and dialogs, adapters, data persistence via shared preferences, SQLite, and web backends. Emphasis is on hands-on use of these components in application development. Includes a substantial team project (UI mockups, user stories, UML design, development, testing, and presentation).

CSSE 484 iOS Application Development 3R-3L-4C W

Prerequisites: CSSE 230
Corequisites: There are no corequisites for this course.
An introduction to programming mobile applications using the iOS stack. Topics include using X-Code for Swift and Objective-C app development, UI components, Storyboards, view controller actions and outlets, table views, navigation controllers, Core Data, and APIs for backend communication. Emphasis is on hands-on use of these components in application development. Includes a substantial team project (UI mockups, user stories, development, testing, and presentation).

CSSE 487 Senior Research Project I 4C

Prerequisites: ENGL H290 and senior standing
Corequisites: There are no corequisites for this course.
Individual or group research on an unsolved technical problem. The problem is expected to be at an advanced level and have an appropriate client. A prototype system, a technical report, and a public presentation are required.

CSSE 488 Senior Research Project II 4C

Prerequisites: CSSE 487
Corequisites: There are no corequisites for this course.
Individual or group research on an unsolved technical problem. The problem is expected to be at an advanced level and have an appropriate client. A prototype system, a technical report, and a public presentation are required.

CSSE 489 Senior Research Project III 4C

Prerequisites: CSSE 488
Corequisites: There are no corequisites for this course.
Individual or group research on an unsolved technical problem. The problem is expected to be at an advanced level and have an appropriate client. A prototype system, a technical report, and a public presentation are required.

CSSE 490 Special Topics in Computer Science 1-4C

Prerequisites: Instructor consent
Corequisites: There are no corequisites for this course.
Selected topics of current interest. May be repeated for credit if topic is different.

CSSE 491 Directed Independent Studies 1-4C

Prerequisites: Consent of instructor and department head
Corequisites: There are no corequisites for this course.
Independent study of an advanced subject not included in regularly offered courses. May be repeated for credit if topic or level is different.

CSSE 492 Undergraduate Research in Computer Science 1-4C

Prerequisites: Consent of instructor and department head
Corequisites: There are no corequisites for this course.
Research under direction of a faculty member. Presentation of preliminary and final results to departmental seminar. Presentation of work at professional meetings or by

publication in professional journals is strongly encouraged. May be repeated for credit if topic or level is different.

CSSE 493 Undergraduate Research in Software Engineering 1-4C

Prerequisites: Consent of instructor and department head

Corequisites: There are no corequisites for this course.

The Computer Science curriculum prepares students for careers in all areas of the computer industry as well as for graduate studies in computer science and computer related fields. Students have also found a computer science major to be excellent preparation for careers in law, medicine, business administration, industrial engineering, biomedical engineering, and other technical and non-technical fields.

CSSE 494 Senior Thesis I 4C

Prerequisites: ENGL H290 Consent of instructor and department head

Corequisites: There are no corequisites for this course.

Individual study and research of a topic in computer science or software engineering. Topic is expected to be at an advanced level. Research paper and presentation to department seminar are required.

CSSE 495 Senior Thesis II 4C

Prerequisites: CSSE 494 Consent of instructor and department head

Corequisites: There are no corequisites for this course.

Individual study and research of a topic in computer science or software engineering. Topic is expected to be at an advanced level. Research paper and presentation to department seminar are required.

CSSE 496 Senior Thesis III 4C

Prerequisites: CSSE 495 Consent of instructor and department head

Corequisites: There are no corequisites for this course.

Individual study and research of a topic in computer science or software engineering. Topic is expected to be at an advanced level. Research paper and presentation to department seminar are required.

CSSE 497 Senior Capstone Project I 4C F

Prerequisites: CSSE 371, CSSE 374* and senior standing

Corequisites: There are no corequisites for this course.

For a capstone experience, students work on a team to complete a three-term software engineering project for an approved client. Students choose from two approaches to complete their capstone: 1) Develop a substantive software product, using defensible software processes. The teams focus on delivering key software development, administrative, and user artifacts to the client. Tasks include project planning, risk analysis, use of standards, prototyping, configuration management, quality assurance, project reviews and reports, team management and organization, copyright, liability, and handling project failure. 2) Investigate a substantive software product or engineering process problem, using a defensible and documented research approach. Tasks include problem analysis, developing alternative solutions, evaluating the solutions via prototyping and iterative processes of investigation, comparing the potential solutions, recording the investigation experience in a research report, and delivering the research artifacts to the client.

CSSE 498 Senior Capstone Project II 4C W

Prerequisites: CSSE 371, CSSE 374, and CSSE 497

Corequisites: There are no corequisites for this course.

For a capstone experience, students work on a team to complete a three-term software engineering project for an approved client. Students choose from two approaches to complete their capstone: 1) Develop a substantive software product, using defensible software processes. The teams focus on delivering key software development, administrative, and user artifacts to the client. Tasks include project planning, risk analysis, use of standards, prototyping, configuration management, quality assurance, project reviews and reports, team management and organization, copyright, liability, and handling project failure. 2) Investigate a substantive software product or engineering process problem, using a defensible and documented research approach. Tasks include problem analysis, developing alternative solutions, evaluating the solutions via prototyping and iterative processes of investigation, comparing the potential solutions, recording the investigation experience in a research report, and delivering the research artifacts to the client.

CSSE 499 Senior Capstone Project III 4C S

Prerequisites: CSSE 371, CSSE 374, and CSSE 498

Corequisites: There are no corequisites for this course.

For a capstone experience, students work on a team to complete a three-term software engineering project for an approved client. Students choose from two approaches to complete their capstone: 1) Develop a substantive software product, using defensible software processes. The teams focus on delivering key software development, administrative, and user artifacts to the client. Tasks include project planning, risk analysis, use of standards, prototyping, configuration management, quality assurance, project reviews and reports, team management and organization, copyright, liability, and handling project failure. 2) Investigate a substantive software product or engineering process problem, using a defensible and documented research approach. Tasks include problem analysis, developing alternative solutions, evaluating the solutions via prototyping and iterative processes of investigation, comparing the potential solutions, recording the investigation experience in a research report, and delivering the research artifacts to the client.

Last updated: 08/31/2023

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