***Twin Cities Campus***

# Computer Engineering B.Comp.E.

*Electrical and Computer Engineering*

**College of Science and Engineering**

- Program Type: Baccalaureate
- Requirements for this program are current for Fall 2020
- Required credits to graduate with this degree: 124
- Required credits within the major: 104
- Degree: Bachelor of Computer Engineering

The mission of the computer engineering program is to educate students in core topics, as well as in a broad set of specialties of computer engineering; to impart students with professional attributes that characterize a well-schooled engineer and citizen; and to provide students with opportunities for research experience in one of the leading computer engineering centers of scholarship.

The field of computer engineering resulted from the tremendous development of computers and, in particular, the evolution of microprocessors. The design process for almost every electronic system includes the specification and development of the control program for the system's microprocessor. A particular computer engineering job can be more closely related to hardware or software, to functional design or detailed design. The B.Comp.Eng. degree provides the background necessary for persons, with continuing study, to work in many computer engineering subfields. The bachelor's degree itself does not, however, provide highly specialized knowledge in any particular subfield.

The program is accredited by the Engineering Accreditation Commission of ABET, www.abet.org.

## Program Delivery

This program is available:

- via classroom (the majority of instruction is face-to-face)

## Admission Requirements

Students must complete 8 courses before admission to the program.

Freshman and transfer students students are usually admitted to pre-major status before admission to this major

Students interested in pursuing a degree in computer engineering or electrical engineering are encouraged to take EE 1001 in their first year.

For information about University of Minnesota admission requirements, visit the Office of Admissions website.

**Required prerequisites**

**Mathematics**

MATH 1271 - Calculus I [MATH] (4.0 cr)
*or* MATH 1371 - CSE Calculus I [MATH] (4.0 cr)
*or* MATH 1571H - Honors Calculus I [MATH] (4.0 cr)
MATH 1272 - Calculus II (4.0 cr)
*or* MATH 1372 - CSE Calculus II (4.0 cr)
*or* MATH 1572H - Honors Calculus II (4.0 cr)
MATH 2243 - Linear Algebra and Differential Equations (4.0 cr)
*or* MATH 2373 - CSE Linear Algebra and Differential Equations (4.0 cr)
*or* MATH 2574H - Honors Calculus IV (4.0 cr)

**Physics**

PHYS 1301W - Introductory Physics for Science and Engineering I [PHYS, WI] (4.0 cr)
*or* PHYS 1401V - Honors Physics I [PHYS, WI] (4.0 cr)
PHYS 1302W - Introductory Physics for Science and Engineering II [PHYS, WI] (4.0 cr)
*or* PHYS 1402V - Honors Physics II [PHYS, WI] (4.0 cr)

**Lower Division Core Courses Required for Admission to Upper Division**

EE 2015 - Signals, Circuits and Electronics (4.0 cr)
EE 1301 - Introduction to Computing Systems (4.0 cr)
*or* CSCI 1113 - Introduction to C/C++ Programming for Scientists and Engineers (4.0 cr)
*or* CSCI 1133 - Introduction to Computing and Programming Concepts (4.0 cr)
CSCI 1913 - Introduction to Algorithms, Data Structures, and Program Development (4.0 cr)

*or* CSCI 1933 - Introduction to Algorithms and Data Structures (4.0 cr)

**First Digital Electronics Course**

Students must take one of the two courses listed below for admission. The remaining course can be taken after admission to the major.

EE 2301 - Introduction to Digital System Design (4.0 cr)

*or* EE 2361 - Introduction to Microcontrollers (4.0 cr)

## General Requirements

All students are required to complete general University and college requirements including writing and liberal education courses. For more information about University-wide requirements, see the liberal education requirements.Required courses for the major or minor in which a student receives a D grade (with or without plus or minus) do not count toward the major or minor (including transfer courses).

## Program Requirements

All freshmen in the College of Science and Engineering must complete CSE 1001: First-Year Experience. At least 26 upper division credits in the major must be taken at the University of Minnesota Twin Cities Campus.

**Lower Division Required Courses**

**Mathematics**

MATH 2374 - CSE Multivariable Calculus and Vector Analysis (4.0 cr)

*or* MATH 2263 - Multivariable Calculus (4.0 cr)

*or* MATH 2573H - Honors Calculus III (4.0 cr)

*or* MATH 3584H *{Inactive}*(5.0 cr)

**Electrical Engineering and Computer Science Core**

CSCI 2011 - Discrete Structures of Computer Science (4.0 cr)

EE 2115 - Analog and Digital Electronics (4.0 cr)

**Second Digital Electronics Course**

Students must take the remaining lower division Digital Electronics course.

EE 2301 - Introduction to Digital System Design (4.0 cr)

*or* EE 2361 - Introduction to Microcontrollers (4.0 cr)

**Upper Division Required Courses**

**Computer Science Core**

CSCI 4041 - Algorithms and Data Structures (4.0 cr)

CSCI 4061 - Introduction to Operating Systems (4.0 cr)

**Electrical Engineering Core**

EE 3015 - Signals and Systems (3.0 cr)

EE 3025 - Statistical Methods in Electrical and Computer Engineering (3.0 cr)

EE 3101 - Signals, Circuits and Electronics Laboratory (1.0 cr)

EE 3102 *{Inactive}*(2.0 cr)

EE 3115 - Analog Electronics (3.0 cr)

EE 4363 - Computer Architecture and Machine Organization (4.0 cr)

*or* CSCI 4203 - Computer Architecture (4.0 cr)

**Upper Division Writing Intensive within the major**

Students are required to take one upper division writing intensive course within the major; students must take the following course which also fulfills the Senior Design Project requirement.

Take 0 - 1 course(s) from the following:

•EE 4951W - Senior Design Project [WI] (4.0 cr)

**Computer Engineering Technical Electives and Specializations**

**CompE Technical Electives (No Specialization)**

Students who do not choose one of the emphases must complete the additional computer engineering technical electives requirements listed here. Students must complete 28 technical elective credits, with a minimum of 22 coming from EE 4xxx/5xxx or CSCI 4xxx/5xxx courses.

Take 28 or more credit(s) from the following:

**Core Department Electives**

Take 22 or more credit(s) from the following:

**Senior Design Project**

A senior design project is required.

•EE 4951W - Senior Design Project [WI] (4.0 cr)

•**Lab Courses**

Two additional EE or CSCI lab courses are required.
Take 2 or more course(s) from the following:
- •EE 4111 - Advanced Analog Electronics Design (4.0 cr)
- •EE 4163 - Energy Conversion and Storage Laboratory (1.0 cr)
- •EE 4235 - Linear Control Systems Laboratory (1.0 cr)
- •EE 4237 - State Space Control Laboratory (1.0 cr)
- •EE 4301 - Digital Design With Programmable Logic (4.0 cr)
- •EE 4341 - Embedded System Design (4.0 cr)
- •EE 4505 - Communications Systems Laboratory (1.0 cr)
- •EE 4703 - Electric Drives Laboratory (1.0 cr)
- •EE 4722 - Power System Analysis Laboratory (1.0 cr)
- •EE 4743 - Switch-Mode Power Electronics Laboratory (1.0 cr)
- •EE 4930 - Special Topics in Electrical and Computer Engineering Laboratory (1.0 - 2.0 cr)
- •EE 5141 - Introduction to Microsystem Technology (4.0 cr)
- •EE 5173 - Basic Microelectronics Laboratory (1.0 cr)
- •EE 5327 - VLSI Design Laboratory (3.0 cr)
- •EE 5373 - Data Modeling Using R (1.0 cr)
- •EE 5545 - Digital Signal Processing Design (3.0 cr)
- •EE 5613 - RF/Microwave Circuit Design Laboratory (2.0 cr)
- •EE 5622 - Physical Optics Laboratory (1.0 cr)
- •EE 5657 - Physical Principles of Thin Film Technology (4.0 cr)
- •EE 5707 - Electric Drives in Sustainable Energy Systems Laboratory (1.0 cr)
- •EE 5811 - Biological Instrumentation (3.0 cr)
- •CSCI 4511W - Introduction to Artificial Intelligence [WI] (4.0 cr)
- •CSCI 5511 - Artificial Intelligence I (3.0 cr)
- •CSCI 5551 - Introduction to Intelligent Robotic Systems (3.0 cr)

**•Breadth and Depth Requirements (Specialty Areas)**

Take one course in 4 Breadth and Depth Requirement categories below (breadth). Within one of those categories, take a total of 2 courses (depth).

**Computer Architecture**

Take 0 or more course(s) from the following:
- •EE 4389W - Introduction to Predictive Learning [WI] (3.0 cr)
- •EE 5340 - Introduction to Quantum Computing and Physical Basics of Computing (3.0 cr)
- •EE 5351 - Applied Parallel Programming (3.0 cr)
- •EE 5364 - Advanced Computer Architecture (3.0 cr)
- •EE 5371 - Computer Systems Performance Measurement and Evaluation (3.0 cr)
- •EE 5391 *{Inactive}*(3.0 cr)
- •EE 5393 - Circuits, Computation, and Biology (3.0 cr)
- •CSCI 5204 - Advanced Computer Architecture (3.0 cr)

**Robotics and Embedded System Design**

Take 0 or more course(s) from the following:
- •EE 4231 - Linear Control Systems: Designed by Input/Output Methods (3.0 cr)
- •EE 4233 - State Space Control System Design (3.0 cr)
- •EE 4341 - Embedded System Design (4.0 cr)
- •EE 5340 - Introduction to Quantum Computing and Physical Basics of Computing (3.0 cr)
- •EE 5391 *{Inactive}*(3.0 cr)
- •CSCI 4511W - Introduction to Artificial Intelligence [WI] (4.0 cr)
- •CSCI 5143 - Real-Time and Embedded Systems (3.0 cr)
- •CSCI 5511 - Artificial Intelligence I (3.0 cr)
- •CSCI 5512 - Artificial Intelligence II (3.0 cr)
- •CSCI 5521 - Machine Learning Fundamentals (3.0 cr)
- •CSCI 5525 - Machine Learning: Analysis and Methods (3.0 cr)
- •CSCI 5551 - Introduction to Intelligent Robotic Systems (3.0 cr)
- •CSCI 5552 - Sensing and Estimation in Robotics (3.0 cr)
- •CSCI 5561 - Computer Vision (3.0 cr)
- •EE 5271 - Robot Vision (3.0 cr)

**VLSI and CAD**

Take 0 or more course(s) from the following:
- •EE 4301 - Digital Design With Programmable Logic (4.0 cr)
- •EE 5301 - VLSI Design Automation I (3.0 cr)
- •EE 5302 - VLSI Design Automation II (3.0 cr)
- •EE 5323 - VLSI Design I (3.0 cr)
- •EE 5324 - VLSI Design II (3.0 cr)
- •EE 5327 - VLSI Design Laboratory (3.0 cr)
- •EE 5329 - VLSI Digital Signal Processing Systems (3.0 cr)
- •EE 5333 - Analog Integrated Circuit Design (3.0 cr)

**Networks and Communication**
Take 0 or more course(s) from the following:
•EE 4501 - Communications Systems (3.0 cr)
•CSCI 4131 - Internet Programming (3.0 cr)
•CSCI 4211 - Introduction to Computer Networks (3.0 cr)
•CSCI 5117 - Developing the Interactive Web (3.0 cr)
•CSCI 5211 - Data Communications and Computer Networks (3.0 cr)
•CSCI 5221 - Foundations of Advanced Networking (3.0 cr)
•CSCI 5231 *{Inactive}*(3.0 cr)
•CSCI 5271 - Introduction to Computer Security (3.0 cr)
•CSCI 5471 - Modern Cryptography (3.0 cr)
**Systems and Software Design**
Take 0 or more course(s) from the following:
•EE 5355 - Algorithmic Techniques for Scalable Many-core Computing (3.0 cr)
•CSCI 4011 - Formal Languages and Automata Theory (4.0 cr)
•CSCI 4707 - Practice of Database Systems (3.0 cr)
•CSCI 5103 - Operating Systems (3.0 cr)
•CSCI 5105 - Introduction to Distributed Systems (3.0 cr)
•CSCI 5106 - Programming Languages (3.0 cr)
•CSCI 5117 - Developing the Interactive Web (3.0 cr)
•CSCI 5125 - Collaborative and Social Computing (3.0 cr)
•CSCI 5161 - Introduction to Compilers (3.0 cr)
•CSCI 5271 - Introduction to Computer Security (3.0 cr)
•CSCI 5421 - Advanced Algorithms and Data Structures (3.0 cr)
•CSCI 5451 - Introduction to Parallel Computing: Architectures, Algorithms, and Programming (3.0 cr)
•CSCI 5707 - Principles of Database Systems (3.0 cr)
•CSCI 5708 - Architecture and Implementation of Database Management Systems (3.0 cr)
•CSCI 5801 - Software Engineering I (3.0 cr)
•CSCI 5802 - Software Engineering II (3.0 cr)
**Computational Science**
Take 0 or more course(s) from the following:
•CSCI 5302 - Analysis of Numerical Algorithms (3.0 cr)
•CSCI 5304 - Computational Aspects of Matrix Theory (3.0 cr)
•CSCI 5451 - Introduction to Parallel Computing: Architectures, Algorithms, and Programming (3.0 cr)
•CSCI 5461 - Functional Genomics, Systems Biology, and Bioinformatics (3.0 cr)
•CSCI 5481 - Computational Techniques for Genomics (3.0 cr)
•CSCI 5523 - Introduction to Data Mining (3.0 cr)
•CSCI 5609 - Visualization (3.0 cr)
•CSCI 5715 - From GPS, Google Maps, and Uber to Spatial Data Science (3.0 cr)
•**Graphics, Virtual Reality and User Interface Design**
Take 0 or more course(s) from the following:
•CSCI 4611 - Programming Interactive Computer Graphics and Games (3.0 cr)
•CSCI 5115 - User Interface Design, Implementation and Evaluation (3.0 cr)
•CSCI 5127W - Embodied Computing: Design & Prototyping [WI] (3.0 cr)
•CSCI 5607 - Fundamentals of Computer Graphics 1 (3.0 cr)
•CSCI 5611 - Animation & Planning in Games (3.0 cr)
•CSCI 5619 - Virtual Reality and 3D Interaction (3.0 cr)
•**Other Approved Technical Electives**
Up to 6 credits can count from the following courses, fulfilling a portion of the required 28 technical elective credits (additional electives). Excludes CSCI 4921. Additional options may be available each semester, including Learning Abroad courses and Grand Challenges courses. Consult with ECE department as needed.
Take 0 or more credit(s) from the following:
•AEM 2011 - Statics (3.0 cr)
•AEM 2012 - Dynamics (3.0 cr)
•AEM 2021 - Statics and Dynamics (4.0 cr)
•AEM 3031 - Deformable Body Mechanics (3.0 cr)
•AEM 4601 - Instrumentation Laboratory (3.0 cr)
•AST 2001 - Fundamental Astrophysics (4.0 cr)
•BBE 3013 - Engineering Principles of Molecular and Cellular Processes (3.0 cr)
•BIOC 3021 - Biochemistry (3.0 cr)
•BMEN 5101 - Advanced Bioelectricity and Instrumentation (3.0 cr)
•BMEN 5111 - Biomedical Ultrasound (3.0 cr)
•BMEN 5151 - Introduction to BioMEMS and Medical Microdevices (2.0 cr)
•BMEN 5401 - Advanced Biomedical Imaging (3.0 cr)
•BMEN 5411 - Neural Engineering (3.0 cr)
•BMEN 5412 - Neuromodulation (3.0 cr)

•BMEN 5421 - Introduction to Biomedical Optics (3.0 cr)
•CEGE 3501 - Introduction to Environmental Engineering [ENV] (3.0 cr)
•CEGE 3502 - Fluid Mechanics (4.0 cr)
•CHEM 1062 - Chemical Principles II [PHYS] (3.0 cr)
•CHEM 1066 - Chemical Principles II Laboratory [PHYS] (1.0 cr)
•CHEM 2301 - Organic Chemistry I (3.0 cr)
•CHEM 2302 - Organic Chemistry II (3.0 cr)
•CHEM 2311 - Organic Lab (4.0 cr)
•CHEM 4501 - Introduction to Thermodynamics, Kinetics, and Statistical Mechanics (3.0 cr)
•CHEM 4502 - Introduction to Quantum Mechanics and Spectroscopy (3.0 cr)
•CSCI 4xxx
•CSCI 5xxx
•EE 2701 - Sustainable Electricity Supply: Renewables and Conservation [TS] (3.0 cr)
•EE 4xxx
•EE 5xxx
•GCC 3011 - Pathways to Renewable Energy [TS] (3.0 cr)
•GCC 3027 - Power Systems Journey: Making the Invisible Visible and Actionable [TS] (3.0 cr)
•GCC 5011 - Pathways to Renewable Energy [TS] (3.0 cr)
•GCC 5027 - Power Systems Journey: Making the Invisible Visible and Actionable [TS] (3.0 cr)
•IE 5111 - Systems Engineering I (2.0 cr)
•IE 5113 - Systems Engineering II (4.0 cr)
•IE 5441 - Financial Decision Making (4.0 cr)
•IE 5511 - Human Factors and Work Analysis (4.0 cr)
•IE 5513 - Engineering Safety (4.0 cr)
•IE 5522 - Quality Engineering and Reliability (4.0 cr)
•IE 5531 - Engineering Optimization I (4.0 cr)
•IE 5541 - Project Management (4.0 cr)
•IE 5551 - Production and Inventory Systems (4.0 cr)
•IE 5553 - Simulation (4.0 cr)
•INET 4021 - Dev Ops I: Network Programming (4.0 cr)
•MATH 3283W - Sequences, Series, and Foundations: Writing Intensive [WI] (4.0 cr)
•MATH 4xxx
•MATH 5xxx
•MATS 3011 - Introduction to Materials Science and Engineering (3.0 cr)
•MATS 3012 - Metals and Alloys (3.0 cr)
•MATS 3013 - Electrical and Magnetic Properties of Materials (3.0 cr)
•MATS 3851W - Materials Properties Lab [WI] (4.0 cr)
•ME 3324 - Introduction to Thermal Science (3.0 cr)
•ME 3331 - Thermodynamics (3.0 cr)
•ME 3332 - Fluid Mechanics (3.0 cr)
•ME 3333 - Heat Transfer (3.0 cr)
•PHSL 3061 - Principles of Physiology (4.0 cr)
•PHYS 2303 - Physics III: Physics of Matter (4.0 cr)
•PHYS 2311 *{Inactive}*(4.0 cr)
•PHYS 2503 - Physics III: Intro to Waves, Optics, and Special Relativity (4.0 cr)
•PHYS 2503H - Honors Physics III (4.0 cr)
•PHYS 2601 - Quantum Physics (4.0 cr)
•PHYS 4101 - Quantum Mechanics (4.0 cr)
•PHYS 4201 - Statistical and Thermal Physics (3.0 cr)
•STAT 5101 - Theory of Statistics I (4.0 cr)
•STAT 5102 - Theory of Statistics II (4.0 cr)
•Students must complete EE 3041 and EE 4043W to receive co-op credit. The third course in the sequence, EE 4044, is optional. Students may take a maximum of 6 credits of co-op courses in partial fulfillment of technical elective requirements (additional electives).
Take exactly 6 credit(s) from the following:
•EE 3041 *{Inactive}*(2.0 cr)
•EE 4043W - Industrial Assignment II [WI] (4.0 cr)
•EE 4044 - Industrial Assignment III (2.0 cr)

**•Other Business, Law, and Entrepreneurial Related Courses**
Students may take a maximum of 4 credits from the following courses in partial fulfillment of technical elective requirements (additional electives).
Take at most 4 credit(s) from the following:
•BLAW 3058 *{Inactive}*(4.0 cr)
•MGMT 4080W - Applied Technology Entrepreneurship [WI] (4.0 cr)
•MOT 4001 - Leadership, Professionalism and Business Basics for Engineers (2.0 cr)

*-OR-*

**Business & Management Emphasis**
Complete the requirements for the Business & Management Emphasis sub-plan.

*-OR-*

**Product Design Emphasis**
Complete the requirements for the Product Design Emphasis sub-plan.

*-OR-*

**Interdisciplinary Design Emphasis**
Complete the requirements for the Interdisciplinary Design Emphasis sub-plan.

## Program Sub-plans

A sub-plan is not required for this program.

### Integrated Bachelor of Computer Eng/Master of Science in Electrical and Computer Eng.

The Department of Electrical and Computer Engineering offers an integrated Bachelors and Masters Degree program. Students accepted to the integrated program will be guaranteed admission to the Electrical and Computer Engineering MS as long as they complete their undergraduate program. Accepted students will not need to take the GRE exam or submit Letters of Recommendation as part of their graduate application, unlike other students applying to our graduate programs.

Applicants must be enrolled University of Minnesota - Twin Cities students admitted to an Electrical Engineering or Computer Engineering undergraduate program. Applicants must meet a Technical GPA minimum of 3.4 (as defined by the College of Science & Engineering) or have at least a 3.2 GPA and additional positive factors that make them eligible.

Students are eligible to apply after they have completed EE 3015, EE 3101, EE 3115, and a minimum of three additional credits of EE 3xxx level, EE 4xxx level or CSCI 4xxx level coursework. Depending on application materials and timing, an applicant may be asked to wait for another semester of grades before being admitted or rejected.

Full application instructions can be found at https://ece.umn.edu/combined-degree-program/.

Courses that will be used to fulfill Masters degree requirements must appear in this sub-plan by the tenth day of the semester in which the student is enrolled in the courses.

Any final edits or updates to this sub-pan must be reflected on the APAS no later than the last day of instruction in the semester in which the undergraduate degree will be awarded. Courses not in this sub-plan by that time cannot be updated at a later time; and, therefore will not be eligible for use towards the Masters degree.

Students can transfer a maximum of 16 credits to the graduate program taken during their integrated senior undergraduate year. Credits being applied to the Master's in Electrical and Computer Engineering taken while the student is an undergraduate for use in the integrated program can also be applied later to an Electrical Engineering Ph.D. within our department if a student applies and is admitted. Credits cannot also be applied to the undergraduate degree (i.e., no double dipping).

### Integrated Bachelor of Computer Engineering/Master of Science in Computer Science and Eng

The Department of Computer Science & Engineering offers an integrated Bachelors and Masters Degree program. Students accepted to the integrated program will be guaranteed admission to the Computer Science MS as long as they complete their undergraduate program. Accepted students will not need to take the GRE exam as part of their graduate application, unlike other students applying to our graduate programs.

Applicants must be enrolled University of Minnesota Twin Cities students admitted to a Computer Science or Computer Engineering undergraduate program. Applicants must meet a Technical GPA minimum of 3.5 (as defined by the College of Science & Engineering) or they must have a strong recommendation from a Computer Science and Engineering faculty member or instructor (not an ECE Faculty member).

Applicants must have at least 75 credits completed at the time of their application.
Applicants must have passed with a C- or better all of the following courses:

CSCI 1933 or 1913
CSCI 2011
CSCI 2021 (CSCI students) or EE 2361 (CompE students)
CSCI 2033 or a math course containing linear algebra content

CSCI 2041 (CSCI students only)
CSCI 3081W (CSCI students only), CSCI 4041, and CSCI 4061 (applicants can have one of these courses in progress at the time of application)

Full application instructions can be found at cs.umn.edu/integrated

Courses that will be used to fulfill Masters degree requirements must appear in this sub-plan by the tenth day of the semester in which the student is enrolled in the courses.

Any final edits or updates to this sub-pan must be reflected on the APAS no later than the last day of instruction in the semester in which the undergraduate degree will be awarded. Courses not in this sub-plan by that time cannot be updated at a later time; and, therefore will not be eligible for use towards the Masters degree.

Students can transfer a maximum of 16 credits to the graduate program taken during their integrated senior undergraduate year. Students must spend a minimum of two semesters as a graduate student after the completion of their undergraduate degree. Coursework applied to the graduate degree must be taken at the graduate level (i.e., 5xxx or above) Credits being applied to the Computer Science Masters taken while the student is an undergraduate for use in the integrated program can also be applied later to a Computer Science Ph.D. within our department if a student applies and is admitted. Credits cannot also be applied to the undergraduate degree (i.e., no double dipping).

Students should consider taking the following courses/requirements to apply to their graduate degree as an undergraduate integrated program student (16 credits max):

CSCI 8970 - Computer Science Colloquium (1 credit)

Course to meet the Theory and Algorithms Breadth requirement (3 credits)*

Course to meet the Architecture, Systems, & Software Breadth requirement (3 credits)*

Course to meet the Applications Breadth requirement (3 credits)*

CSCI 5XXX level course that fits your interests and background (3 credits) or an approved graduate level elective or graduate minor course. We recommend waiting to take CSCI 8XXX level courses for your graduate year, but this level of coursework is still available to you if you have the appropriate prerequisites.

CSCI 5XXX level course that fits your interests and background (3 credits) or an approved graduate level elective or graduate minor course. We recommend waiting to take CSCI 8XXX level courses for your graduate year, but this level of coursework is still available to you if you have the appropriate prerequisites.

*Please refer to the Department of Computer Science & Engineering webpage for more details on which courses count for specific breadth requirements.

## Business & Management Emphasis

**Business & Management Courses**

Students can choose to complete a management emphasis (analogous to the management minor in the Carlson School of Business) alongside this degree program. Students are highly encouraged to apply for a management minor through the Carlson School of Business.

Take 12 or more credit(s) from the following:

- ACCT 3001 - Strategic Management Accounting (3.0 cr)
- FINA 3001 - Finance Fundamentals (3.0 cr)
- HRIR 3021 - Human Capital Management (3.0 cr)
- IDSC 3001 - Information Systems & Digital Transformation [TS] (3.0 cr)
- MGMT 3001 - Fundamentals of Management (3.0 cr)
- MGMT 3015 - Introduction to Entrepreneurship (4.0 cr)
- MKTG 3001 - Principles of Marketing (3.0 cr)
- PA 3003 - Nonprofit and Public Financial Management (3.0 cr)
- PA 4101 - Nonprofit Management and Governance (3.0 cr)
- SCO 3001 - Sustainable Supply Chain and Operations (3.0 cr)

**Core Department Electives**

Students must complete a minimum of 22 credits from EE 4xxx/5xxx or CSCI 4xxx/5xxx courses.

**Core Department Electives**

Take 22 or more credit(s) from the following:

**Senior Design Project**

A senior design project is required.
•EE 4951W - Senior Design Project [WI] (4.0 cr)

•**Lab Courses**

Two additional EE or CSCI lab courses are required.
Take 2 or more course(s) from the following:
•EE 4111 - Advanced Analog Electronics Design (4.0 cr)
•EE 4163 - Energy Conversion and Storage Laboratory (1.0 cr)
•EE 4235 - Linear Control Systems Laboratory (1.0 cr)
•EE 4237 - State Space Control Laboratory (1.0 cr)
•EE 4301 - Digital Design With Programmable Logic (4.0 cr)
•EE 4341 - Embedded System Design (4.0 cr)
•EE 4505 - Communications Systems Laboratory (1.0 cr)
•EE 4703 - Electric Drives Laboratory (1.0 cr)
•EE 4722 - Power System Analysis Laboratory (1.0 cr)
•EE 4743 - Switch-Mode Power Electronics Laboratory (1.0 cr)
•EE 4930 - Special Topics in Electrical and Computer Engineering Laboratory (1.0 - 2.0 cr)
•EE 5141 - Introduction to Microsystem Technology (4.0 cr)
•EE 5173 - Basic Microelectronics Laboratory (1.0 cr)
•EE 5327 - VLSI Design Laboratory (3.0 cr)
•EE 5373 - Data Modeling Using R (1.0 cr)
•EE 5545 - Digital Signal Processing Design (3.0 cr)
•EE 5613 - RF/Microwave Circuit Design Laboratory (2.0 cr)
•EE 5622 - Physical Optics Laboratory (1.0 cr)
•EE 5657 - Physical Principles of Thin Film Technology (4.0 cr)
•EE 5707 - Electric Drives in Sustainable Energy Systems Laboratory (1.0 cr)
•EE 5811 - Biological Instrumentation (3.0 cr)
•CSCI 4511W - Introduction to Artificial Intelligence [WI] (4.0 cr)
•CSCI 5511 - Artificial Intelligence I (3.0 cr)
•CSCI 5551 - Introduction to Intelligent Robotic Systems (3.0 cr)

•**Breadth and Depth Requirements (Specialty Areas)**

Take one course in 4 Breadth and Depth Requirement categories below (breadth). Within one of those categories, take a total of 2 courses (depth).

**Computer Architecture**

Take 0 or more course(s) from the following:
•EE 4389W - Introduction to Predictive Learning [WI] (3.0 cr)
•EE 5340 - Introduction to Quantum Computing and Physical Basics of Computing (3.0 cr)
•EE 5351 - Applied Parallel Programming (3.0 cr)
•EE 5364 - Advanced Computer Architecture (3.0 cr)
•EE 5371 - Computer Systems Performance Measurement and Evaluation (3.0 cr)
•EE 5391 *{Inactive}*(3.0 cr)
•EE 5393 - Circuits, Computation, and Biology (3.0 cr)
•CSCI 5204 - Advanced Computer Architecture (3.0 cr)

**Robotics and Embedded System Design**

Take 0 or more course(s) from the following:
•EE 4231 - Linear Control Systems: Designed by Input/Output Methods (3.0 cr)
•EE 4233 - State Space Control System Design (3.0 cr)
•EE 4341 - Embedded System Design (4.0 cr)
•EE 5340 - Introduction to Quantum Computing and Physical Basics of Computing (3.0 cr)
•EE 5391 *{Inactive}*(3.0 cr)
•CSCI 4511W - Introduction to Artificial Intelligence [WI] (4.0 cr)
•CSCI 5143 - Real-Time and Embedded Systems (3.0 cr)
•CSCI 5511 - Artificial Intelligence I (3.0 cr)
•CSCI 5512 - Artificial Intelligence II (3.0 cr)
•CSCI 5521 - Machine Learning Fundamentals (3.0 cr)
•CSCI 5525 - Machine Learning: Analysis and Methods (3.0 cr)
•CSCI 5551 - Introduction to Intelligent Robotic Systems (3.0 cr)
•CSCI 5552 - Sensing and Estimation in Robotics (3.0 cr)
•CSCI 5561 - Computer Vision (3.0 cr)
•EE 5271 - Robot Vision (3.0 cr)

**VLSI and CAD**

Take 0 or more course(s) from the following:
•EE 4301 - Digital Design With Programmable Logic (4.0 cr)
•EE 5301 - VLSI Design Automation I (3.0 cr)
•EE 5302 - VLSI Design Automation II (3.0 cr)
•EE 5323 - VLSI Design I (3.0 cr)
•EE 5324 - VLSI Design II (3.0 cr)

•EE 5327 - VLSI Design Laboratory (3.0 cr)
•EE 5329 - VLSI Digital Signal Processing Systems (3.0 cr)
•EE 5333 - Analog Integrated Circuit Design (3.0 cr)

**Networks and Communication**

Take 0 or more course(s) from the following:

•EE 4501 - Communications Systems (3.0 cr)
•CSCI 4131 - Internet Programming (3.0 cr)
•CSCI 4211 - Introduction to Computer Networks (3.0 cr)
•CSCI 5117 - Developing the Interactive Web (3.0 cr)
•CSCI 5211 - Data Communications and Computer Networks (3.0 cr)
•CSCI 5221 - Foundations of Advanced Networking (3.0 cr)
•CSCI 5231 *{Inactive}*(3.0 cr)
•CSCI 5271 - Introduction to Computer Security (3.0 cr)
•CSCI 5471 - Modern Cryptography (3.0 cr)

**Systems and Software Design**

Take 0 or more course(s) from the following:

•EE 5355 - Algorithmic Techniques for Scalable Many-core Computing (3.0 cr)
•CSCI 4011 - Formal Languages and Automata Theory (4.0 cr)
•CSCI 4707 - Practice of Database Systems (3.0 cr)
•CSCI 5103 - Operating Systems (3.0 cr)
•CSCI 5105 - Introduction to Distributed Systems (3.0 cr)
•CSCI 5106 - Programming Languages (3.0 cr)
•CSCI 5117 - Developing the Interactive Web (3.0 cr)
•CSCI 5125 - Collaborative and Social Computing (3.0 cr)
•CSCI 5161 - Introduction to Compilers (3.0 cr)
•CSCI 5271 - Introduction to Computer Security (3.0 cr)
•CSCI 5421 - Advanced Algorithms and Data Structures (3.0 cr)
•CSCI 5451 - Introduction to Parallel Computing: Architectures, Algorithms, and Programming (3.0 cr)
•CSCI 5707 - Principles of Database Systems (3.0 cr)
•CSCI 5708 - Architecture and Implementation of Database Management Systems (3.0 cr)
•CSCI 5801 - Software Engineering I (3.0 cr)
•CSCI 5802 - Software Engineering II (3.0 cr)

**Computational Science**

Take 0 or more course(s) from the following:

•CSCI 5302 - Analysis of Numerical Algorithms (3.0 cr)
•CSCI 5304 - Computational Aspects of Matrix Theory (3.0 cr)
•CSCI 5451 - Introduction to Parallel Computing: Architectures, Algorithms, and Programming (3.0 cr)
•CSCI 5461 - Functional Genomics, Systems Biology, and Bioinformatics (3.0 cr)
•CSCI 5481 - Computational Techniques for Genomics (3.0 cr)
•CSCI 5523 - Introduction to Data Mining (3.0 cr)
•CSCI 5609 - Visualization (3.0 cr)
•CSCI 5715 - From GPS, Google Maps, and Uber to Spatial Data Science (3.0 cr)

•**Graphics, Virtual Reality and User Interface Design**

Take 0 or more course(s) from the following:

•CSCI 4611 - Programming Interactive Computer Graphics and Games (3.0 cr)
•CSCI 5115 - User Interface Design, Implementation and Evaluation (3.0 cr)
•CSCI 5127W - Embodied Computing: Design & Prototyping [WI] (3.0 cr)
•CSCI 5607 - Fundamentals of Computer Graphics 1 (3.0 cr)
•CSCI 5611 - Animation & Planning in Games (3.0 cr)
•CSCI 5619 - Virtual Reality and 3D Interaction (3.0 cr)

## Product Design Emphasis

**Product Design Courses**

Students can choose to complete a Product Design emphasis (analogous to the Product Design minor) alongside this degree program in consultation with the advising office. Only the following courses can be counted. Students are highly encouraged to apply for a Product Design minor through CDES.

DES 2701 - Creative Design Methods (3.0 cr)
PDES 2702 - Concept Sketching (3.0 cr)
PDES 3711 - Product Innovation Lab (4.0 cr)
*or* PDES 5711 - Product Innovation Lab (4.0 cr)

**Core Department Electives**

Students must complete a minimum of 22 credits from EE 4xxx/5xxx or CSCI 4xxx/5xxx courses.

**Core Department Electives**

Take 22 or more credit(s) from the following:

**Senior Design Project**

A senior design project is required.

- •EE 4951W - Senior Design Project [WI] (4.0 cr)

•**Lab Courses**

Two additional EE or CSCI lab courses are required.
Take 2 or more course(s) from the following:

- •EE 4111 - Advanced Analog Electronics Design (4.0 cr)
- •EE 4163 - Energy Conversion and Storage Laboratory (1.0 cr)
- •EE 4235 - Linear Control Systems Laboratory (1.0 cr)
- •EE 4237 - State Space Control Laboratory (1.0 cr)
- •EE 4301 - Digital Design With Programmable Logic (4.0 cr)
- •EE 4341 - Embedded System Design (4.0 cr)
- •EE 4505 - Communications Systems Laboratory (1.0 cr)
- •EE 4703 - Electric Drives Laboratory (1.0 cr)
- •EE 4722 - Power System Analysis Laboratory (1.0 cr)
- •EE 4743 - Switch-Mode Power Electronics Laboratory (1.0 cr)
- •EE 4930 - Special Topics in Electrical and Computer Engineering Laboratory (1.0 - 2.0 cr)
- •EE 5141 - Introduction to Microsystem Technology (4.0 cr)
- •EE 5173 - Basic Microelectronics Laboratory (1.0 cr)
- •EE 5327 - VLSI Design Laboratory (3.0 cr)
- •EE 5373 - Data Modeling Using R (1.0 cr)
- •EE 5545 - Digital Signal Processing Design (3.0 cr)
- •EE 5613 - RF/Microwave Circuit Design Laboratory (2.0 cr)
- •EE 5622 - Physical Optics Laboratory (1.0 cr)
- •EE 5657 - Physical Principles of Thin Film Technology (4.0 cr)
- •EE 5707 - Electric Drives in Sustainable Energy Systems Laboratory (1.0 cr)
- •EE 5811 - Biological Instrumentation (3.0 cr)
- •CSCI 4511W - Introduction to Artificial Intelligence [WI] (4.0 cr)
- •CSCI 5511 - Artificial Intelligence I (3.0 cr)
- •CSCI 5551 - Introduction to Intelligent Robotic Systems (3.0 cr)

•**Breadth and Depth Requirements (Specialty Areas)**

Take one course in 4 Breadth and Depth Requirement categories below (breadth). Within one of those categories, take a total of 2 courses (depth).

**Computer Architecture**

Take 0 or more course(s) from the following:

- •EE 4389W - Introduction to Predictive Learning [WI] (3.0 cr)
- •EE 5340 - Introduction to Quantum Computing and Physical Basics of Computing (3.0 cr)
- •EE 5351 - Applied Parallel Programming (3.0 cr)
- •EE 5364 - Advanced Computer Architecture (3.0 cr)
- •EE 5371 - Computer Systems Performance Measurement and Evaluation (3.0 cr)
- •EE 5391 *{Inactive}*(3.0 cr)
- •EE 5393 - Circuits, Computation, and Biology (3.0 cr)
- •CSCI 5204 - Advanced Computer Architecture (3.0 cr)

**Robotics and Embedded System Design**

Take 0 or more course(s) from the following:

- •EE 4231 - Linear Control Systems: Designed by Input/Output Methods (3.0 cr)
- •EE 4233 - State Space Control System Design (3.0 cr)
- •EE 4341 - Embedded System Design (4.0 cr)
- •EE 5340 - Introduction to Quantum Computing and Physical Basics of Computing (3.0 cr)
- •EE 5391 *{Inactive}*(3.0 cr)
- •CSCI 4511W - Introduction to Artificial Intelligence [WI] (4.0 cr)
- •CSCI 5143 - Real-Time and Embedded Systems (3.0 cr)
- •CSCI 5511 - Artificial Intelligence I (3.0 cr)
- •CSCI 5512 - Artificial Intelligence II (3.0 cr)
- •CSCI 5521 - Machine Learning Fundamentals (3.0 cr)
- •CSCI 5525 - Machine Learning: Analysis and Methods (3.0 cr)
- •CSCI 5551 - Introduction to Intelligent Robotic Systems (3.0 cr)
- •CSCI 5552 - Sensing and Estimation in Robotics (3.0 cr)
- •CSCI 5561 - Computer Vision (3.0 cr)
- •EE 5271 - Robot Vision (3.0 cr)

**VLSI and CAD**

Take 0 or more course(s) from the following:

- •EE 4301 - Digital Design With Programmable Logic (4.0 cr)
- •EE 5301 - VLSI Design Automation I (3.0 cr)
- •EE 5302 - VLSI Design Automation II (3.0 cr)
- •EE 5323 - VLSI Design I (3.0 cr)
- •EE 5324 - VLSI Design II (3.0 cr)
- •EE 5327 - VLSI Design Laboratory (3.0 cr)

•EE 5329 - VLSI Digital Signal Processing Systems (3.0 cr)
•EE 5333 - Analog Integrated Circuit Design (3.0 cr)

**Networks and Communication**

Take 0 or more course(s) from the following:
•EE 4501 - Communications Systems (3.0 cr)
•CSCI 4131 - Internet Programming (3.0 cr)
•CSCI 4211 - Introduction to Computer Networks (3.0 cr)
•CSCI 5117 - Developing the Interactive Web (3.0 cr)
•CSCI 5211 - Data Communications and Computer Networks (3.0 cr)
•CSCI 5221 - Foundations of Advanced Networking (3.0 cr)
•CSCI 5231 *{Inactive}*(3.0 cr)
•CSCI 5271 - Introduction to Computer Security (3.0 cr)
•CSCI 5471 - Modern Cryptography (3.0 cr)

**Systems and Software Design**

Take 0 or more course(s) from the following:
•EE 5355 - Algorithmic Techniques for Scalable Many-core Computing (3.0 cr)
•CSCI 4011 - Formal Languages and Automata Theory (4.0 cr)
•CSCI 4707 - Practice of Database Systems (3.0 cr)
•CSCI 5103 - Operating Systems (3.0 cr)
•CSCI 5105 - Introduction to Distributed Systems (3.0 cr)
•CSCI 5106 - Programming Languages (3.0 cr)
•CSCI 5117 - Developing the Interactive Web (3.0 cr)
•CSCI 5125 - Collaborative and Social Computing (3.0 cr)
•CSCI 5161 - Introduction to Compilers (3.0 cr)
•CSCI 5271 - Introduction to Computer Security (3.0 cr)
•CSCI 5421 - Advanced Algorithms and Data Structures (3.0 cr)
•CSCI 5451 - Introduction to Parallel Computing: Architectures, Algorithms, and Programming (3.0 cr)
•CSCI 5707 - Principles of Database Systems (3.0 cr)
•CSCI 5708 - Architecture and Implementation of Database Management Systems (3.0 cr)
•CSCI 5801 - Software Engineering I (3.0 cr)
•CSCI 5802 - Software Engineering II (3.0 cr)

**Computational Science**

Take 0 or more course(s) from the following:
•CSCI 5302 - Analysis of Numerical Algorithms (3.0 cr)
•CSCI 5304 - Computational Aspects of Matrix Theory (3.0 cr)
•CSCI 5451 - Introduction to Parallel Computing: Architectures, Algorithms, and Programming (3.0 cr)
•CSCI 5461 - Functional Genomics, Systems Biology, and Bioinformatics (3.0 cr)
•CSCI 5481 - Computational Techniques for Genomics (3.0 cr)
•CSCI 5523 - Introduction to Data Mining (3.0 cr)
•CSCI 5609 - Visualization (3.0 cr)
•CSCI 5715 - From GPS, Google Maps, and Uber to Spatial Data Science (3.0 cr)

•**Graphics, Virtual Reality and User Interface Design**

Take 0 or more course(s) from the following:
•CSCI 4611 - Programming Interactive Computer Graphics and Games (3.0 cr)
•CSCI 5115 - User Interface Design, Implementation and Evaluation (3.0 cr)
•CSCI 5127W - Embodied Computing: Design & Prototyping [WI] (3.0 cr)
•CSCI 5607 - Fundamentals of Computer Graphics 1 (3.0 cr)
•CSCI 5611 - Animation & Planning in Games (3.0 cr)
•CSCI 5619 - Virtual Reality and 3D Interaction (3.0 cr)

## Interdisciplinary Design Emphasis

**Interdisciplinary Design Courses**

Students can choose to complete an Interdisciplinary Design emphasis (analogous to the Interdisciplinary Design minor) alongside this degree program in consultation with the advising office. Only the following courses can be counted. Students are highly encouraged to apply for a Interdisciplinary Design minor through CDES.

**Lower Division Design Courses**

Take 3 or more credit(s) from the following:
•DES 1000 - D@MN: Design@Minnesota [AH] (3.0 cr)
•DES 1101V - Honors: Introduction to Design Thinking [AH, WI] (4.0 cr)
•DES 1101W - Introduction to Design Thinking [AH, WI] (4.0 cr)
•LA 1001 *{Inactive}*[ENV] (3.0 cr)
•LA 1401 - The Designed Environment [AH] (3.0 cr)
•LA 1601 - Design and Equity [DSJ, AH] (3.0 cr)
•LA 3601 - Design and Equity [DSJ, AH] (3.0 cr)

**Upper Division Design Courses**

Take 8 or more credit(s) from the following:

•ARCH 5611 - Design in the Digital Age (3.0 cr)
•DES 3131 - User Experience in Design (4.0 cr)
•GDES 5341 - Interaction Design (3.0 cr)
•GDES 5342 - Advanced Web Design (3.0 cr)
•GDES 5383 - Digital Illustration and Animation (3.0 cr)
•GDES 5386 - Fundamentals of Game Design (3.0 cr)
•KIN 5505 - Human-Centered Design - Principles and Applications (3.0 cr)
•PDES 5701 - User-Centered Design Studio (4.0 cr)
•PDES 5702 - Visual Communication (3.0 cr)
•PDES 5703 - Prototyping Methods (4.0 cr)
•PDES 5711 - Product Innovation Lab (4.0 cr)

**Core Department Electives**

Students must complete a minimum of 22 credits from EE 4xxx/5xxx or CSCI 4xxx/5xxx courses.

**Core Department Electives**

Take 22 or more credit(s) from the following:

**Senior Design Project**

A senior design project is required.
•EE 4951W - Senior Design Project [WI] (4.0 cr)

•**Lab Courses**

Two additional EE or CSCI lab courses are required.
Take 2 or more course(s) from the following:
•EE 4111 - Advanced Analog Electronics Design (4.0 cr)
•EE 4163 - Energy Conversion and Storage Laboratory (1.0 cr)
•EE 4235 - Linear Control Systems Laboratory (1.0 cr)
•EE 4237 - State Space Control Laboratory (1.0 cr)
•EE 4301 - Digital Design With Programmable Logic (4.0 cr)
•EE 4341 - Embedded System Design (4.0 cr)
•EE 4505 - Communications Systems Laboratory (1.0 cr)
•EE 4703 - Electric Drives Laboratory (1.0 cr)
•EE 4722 - Power System Analysis Laboratory (1.0 cr)
•EE 4743 - Switch-Mode Power Electronics Laboratory (1.0 cr)
•EE 4930 - Special Topics in Electrical and Computer Engineering Laboratory (1.0 - 2.0 cr)
•EE 5141 - Introduction to Microsystem Technology (4.0 cr)
•EE 5173 - Basic Microelectronics Laboratory (1.0 cr)
•EE 5327 - VLSI Design Laboratory (3.0 cr)
•EE 5373 - Data Modeling Using R (1.0 cr)
•EE 5545 - Digital Signal Processing Design (3.0 cr)
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•EE 5622 - Physical Optics Laboratory (1.0 cr)
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•CSCI 4511W - Introduction to Artificial Intelligence [WI] (4.0 cr)
•CSCI 5511 - Artificial Intelligence I (3.0 cr)
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•**Breadth and Depth Requirements (Specialty Areas)**

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•EE 5364 - Advanced Computer Architecture (3.0 cr)
•EE 5371 - Computer Systems Performance Measurement and Evaluation (3.0 cr)
•EE 5391 *{Inactive}*(3.0 cr)
•EE 5393 - Circuits, Computation, and Biology (3.0 cr)
•CSCI 5204 - Advanced Computer Architecture (3.0 cr)

**Robotics and Embedded System Design**

Take 0 or more course(s) from the following:
•EE 4231 - Linear Control Systems: Designed by Input/Output Methods (3.0 cr)
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- •CSCI 5521 - Machine Learning Fundamentals (3.0 cr)
- •CSCI 5525 - Machine Learning: Analysis and Methods (3.0 cr)
- •CSCI 5551 - Introduction to Intelligent Robotic Systems (3.0 cr)
- •CSCI 5552 - Sensing and Estimation in Robotics (3.0 cr)
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- •EE 5327 - VLSI Design Laboratory (3.0 cr)
- •EE 5329 - VLSI Digital Signal Processing Systems (3.0 cr)
- •EE 5333 - Analog Integrated Circuit Design (3.0 cr)

**Networks and Communication**

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- •CSCI 4131 - Internet Programming (3.0 cr)
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- •CSCI 5211 - Data Communications and Computer Networks (3.0 cr)
- •CSCI 5221 - Foundations of Advanced Networking (3.0 cr)
- •CSCI 5231 *{Inactive}*(3.0 cr)
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**Systems and Software Design**

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- •CSCI 4707 - Practice of Database Systems (3.0 cr)
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- •CSCI 5106 - Programming Languages (3.0 cr)
- •CSCI 5117 - Developing the Interactive Web (3.0 cr)
- •CSCI 5125 - Collaborative and Social Computing (3.0 cr)
- •CSCI 5161 - Introduction to Compilers (3.0 cr)
- •CSCI 5271 - Introduction to Computer Security (3.0 cr)
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- •CSCI 5707 - Principles of Database Systems (3.0 cr)
- •CSCI 5708 - Architecture and Implementation of Database Management Systems (3.0 cr)
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- •CSCI 5481 - Computational Techniques for Genomics (3.0 cr)
- •CSCI 5523 - Introduction to Data Mining (3.0 cr)
- •CSCI 5609 - Visualization (3.0 cr)
- •CSCI 5715 - From GPS, Google Maps, and Uber to Spatial Data Science (3.0 cr)

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Take 0 or more course(s) from the following:

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- •CSCI 5127W - Embodied Computing: Design & Prototyping [WI] (3.0 cr)
- •CSCI 5607 - Fundamentals of Computer Graphics 1 (3.0 cr)
- •CSCI 5611 - Animation & Planning in Games (3.0 cr)
- •CSCI 5619 - Virtual Reality and 3D Interaction (3.0 cr)