

# Materials Science and Engineering

## Bachelor of Science (BS)

Materials Scientists and Engineers are involved in every aspect of technology, ranging from the design of materials appropriate for use in integrated circuits and biological applications to those materials needed for energy generation (both conventional energy sources and green sources) and for building bridges, roads, and buildings.

Upon graduation, students are prepared for a number of different careers paths. Many go on to graduate studies at prestigious universities. Others head directly into the workforce as engineers in Silicon Valley, the biotechnology sector, the aerospace or automotive fields, and energy-related industries.

The objectives of the undergraduate program in Materials Science and Engineering (MSE) are to educate graduates who have the following skills:

- Knowledge of the fundamental science and engineering principles relevant to materials design, development and engineering application.
- Understanding of the relationship between nano/microstructure, characterization, properties and processing and design of materials.
- Have the experimental and computational skills for a professional career or graduate study in materials.
- Possess a knowledge of the significance of research, the value of continued learning and environmental/social issues surrounding materials.
- Ability to communicate effectively, to work in teams, and to assume positions as leaders.

This major program leads to a Bachelor of Science (BS) degree.

## Admission to the Major

Prospective undergraduates to the College of Engineering will apply for admission to a specific program in the College. For further information, please see the College of Engineering's website (<http://coe.berkeley.edu/students/prospective-students/admissions.html>) .

Admission to Engineering via a Change of College application for current UC Berkeley students is highly unlikely and very competitive as there few, if any, spaces that open in the College each year to students admitted to other colleges at UC Berkeley. For further information regarding a Change of College to Engineering, please see the College's website (<http://coe.berkeley.edu/students/current-undergraduates/change-of-college>) .

## Five-Year BS/MS Program

The five-year combined Bachelor of Science/Master of Science program augments the existing four-year undergraduate program with a fifth year of graduate study that provides a professionally oriented component, preparing students for careers in engineering or engineering management within the business, government, and/or industrial sectors. In this program, students earn a bachelor's degree and subsequently, a Master of Science degree under Plan II (without thesis) of the Academic Senate. This five-year program emphasizes

interdisciplinary study through an independent project coupled to coursework. The program is open to undergraduate materials science and engineering majors (both single or joint majors) only. For further information regarding this program, please see the department's website (<http://www.mse.berkeley.edu/undergrad/five-year>) .

## Minor Program

The department offers a minor in Materials Science and Engineering that is open to all students who are not majoring in MSE and who have completed the necessary prerequisites. To be eligible for the program, students are required to have a minimum overall grade point average (GPA) of 3.0 and a minimum GPA of 3.0 in the prerequisite courses. For information regarding the prerequisites, please see the Minor Requirements tab on this page.

To apply for the minor, submit the Petition for Admission to the Undergraduate Minor (<http://www.mse.berkeley.edu/wp-content/uploads/mse-minor-petition-version-8.14.pdf>) to the undergraduate adviser after completion of the prerequisite courses. Upon completion of the minor requirements, submit a Petition for Completion of the Undergraduate Minor (<http://www.mse.berkeley.edu/wp-content/uploads/MSE-confirmation-of-completion-for-Minor-Version-8.14.pdf>) to the undergraduate adviser.

## Joint Majors

The Department of Materials Science and Engineering also offers four joint majors, with other departments in the College of Engineering, and one joint major with a department in the College of Chemistry. For further information on these programs, please see the links below:

Chemical Engineering/Materials Science and Engineering (<http://guide.berkeley.edu/archive/2016-17/undergraduate/degree-programs/chemical-engineering-materials-science-joint-major>) (Department of Chemical and Biomolecular Engineering, College of Chemistry)  
 Bioengineering/Materials Science and Engineering (<http://guide.berkeley.edu/archive/2016-17/undergraduate/degree-programs/bioengineering-materials-science-engineering-joint-major>) (Department of Bioengineering)  
 Electrical Engineering and Computer Sciences/Materials Science and Engineering (<http://guide.berkeley.edu/archive/2016-17/undergraduate/degree-programs/electrical-engineering-computer-sciences-materials>) (Department of Electrical Engineering and Computer Sciences)  
 Materials Science and Engineering/Mechanical Engineering (<http://guide.berkeley.edu/archive/2016-17/undergraduate/degree-programs/materials-science-engineering-mechanical-joint-major>) (Department of Mechanical Engineering)  
 Materials Science and Engineering/Nuclear Engineering (<http://guide.berkeley.edu/archive/2016-17/undergraduate/degree-programs/materials-science-engineering-nuclear-joint-major>) (Department of Nuclear Engineering)

In addition to the University, campus, and college requirements, students must fulfill the below requirements specific to their major program.

## General Guidelines

1. All technical courses (courses in engineering, mathematics, chemistry, physics, statistics, biological sciences, and computer science) must be taken for a letter grade.
2. No more than one upper division course may be used to simultaneously fulfill requirements for a student's major and minor programs.

- A minimum overall grade point average (GPA) of 2.0 is required for all work undertaken at UC Berkeley.
- A minimum GPA of 2.0 is required for all technical courses taken in satisfaction of major requirements.

For information regarding residence requirements and unit requirements, please see the College Requirements tab.

For a detailed plan of study by year and semester, please see the plan of study tab.

## Lower Division Requirements

MATH 1A	Calculus	4
MATH 1B	Calculus	4
MATH 53	Multivariable Calculus	4
MATH 54	Linear Algebra and Differential Equations	4
CHEM 1A & 1AL or CHEM 4A	General Chemistry and General Chemistry Laboratory <sup>1</sup> General Chemistry and Quantitative Analysis	4
CHEM 1B or CHEM 4B	General Chemistry <sup>1</sup> General Chemistry and Quantitative Analysis	4
PHYSICS 7A	Physics for Scientists and Engineers	4
PHYSICS 7B	Physics for Scientists and Engineers	4
PHYSICS 7C	Physics for Scientists and Engineers	4
ENGIN 7	Introduction to Computer Programming for Scientists and Engineers	4
ENGIN 45 & 45L	Properties of Materials and Properties of Materials Laboratory	4
MEC ENG C85/ CIV ENG C30	Introduction to Solid Mechanics	3

<sup>1</sup> CHEM 4A and CHEM 4B are designed for students majoring in chemistry or a closely-related field.

## Upper Division Requirements

ENGIN 115	Engineering Thermodynamics	4
ENGIN 117	Methods of Engineering Analysis	3
MAT SCI 102	Bonding, Crystallography, and Crystal Defects	3
MAT SCI 103	Phase Transformations and Kinetics	3
MAT SCI 104	Materials Characterization	4
MAT SCI 111	Properties of Electronic Materials	4
MAT SCI 112	Corrosion (Chemical Properties)	3
MAT SCI 113	Mechanical Behavior of Engineering Materials	3
MAT SCI 130	Experimental Materials Science and Design	3
MAT SCI 151	Polymeric Materials	3
MAT SCI 120 Series Course <sup>1</sup>		3-4
Upper Division Engineering Elective <sup>2</sup>		3-4

<sup>1</sup> Must include at least one course from the MAT SCI 120 series: MAT SCI 120, MAT SCI 121, MAT SCI 122, MAT SCI 123, MAT SCI 125.

- An Upper Division Engineering Elective is chosen in consultation with the student's faculty adviser. Students may use three units of credit for work on a research project in MAT SCI H194 (Honors Undergraduate Research). Other letter-graded research courses may be approved by petition.

Upper Division Engineering Electives cannot include:

- Any course taken on a *Pass/No Pass* basis
- Courses numbered 24, 39, or 84
- Any of the following courses:  
BIO ENG 100, CHM ENG 185, COMPSCI 195, COMPSCI H195,  
DES INV courses (except  
DES INV 190E), ENGIN 125, ENGIN 157AC, IND ENG 172, IND ENG 185, IND ENG 190, IND ENG 190 series courses, IND ENG 191, IND ENG 192, IND ENG 195,  
MEC ENG 190K, MEC ENG 191AC, and MEC ENG 191K

Minor programs are areas of concentration requiring fewer courses than an undergraduate major. These programs are optional but can provide depth and breadth to a UC Berkeley education. The College of Engineering does not offer additional time to complete a minor, but it is usually possible to finish within the allotted time with careful course planning. Students are encouraged to meet with their ESS adviser to discuss the feasibility of completing a minor program.

All the engineering departments offer minors. Students may also consider pursuing a minor in another school or college.

## General Guidelines

- All courses taken to fulfill the minor requirements must be taken for graded credit.
- A minimum overall grade point average (GPA) of 3.0 and a minimum GPA of 3.0 in the prerequisite courses is required for acceptance into the minor program.
- A minimum grade point average (GPA) of 2.0 is required for courses used to fulfill the minor requirements.
- No more than one upper division course may be used to simultaneously fulfill requirements for a student's major and minor programs.
- Completion of the minor program cannot delay a student's graduation.

## Requirements

### Prerequisites

ENGIN 45 & 45L	Properties of Materials and Properties of Materials Laboratory	4
ENGIN 115	Engineering Thermodynamics	4

### Upper Division Requirements

MAT SCI 102	Bonding, Crystallography, and Crystal Defects	3
MAT SCI 103	Phase Transformations and Kinetics	3

Select one of the following:

MAT SCI 104	Materials Characterization
MAT SCI 111	Properties of Electronic Materials
MAT SCI 112	Corrosion (Chemical Properties)
MAT SCI 113	Mechanical Behavior of Engineering Materials
MAT SCI 117	Properties of Dielectric and Magnetic Materials
MAT SCI 120	Materials Production
MAT SCI 121	Metals Processing

MAT SCI 122 Ceramic Processing

MAT SCI 123 ELECTRONIC MATERIALS PROCESSING

MAT SCI 125 Thin-Film Materials Science

## Students in the College of Engineering must complete no fewer than 120 semester units with the following provisions:

1. Completion of the requirements of one engineering major program (<http://coe.berkeley.edu/students/guide/departments>) of study.
2. A minimum overall grade point average of 2.00 (C average) and a minimum 2.00 grade point average in upper division technical coursework required of the major.
3. The final 30 units and two semesters must be completed in residence in the College of Engineering on the Berkeley campus.
4. All technical courses (math, science and engineering), required of the major or not, must be taken on a letter graded basis (unless they are only offered P/NP).
5. Entering freshmen are allowed a maximum of eight semesters to complete their degree requirements. Entering junior transfers are allowed a maximum of four semesters to complete their degree requirements. (Note: junior transfers admitted missing three or more courses from the lower division curriculum are allowed five semesters.) Summer terms are optional and do not count toward the maximum. Students are responsible for planning and satisfactorily completing all graduation requirements within the maximum allowable semesters.
6. Adhere to all college policies and procedures (<http://engineering.berkeley.edu/academics/undergraduate-guide>) as they complete degree requirements.
7. Complete the lower division program before enrolling in upper division engineering courses.

## Humanities and Social Science (H/SS) Requirement

To promote a rich and varied educational experience outside of the technical requirements for each major, the College of Engineering has a six-course Humanities and Social Sciences breadth requirement (<http://engineering.berkeley.edu/student-services/degree-requirements/humanities-and-social-sciences>), which must be completed to graduate. This requirement, built into all the engineering programs of study, includes two reading and composition courses (R&C), and four additional courses within which a number of specific conditions must be satisfied. Follow these guidelines to fulfill this requirement:

1. Complete a minimum of six courses from the approved Humanities/Social Sciences (H/SS) lists (<http://coe.berkeley.edu/hssreq>).
2. Courses must be a minimum of 3 semester units (or 4 quarter units).
3. Two of the six courses must fulfill the college's Reading and Composition (R&C) requirement. These courses must be taken for a letter grade (C- or better required) and must be completed by no later than the end of the sophomore year (fourth semester of enrollment). The first half of R&C, the "A" course, must be completed by the end of the freshman year; the second half of R&C, the "B" course, must be completed by no later than the end of the sophomore year. View a detailed lists of courses (<http://ls-advise.berkeley.edu/requirement/rcourses.html>) that fulfill Reading and Composition requirements, or use the College of Letters and Sciences search engine (<http://ls-breadth.berkeley.edu>) to view R&C courses offered in a given semester.

4. The four additional courses must be chosen within College of Engineering guidelines from the H/SS lists (see below). These courses may be taken on a Pass/Not Passed basis (P/NP).
5. Two of the six courses must be upper division (courses numbered 100-196).
6. One of the six courses must satisfy the campus American Cultures requirement. For detailed lists of courses that fulfill American Cultures requirements, visit the American Cultures (<http://guide.berkeley.edu/archive/2016-17/undergraduate/colleges-schools/engineering/american-cultures-requirement>) site.
7. A maximum of two exams (Advanced Placement, International Baccalaureate, or A-Level) may be used toward completion of the H/SS requirement. View the list of exams (<http://engineering.berkeley.edu/academics/undergraduate-guide/exams-ap-ib-level-and-transfer-credit-information>) that can be applied toward H/SS requirements.
8. Courses may fulfill multiple categories. For example, if you complete CY PLAN 118AC (<http://guide.berkeley.edu/search/?P=CYP%20PLAN%20118AC>) that would satisfy the American Cultures requirement and one upper division H/SS requirement.
9. No courses offered by any engineering department other than BIO ENG 100 (<http://guide.berkeley.edu/search/?P=BIO%20ENG%20100>), COMPSCI C79 (<http://guide.berkeley.edu/search/?P=COMPSCI%20C79>), ENGIN 125 (<http://guide.berkeley.edu/search/?P=ENGIN%20125>), ENGIN 157AC (<http://guide.berkeley.edu/search/?P=ENGIN%20157AC>), MEC ENG 191K (<http://guide.berkeley.edu/search/?P=MEC%20ENG%20191K>) and MEC ENG 191AC (<http://guide.berkeley.edu/search/?P=MEC%20ENG%20191AC>) may be used to complete H/SS requirements.
10. Foreign language courses may be used to complete H/SS requirements. View the list of language options (<http://ls-advise.berkeley.edu/requirement/fl.html>).
11. Courses numbered 97, 98, 99, or above 196 may not be used to complete any H/SS requirement.
12. The College of Engineering uses modified versions of five of the College of Letters and Science (L&S) breadth requirements lists to provide options to our students for completing the H/SS requirement. No courses on the L&S Biological Sciences or Physical Sciences breadth lists may be used to complete H/SS requirements. Within the guidelines above, choose courses from any of the lists below.
  - Arts and Literature (<http://guide.berkeley.edu/archive/2016-17/undergraduate/colleges-schools/letters-science/breadth-requirement-arts-literature>)
  - Foreign Language (<http://ls-advise.berkeley.edu/requirement/fl.html>)
  - Historical Studies (<http://guide.berkeley.edu/archive/2016-17/undergraduate/colleges-schools/letters-science/breadth-requirement-historical-studies>)
  - International Studies (<http://guide.berkeley.edu/archive/2016-17/undergraduate/colleges-schools/letters-science/breadth-requirement-international-studies>)
  - Philosophy and Values (<http://guide.berkeley.edu/archive/2016-17/undergraduate/colleges-schools/letters-science/breadth-requirement-philosophy-values>)

- Social and Behavioral Studies (<http://guide.berkeley.edu/archive/2016-17/undergraduate/colleges-schools/letters-science/breadth-requirement-social-behavioral-sciences>)

## Class Schedule Requirements

- Minimum units per semester: 12.0.
- Maximum units per semester: 20.5.
- Minimum technical courses: College of Engineering undergraduates must enroll each semester in no fewer than two technical courses (of a minimum of 3 units each) required of the major program of study in which the student is officially declared. (Note: for most majors, normal progress will require enrolling in 3-4 technical courses each semester).
- All technical courses (math, science, engineering), required of the major or not, must be taken on a letter graded basis (unless only offered as P/NP).
- A student's proposed schedule must be approved by a faculty adviser (or on approval from the dean or a designated staff adviser) each semester prior to enrolling in courses.

## Minimum Academic (Grade) Requirements

- A minimum overall and semester grade point average of 2.00 (C average) is required of engineering undergraduates. A student will be subject to dismissal from the University if during any fall or spring semester their overall UC GPA falls below a 2.00, or their semester GPA is less than 2.00.
- Students must achieve a minimum grade point average of 2.00 (C average) in upper division technical courses required of the major curriculum each semester. A student will be subject to dismissal from the University if their upper division technical grade point average falls below 2.00.
- A minimum overall grade point average of 2.00, and a minimum 2.00 grade point average in upper division technical course work required of the major is needed to earn a Bachelor of Science in Engineering.

## Unit Requirements

To earn a Bachelor of Science in Engineering, students must complete at least 120 semester units of courses subject to certain guidelines:

- Completion of the requirements of one engineering major program (<http://coe.berkeley.edu/students/guide/departments>) of study.
- A maximum of 16 units of special studies coursework (courses numbered 97, 98, 99, 197, 198, or 199) is allowed towards the 120 units; a maximum of four is allowed in a given semester.
- A maximum of 4 units of physical education from any school attended will count towards the 120 units.
- Students may receive unit credit for courses graded P (including P/ NP units taken through EAP) up to a limit of one-third of the total units taken and passed on the Berkeley campus at the time of graduation.

## Normal Progress

Students in the College of Engineering must enroll in a full-time program and make normal progress each semester toward the bachelor's degree. The continued enrollment of students who fail to achieve minimum academic progress shall be subject to the approval of the dean. (Note: students with official accommodations established by the Disabled Students' Program, with health or family issues, or with other reasons

deemed appropriate by the dean may petition for an exception to normal progress rules.)

For more detailed information regarding the courses listed below (e.g., elective information, GPA requirements, etc.), please see the College Requirements and Major Requirements tabs.

Freshman				
	Fall	Units	Spring	Units
CHEM 4A or 1A <i>and</i> 1AL <sup>1</sup>		4	MATH 1B	4
MATH 1A		4	PHYSICS 7A	4
Reading & Composition course from List A <sup>2</sup>		4	CHEM 1B or 4B <sup>1</sup>	4
Humanities/Social Science Course <sup>2</sup>		3-4	ENGIN 7	4
		15-16		16
Sophomore				
	Fall	Units	Spring	Units
MATH 53		4	MATH 54	4
PHYSICS 7B		4	PHYSICS 7C	4
ENGIN 45 & 45L		4	MAT SCI 151	3
Reading & Composition Course from List B <sup>2</sup>		4	MEC ENG C8:	3
		16		14
Junior				
	Fall	Units	Spring	Units
MAT SCI 102		3	MAT SCI 103	3
ENGIN 115		4	MAT SCI 104	4
ENGIN 117		3	MAT SCI 111	4
Humanities/Social Science Course <sup>2</sup>		3-4	MAT SCI 112	3
		13-14		14
Senior				
	Fall	Units	Spring	Units
MAT SCI 113		3	Upper Division Engineering Elective <sup>4</sup>	3-4
MAT SCI 130		3	Humanities/Social Science Course <sup>2</sup>	3-4
MAT SCI 120 Series Course <sup>3</sup>		3	Free Electives	10
Humanities/Social Science Course <sup>2</sup>		3-4		
Free Elective		4		
		16-17		16-18

**Total Units: 120-125**

- <sup>1</sup> CHEM 4A is intended for students majoring in chemistry or a closely-related field.
- <sup>2</sup> The Humanities/Social Science (H/SS) requirement includes two approved reading and composition courses and four additional approved courses, with which a number of specific conditions must be satisfied. Reading and Composition "A" and "B" must be completed by no later than the end of the sophomore year. The remaining courses may be taken at any time during the program. See [engineering.berkeley.edu/hss](http://engineering.berkeley.edu/hss) (<http://engineering.berkeley.edu/student-services/degree-requirements/humanities-and-social-sciences>) for complete details and a list of approved courses.
- <sup>3</sup> Must include at least one course from the MAT SCI 120 series: MAT SCI 120, MAT SCI 121, MAT SCI 122, MAT SCI 123, MAT SCI 125.



- <sup>4</sup> An Upper Division Engineering Elective is chosen in consultation with the student's faculty adviser. Students may use three units of credit for work on a research project in MAT SCI H194 (<http://guide.berkeley.edu/archive/2016-17/search/?P=MAT%20SCI%20H194>) (Honors Undergraduate Research) for the Engineering Elective. Other letter-graded research courses may be approved by petition.

Upper Division Engineering Electives cannot include:

- Any course taken on a *Pass/No Pass* basis
- Courses numbered 24, 39, or 84
- Any of the following courses:  
BIO ENG 100, CHM ENG 185, COMPSCI 195, COMPSCI H195,  
DES INV courses (except DES INV 190E),  
ENGIN 125, ENGIN 157AC, IND ENG 172, IND ENG 185, IND ENG 186, IND  
ENG 190 series courses, IND ENG 191, IND ENG 192, IND ENG 195,  
MEC ENG 190K, MEC ENG 191AC, and MEC ENG 191K

## Learning Goals of the Major

### Measured Curricular Outcomes

The program is designed around a set of curricular outcomes. Specifically, upon completion of our ABET accredited program in Materials Science and Engineering, the graduate will possess the following skills:

1. Be able to apply general math, science and engineering skills to the solution of engineering problems.
2. Be aware of the social, safety and environmental consequences of their work, and be able to engage in public debate regarding these issues.
3. Be able to apply core concepts in materials science to solve engineering problems.
4. Be knowledgeable of contemporary issues relevant to materials science and engineering.
5. Be able to select materials for design and construction.
6. Understand the importance of life-long learning.
7. Be able to design and conduct experiments, and to analyze data.
8. Understand the professional and ethical responsibilities of a materials scientist and engineer.
9. Be able to work both independently and as part of a team.
10. Be able to communicate effectively while speaking, employing graphics, and writing.
11. Possess the skills and techniques necessary for modern materials engineering practice.

## Educational Objectives for Graduates

Stated succinctly, graduates from the program will have the following skills:

1. Know the fundamental science and engineering principles relevant to materials.
2. Understand the relationship between nano/microstructure, characterization, properties and processing, and design of materials.
3. Have the experimental and computational skills for a professional career or graduate study in materials.
4. Possess a knowledge of the significance of research, the value of continued learning, and environmental/social issues surrounding materials.
5. Be able to communicate effectively, to work in teams and to assume positions as leaders.

## Undergraduate Research

There is nothing more tangible in engineering products than the materials of which they are made, and this fact dominates the research agenda in materials science & engineering around the world. At Berkeley, research programs in new materials synthesis, processing, characterization, integration, and theoretical modeling dominate the laboratory space and multiple servers dedicated to basic and applied research programs in the department, including many that are conducted at the Lawrence Berkeley National Laboratory. Undergraduate students are strongly encouraged to meet with the many faculty members in the department who sponsor student research projects and learn about the many exciting options available to them. Sometimes a new student's research experience begins by shadowing a senior graduate student to learn the ropes, but sometimes the project is fully unique, and exclusively theirs! Undergraduate students can earn units for their research efforts by enrolling in MAT SCI 199, which is offered on a *Pass/No Pass* basis. Another option is an honors thesis project, MAT SCI H194, offered to qualified students as a graded course, which can therefore be counted as an upper division technical elective. There are also a number of paid research positions, especially over the summer. Students should not be shy about asking and should consider adding materials research to their undergraduate experience at Berkeley.

## Student Groups and Organizations

The Materials Science & Engineering Association (MSEA) serves a large number of students on the Berkeley campus, including many non-majors, who know that a future in the materials disciplines is an enticing career option. Officers in MSEA sponsor both scholarly and social events to broaden undergraduates' experiences here, and through a professional connection called Materials Advantage, students can join four national materials societies to launch their professional careers early.

Undergraduate students in the department are also highly respected members of several engineering student projects because of the materials issues involved. These include the Solar Car (CalSol) project, the Formula SAE race car team, the Human Powered Vehicle team, the Supermileage Vehicle team, and others offering deep immersion in actual engineering design and construction of a functional product. For students interested in shaping a carbon-fiber skin component or welding a 6061 aluminum alloy roll bar component, there are many opportunities to learn these and other valuable skills as a student in MSE.

## Materials Science and Engineering

### MAT SCI 24 Freshman Seminar 1 Unit

Terms offered: Spring 2018, Spring 2017, Spring 2016

The Freshman Seminar Program has been designed to provide new students with the opportunity to explore an intellectual topic with a faculty member in a small seminar setting. Freshman seminars are offered in all campus departments, and topics vary from department to department and semester to semester. Enrollment limited to 20 freshmen.

Freshman Seminar: Read More [\[+\]](#)

#### Hours & Format

**Fall and/or spring:** 15 weeks - 1 hour of lecture per week

#### Additional Details

**Subject/Course Level:** Materials Science and Engineering/  
Undergraduate

**Grading/Final exam status:** Offered for pass/not pass grade only. Final exam required.

Freshman Seminar: Read Less [\[-\]](#)

### MAT SCI 45 Properties of Materials 3 Units

Terms offered: Spring 2018, Fall 2017

Application of basic principles of physics and chemistry to the engineering properties of materials. Special emphasis devoted to relation between microstructure and the mechanical properties of metals, concrete, polymers, and ceramics, and the electrical properties of semiconducting materials. Sponsoring Department: Materials Science and Engineering  
Properties of Materials: Read More [\[+\]](#)

#### Rules & Requirements

**Prerequisites:** Physics 7A (may be taken concurrently)

**Credit Restrictions:** Students will receive no credit for MSE 45 after taking E45

#### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture per week

#### Additional Details

**Subject/Course Level:** Materials Science and Engineering/  
Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

**Instructors:** Martin, Messersmith

Bonding, Crystallography, and Crystal Defects: Read Less [\[-\]](#)

### MAT SCI 45L Properties of Materials Laboratory 1 Unit

Terms offered: Spring 2018, Fall 2017

This course presents laboratory applications of the basic principles introduced in the lecture-based course MSE45 – Properties of Materials. Properties of Materials Laboratory: Read More [\[+\]](#)

#### Rules & Requirements

**Credit Restrictions:** Students will receive no credit for MSE 45L after taking E45L

#### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of laboratory per week

#### Additional Details

**Subject/Course Level:** Materials Science and Engineering/  
Undergraduate

**Grading/Final exam status:** Letter grade. Final exam not required.

**Instructors:** Martin, Messersmith

Properties of Materials Laboratory: Read Less [\[-\]](#)

### MAT SCI 102 Bonding, Crystallography, and Crystal Defects 3 Units

Terms offered: Fall 2017, Fall 2016, Fall 2015

Bonding in solids; classification of metals, semiconductors, and insulators; crystal systems; point, line, and planar defects in crystals; examples of crystallographic and defect analysis in engineering materials; relationship to physical and mechanical properties.  
Bonding, Crystallography, and Crystal Defects: Read More [\[+\]](#)

#### Rules & Requirements

**Prerequisites:** Engineering 45

#### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture per week

#### Additional Details

**Subject/Course Level:** Materials Science and Engineering/  
Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

**Instructor:** Chrzan

Bonding, Crystallography, and Crystal Defects: Read Less [\[-\]](#)

## MAT SCI 103 Phase Transformations and Kinetics 3 Units

Terms offered: Spring 2018, Spring 2017, Spring 2016

The nature, mechanisms, and kinetics of phase transformations and microstructural changes in the solid state. Atom diffusion in solids. Phase transformations through the nucleation and growth of new matrix or precipitate phases. Martensitic transformations, spinodal decomposition. The use of phase transformations to control microstructure.

Phase Transformations and Kinetics: Read More [a+]

### Rules & Requirements

**Prerequisites:** 102 and Engineering 115

### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/  
Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

Phase Transformations and Kinetics: Read Less [-]

## MAT SCI 104 Materials Characterization 4 Units

Terms offered: Spring 2018, Spring 2017, Spring 2016

Physical and chemical characterization of materials: Diffraction, imaging, and spectroscopy using optical, electron, and X-ray methods for bulk and surface analysis. Measurement of mechanical and physical properties. Project laboratory focusing on mechanical, chemical, electrical, and magnetic properties of materials, and materials characterization. Field trips.

Materials Characterization: Read More [a+]

### Rules & Requirements

**Prerequisites:** 102

### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture and 3 hours of laboratory per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/  
Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

**Instructor:** Gronskey

Materials Characterization: Read Less [-]

## MAT SCI 111 Properties of Electronic Materials 4 Units

Terms offered: Spring 2018, Spring 2017, Spring 2016

Introduction to the physical principles underlying the electric properties of modern solids with emphasis on semiconductors; control of defects and impurities through physical purification, bulk and thin film crystal growth and doping processes, materials basis of electronic and optoelectronic devices (diodes, transistors, semiconductor lasers) and optical fibers; properties of metal and oxide superconductors and their applications.

Properties of Electronic Materials: Read More [a+]

### Rules & Requirements

**Prerequisites:** Physics 7A-7B-7C or Physics 7A-7B and consent of instructor

### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture and 1 hour of discussion per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/  
Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

**Instructors:** Dubon, Wu, Yao

Properties of Electronic Materials: Read Less [-]

## MAT SCI 112 Corrosion (Chemical Properties) 3 Units

Terms offered: Spring 2018, Spring 2017, Spring 2016

Electrochemical theory of corrosion. Mechanisms and rates in relation to physiochemical and metallurgical factors. Stress corrosion and mechanical influences on corrosion. Corrosion protection by design, inhibition, cathodic protection, and coatings.

Corrosion (Chemical Properties): Read More [a+]

### Rules & Requirements

**Prerequisites:** Engineering 45 and Engineering 115

### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/  
Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

**Instructor:** Devine

Corrosion (Chemical Properties): Read Less [-]

## MAT SCI 113 Mechanical Behavior of Engineering Materials 3 Units

Terms offered: Fall 2017, Fall 2016, Fall 2015

This course covers elastic and plastic deformation under static and dynamic loads. Prediction and prevention of failure by yielding, fracture, fatigue, wear and environmental factors are addressed. Design issues pertaining to materials selection for load bearing applications are discussed. Case studies of engineering failures are presented. Topics include engineering materials, structure-property relationships, materials selection for design, mechanical behavior of polymers and design of plastic components, complex states of stress and strain, elastic deformation and multiaxial loading, plastic deformation and yield criteria, dislocation plasticity and strengthening mechanisms, creep, effects of stress concentrations, fracture, fatigue, and contact stresses.

Mechanical Behavior of Engineering Materials: Read More [\[+\]](#)

### Rules & Requirements

**Prerequisites:** C30/Mechanical Engineering C85 and Engineering 45

**Credit Restrictions:** Students will receive no credit for 113 after taking C113 or Mechanical Engineering C124. Deficiency in C113 or Mechanical Engineering C124 maybe removed by taking 113.

### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/ Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

**Instructor:** Ritchie

Mechanical Behavior of Engineering Materials: Read Less [\[-\]](#)

## MAT SCI 117 Properties of Dielectric and Magnetic Materials 3 Units

Terms offered: Spring 2017, Spring 2011, Fall 2010

Introduction to the physical principles underlying the dielectric and magnetic properties of solids. Processing-microstructure-property relationships of dielectric materials, including piezoelectric, pyroelectric, and ferroelectric oxides, and of magnetic materials, including hard- and soft ferromagnets, ferrites and magneto-optic and -resistive materials. The course also covers the properties of grain boundary devices (including varistors) as well as ion-conducting and mixed conducting materials for applications in various devices such as sensors, fuel cells, and electric batteries.

Properties of Dielectric and Magnetic Materials: Read More [\[+\]](#)

### Rules & Requirements

**Prerequisites:** Physics 7A-7B-7C or Physics 7A-7B and consent of instructor; 111 is recommended

### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/ Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

Properties of Dielectric and Magnetic Materials: Read Less [\[-\]](#)



## MAT SCI C118 Biological Performance of Materials 4 Units

Terms offered: Fall 2017, Fall 2015, Fall 2014

This course is intended to give students the opportunity to expand their knowledge of topics related to biomedical materials selection and design. Structure-property relationships of biomedical materials and their interaction with biological systems will be addressed. Applications of the concepts developed include blood-materials compatibility, biomimetic materials, hard and soft tissue-materials interactions, drug delivery, tissue engineering, and biotechnology.

Biological Performance of Materials: [Read More](#) [+]

### Objectives Outcomes

**Course Objectives:** The course is separated into four parts spanning the principles of synthetic materials and surfaces, principles of biological materials, biological performance of materials and devices, and state-of-the-art materials design. Students are required to attend class and master the material therein. In addition, readings from the clinical, life and materials science literature are assigned. Students are encouraged to seek out additional reference material to complement the readings assigned. A mid-term examination is given on basic principles (parts 1 and 2 of the outline). A comprehensive final examination is given as well. The purpose of this course is to introduce students to problems associated with the selection and function of biomaterials. Through class lectures and readings in both the physical and life science literature, students will gain broad knowledge of the criteria used to select biomaterials, especially in devices where the material-tissue or material-solution interface dominates performance. Materials used in devices for medicine, dentistry, tissue engineering, drug delivery, and the biotechnology industry will be addressed.

This course also has a significant design component (~35%). Students will form small teams (five or less) and undertake a semester-long design project related to the subject matter of the course. The project includes the preparation of a paper and a 20 minute oral presentation critically analyzing a current material-tissue or material-solution problem. Students will be expected to design improvements to materials and devices to overcome the problems identified in class with existing materials.

**Student Learning Outcomes:** Apply math, science & engineering principles to the understanding of soft materials, surface chemistry, DLVO theory, protein adsorption kinetics, viscoelasticity, mass diffusion, and molecular (i.e., drug) delivery kinetics.

- Design experiments and analyze data from the literature in the context of the class design project.

Apply core concepts in materials science to solve engineering problems related to the selection biomaterials, especially in devices where the material-tissue or material-solution interface dominates performance.

Develop an understanding of the social, safety and medical consequences of biomaterial use and regulatory issues associated with the selection of biomaterials in the context of the silicone breast implant controversy and subsequent biomaterials crisis.

Work independently and function on a team, and develop solid communication skills (oral, graphic & written) through the class design project.

- Understanding of the origin of surface forces and interfacial free energy, and how they contribute to the development of the biomaterial interface and ultimately biomaterial performance.

### Rules & Requirements

**Prerequisites:** Engin 45; BioE 103 or equivalent; BioE 102 and BioE 104 recommended

### Hours & Format

## MAT SCI 120 Materials Production 3 Units

Terms offered: Fall 2017, Fall 2016, Fall 2015

Economic and technological significance of metals and other materials. Elementary geology (composition of lithosphere, mineralization). Short survey of mining and mineral processing techniques. Review of chemical thermodynamics and reaction kinetics. Principles of process engineering including material, heat, and mechanical energy balances. Elementary heat transfer, fluid flow, and mass transfer. Electrolytic production and refining of metals. Vapor techniques for production of metals and coatings.

Materials Production: [Read More](#) [+]

### Rules & Requirements

**Prerequisites:** Engineering 115, Mechanical Engineering 40, Chemical Engineering 141, Chemistry 120B or equivalent thermodynamics course

### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/ Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

Materials Production: [Read Less](#) [-]

## MAT SCI 121 Metals Processing 3 Units

Terms offered: Spring 2015, Spring 2014, Spring 2013

The principles of metals processing with emphasis on the use of processing to establish microstructures which impart desirable engineering properties. The techniques discussed include solidification, thermal and mechanical processing, powder processing, welding and joining, and surface treatments.

Metals Processing: [Read More](#) [+]

### Rules & Requirements

**Prerequisites:** Engineering 45

### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/ Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

**Instructor:** Gronsky

Metals Processing: [Read Less](#) [-]

**MAT SCI 122 Ceramic Processing 3 Units**

Terms offered: Fall 2012, Fall 2011, Fall 2010

Powder fabrication by grinding and chemical methods, rheological behavior of powder-fluid suspensions, forming methods, drying, sintering, and grain growth. Relation of processing steps to microstructure development.

Ceramic Processing: Read More [a]

**Rules & Requirements**

**Prerequisites:** Engineering 45, 115

**Hours & Format**

**Fall and/or spring:** 15 weeks - 3 hours of lecture per week

**Additional Details**

**Subject/Course Level:** Materials Science and Engineering/  
Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

Ceramic Processing: Read Less [-]

**MAT SCI 123 ELECTRONIC MATERIALS PROCESSING 4 Units**

Terms offered: Fall 2017, Fall 2016, Fall 2015

This 4-unit course starts with a brief review of the fundamentals of solid-state physics including bands and defects in semiconductors and oxides, and then moves to bulk semiconductor crystals growth and processing including doping, diffusion and implantation, and then to thin film deposition and processing methods, and finishes with a discussion of materials analysis and characterization. Recent advances in nanomaterials research will also be introduced.

ELECTRONIC MATERIALS PROCESSING: Read More [a]

**Objectives Outcomes**

**Course Objectives:** To prepare students a) for work in semiconductor processing facilities and b) for graduate studies related to thin film processing and relevant materials science topics.

To present the relevant materials science issues in semiconductor and oxide processing

To provide an introduction into the principles of thin film processing and related technologies.

**Student Learning Outcomes:** Basic knowledge of gas kinetics and vacuum technology, including ideal gas, gas transport theory, definition, creation and measurement of vacuum.

Knowledge of electrical and optical properties of thin films.

Knowledge of the formation of p-n junction to explain the diode operation and its I-V characteristics. Understanding of the mechanisms of Hall Effect, transport, and C-V measurements, so that can calculate carrier concentration, mobility and conductivity given raw experimental data. The ability to describe major growth techniques of bulk, thin film, and nanostructured semiconductors, with particular emphasis on thin film deposition technologies, including evaporation, sputtering, chemical vapor deposition and epitaxial growths.

To have basic knowledge of doping, purification, oxidation, gettering, diffusion, implantation, metallization, lithography and etching in semiconductor processing.

To have basic knowledge of electronic material characterization methods: x-ray diffraction, SEM and TEM, EDX, Auger, STM and AFM, Rutherford Back Scattering and SIMS, as well as optical methods including photoluminescence, absorption and Raman scattering.

To understand the concepts of bands, bandgap, to distinguish direct and indirect bandgap semiconductors. Understanding of free electron and hole doping of semiconductors to determine Fermi level position.

To understand the effect of defects in semiconductors, so that can describe their electronic and optical behaviors, and the methods to eliminate and control them in semiconductors.

**Rules & Requirements**

**Prerequisites:** MSE 111 or Physics 7C or consent of instructor

**Hours & Format**

**Fall and/or spring:** 15 weeks - 4 hours of lecture per week

**Additional Details**

**Subject/Course Level:** Materials Science and Engineering/  
Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

**Instructors:** Wu, Yao

ELECTRONIC MATERIALS PROCESSING: Read Less [-]

## MAT SCI 125 Thin-Film Materials Science 3 Units

Terms offered: Spring 2016, Spring 2015, Fall 2014

Deposition, processing, and characterization of thin films and their technological applications. Physical and chemical vapor deposition methods. Thin-film nucleation and growth. Thermal and ion processing. Microstructural development in epitaxial, polycrystalline, and amorphous films. Thin-film characterization techniques. Applications in information storage, integrated circuits, and optoelectronic devices. Laboratory demonstrations.

Thin-Film Materials Science: Read More [ + ]

### Rules & Requirements

**Prerequisites:** Upper division or graduate standing in engineering, physics, chemistry, and chemical engineering; Engineering 45 required; 111 or Physics 141A recommended

### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/ Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

**Instructor:** Dubon

Thin-Film Materials Science: Read Less [ - ]

## MAT SCI 130 Experimental Materials Science and Design 3 Units

Terms offered: Fall 2017, Fall 2016, Fall 2015

This course provides a culminating experience for students approaching completion of the materials science and engineering curriculum. Laboratory experiments are undertaken in a variety of areas from the investigations on semiconductor materials to corrosion science and elucidate the relationships among structure, processing, properties, and performance. The principles of materials selection in engineering design are reviewed.

Experimental Materials Science and Design: Read More [ + ]

### Rules & Requirements

**Prerequisites:** Senior standing or consent of instructor

### Hours & Format

**Fall and/or spring:** 15 weeks - 2 hours of lecture and 3 hours of laboratory per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/ Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

Experimental Materials Science and Design: Read Less [ - ]

## MAT SCI 136 Materials in Energy Technologies 4 Units

Terms offered: Fall 2017, Fall 2015, Fall 2011

In many, if not all, technologies, it is materials that play a crucial, enabling role. This course examines potentially sustainable technologies, and the materials properties that enable them. The science at the basis of selected energy technologies are examined and considered in case studies.

Materials in Energy Technologies: Read More [ + ]

### Rules & Requirements

**Prerequisites:** Junior or above standing in Materials Science and Engineering or related field

### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture and 1 hour of discussion per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/ Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

**Formerly known as:** Materials Science and Engineering 126

Materials in Energy Technologies: Read Less [ - ]

## MAT SCI 140 Nanomaterials for Scientists and Engineers 3 Units

Terms offered: Spring 2015, Spring 2013, Spring 2012

This course introduces the fundamental principles needed to understand the behavior of materials at the nanometer length scale and the different classes of nanomaterials with applications ranging from information technology to biotechnology. Topics include introduction to different classes of nanomaterials, synthesis and characterization of nanomaterials, and the electronic, magnetic, optical, and mechanical properties of nanomaterials.

Nanomaterials for Scientists and Engineers: Read More [ + ]

### Rules & Requirements

**Prerequisites:** 102 or equivalent recommended; Physics 7C and Engineering 45 required

### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture and 1 hour of discussion per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/ Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

**Instructor:** Minor

Nanomaterials for Scientists and Engineers: Read Less [ - ]

## MAT SCI C150 Introduction to Materials Chemistry 3 Units

Terms offered: Spring 2018, Spring 2017, Spring 2015, Spring 2014, Spring 2012

The application of basic chemical principles to problems in materials discovery, design, and characterization will be discussed. Topics covered will include inorganic solids, nanoscale materials, polymers, and biological materials, with specific focus on the ways in which atomic-level interactions dictate the bulk properties of matter.

Introduction to Materials Chemistry: Read More [+]

### Rules & Requirements

**Prerequisites:** 104A; 104B is recommended

### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/ Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

**Also listed as:** CHEM C150

Introduction to Materials Chemistry: Read Less [-]

## MAT SCI 151 Polymeric Materials 3 Units

Terms offered: Spring 2018, Spring 2017, Spring 2016

This course is designed for upper division undergraduate and graduate students to gain a fundamental understanding of the science of polymeric materials. Beginning with a treatment of ideal polymeric chain conformations, it develops the thermodynamics of polymer blends and solutions, the modeling of polymer networks and gels, the dynamics of polymer chains, and the morphologies of thin films and other dimensionally-restricted structures relevant to nanotechnology.

Polymeric Materials: Read More [+]

### Rules & Requirements

**Prerequisites:** Chemistry 1A or Engineering 5. 103 is recommended

### Hours & Format

**Fall and/or spring:** 15 weeks - 3 hours of lecture per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/ Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

**Instructor:** Xu

Polymeric Materials: Read Less [-]

## MAT SCI H194 Honors Undergraduate Research 1 - 4 Units

Terms offered: Fall 2016, Spring 2016, Fall 2015

Students who have completed a satisfactory number of advanced courses with a grade-point average of 3.3 or higher may pursue original research under the direction of one of the members of the staff. A maximum of 3 units of H194 may be used to fulfill technical elective requirements in the Materials Science and Engineering program or double majors (unlike 198 or 199, which do not satisfy technical elective requirements). Final report required.

Honors Undergraduate Research: Read More [+]

### Rules & Requirements

**Prerequisites:** Upper division technical GPA of 3.3 or higher and consent of instructor and adviser

**Repeat rules:** Course may be repeated for credit.

### Hours & Format

**Fall and/or spring:** 15 weeks - 1-4 hours of independent study per week

**Summer:** 8 weeks - 1.5-7.5 hours of independent study per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/ Undergraduate

**Grading/Final exam status:** Letter grade. Final exam not required.

Honors Undergraduate Research: Read Less [-]

## MAT SCI 195 Special Topics for Advanced Undergraduates 1 Unit

Terms offered: Spring 2012, Spring 2011, Spring 2010

Group study of special topics in materials science and engineering. Selection of topics for further study of underlying concepts and relevant literature, in consultation with appropriate faculty members.

Special Topics for Advanced Undergraduates: Read More [+]

### Rules & Requirements

**Prerequisites:** Upper division standing and good academic standing. (2.0 gpa and above)

### Hours & Format

**Fall and/or spring:** 15 weeks - 1 hour of directed group study per week

### Additional Details

**Subject/Course Level:** Materials Science and Engineering/ Undergraduate

**Grading/Final exam status:** Letter grade. Final exam required.

Special Topics for Advanced Undergraduates: Read Less [-]

## **MAT SCI 198 Directed Group Studies for Advanced Undergraduates 1 - 4 Units**

Terms offered: Spring 2016, Fall 2015, Spring 2015

Group studies of selected topics.

Directed Group Studies for Advanced Undergraduates: [Read More](#) [+]

### **Rules & Requirements**

**Prerequisites:** Upper division standing in Engineering

### **Hours & Format**

**Fall and/or spring:** 15 weeks - 1-4 hours of directed group study per week

### **Additional Details**

**Subject/Course Level:** Materials Science and Engineering/  
Undergraduate

**Grading/Final exam status:** Offered for pass/not pass grade only. Final exam not required.

Directed Group Studies for Advanced Undergraduates: [Read Less](#) [-]

## **MAT SCI 199 Supervised Independent Study 1 - 4 Units**

Terms offered: Fall 2016, Spring 2016, Fall 2015

Supervised independent study. Enrollment restrictions apply; see the Introduction to Courses and Curricula section of this catalog.

Supervised Independent Study: [Read More](#) [+]

### **Rules & Requirements**

**Prerequisites:** Consent of instructor and major adviser

**Credit Restrictions:** Course may be repeated for a maximum of four units per semester.

### **Hours & Format**

**Fall and/or spring:** 15 weeks - 1-4 hours of independent study per week

### **Summer:**

6 weeks - 1-5 hours of independent study per week

8 weeks - 1-4 hours of independent study per week

### **Additional Details**

**Subject/Course Level:** Materials Science and Engineering/  
Undergraduate

**Grading/Final exam status:** Offered for pass/not pass grade only. Final exam not required.

Supervised Independent Study: [Read Less](#) [-]