

MATERIALS SCIENCE AND ENGINEERING PROGRAM

Aims and Scope of the Graduate Program

The Materials Science and Engineering (MSE) program equips students with fundamental and applied knowledge of nanomaterials and devices; energy conversion materials and devices; biomaterials; and advanced characterization techniques.

MSE offers its M.S. and Ph.D. students a curriculum based on core and elective courses. Typically, students are evaluated by written exams, course assignments, and oral presentations.

Master's Degree

The master's degree is awarded upon successful completion of a minimum of 36 credit hours. During Fall and Spring semesters, students must enroll in a minimum of nine credits and six credit hours during the summer session. The program is designed for completion in three semesters, commencing and ending in respective Fall Semesters, and inclusive of the summer. However, the program will allow, under specific circumstances, designated students to extend their studies to a fourth semester for a continuation of M.S. thesis research pending the approval of their M.S. thesis advisor. In very rare cases, graduation may be possible in 12 months, with approval of the academic advisor.

There are two M.S. degree options, a thesis and a non-thesis option. A minimum of 24 credit hours of coursework is required for both options, consisting of the following:

1. Core Curriculum: (12 credits) Three core courses from the following list: MSE 301 Crystallography and Diffraction; MSE 302 Electronic Properties of Materials; MSE 303 Statistical Thermodynamics and Equilibrium Processes; MSE 304 Applied Quantum Mechanics; and MSE 305 Kinetics and Phase Transformations plus one Applied Math course
2. Elective Curriculum: (12 credits) Four additional courses from either MSE or any other relevant program, upon that approval of the student's academic advisor
3. Research/Capstone Experience: (12 credits) The requirements for the remaining 12 credits are dependent upon which M.S. Degree option is pursued and require the approval of the student's advisor.

Additionally, students are expected to attend seminars offered by MSE or other programs. Although seminar attendance is required, no degree credit shall be given. A mark of pass/fail is recorded for this requirement. M.S. students must attend seminars during two semesters to meet this requirement.

Thesis Option

It is expected that students will register for 12 credits of thesis research (MSE 297) or internship (MSE 299 – maximum of six credits), where the internship must be related to the thesis project. Under exceptional circumstances, students may be able to complete their thesis work in less than 12 credits. In that case, and with the permission of the M.S. thesis advisor, a student may enroll in one of the following options to earn the remaining credits of degree requirement:

- **Internship:** Up to 6 credits of research-based summer internship (administered as directed research, MSE 299)
- **Non-Technical Broadening Experience Courses:** 3 to 6 credits of courses that broaden a student's M.S. experience.
- **Ph.D.-Level Courses:** 6 credits of MSE courses numbered 300 or greater. Any course in the Ph.D. core requirements that is passed with a minimum grade of B– may be used towards meeting the core Ph.D. requirements of the MSE program if the student chooses to continue for a Ph.D. degree in MSE at KAUST.

Students are permitted to register for more than 12 credits of M.S. thesis research as necessary and with the permission of the thesis advisor.

Evaluation of satisfactory completion of MS thesis work is performed by a committee comprising the M.S. thesis advisor and two other members. The chair of the committee must be a faculty member in the MSE program. The evaluation of M.S. thesis credits is through a pass or a fail grade. MSE thesis option students are required to give a public seminar based on the thesis research. For additional details on thesis requirements and committee formation, see General Degree Program Guidelines.

The student is responsible for scheduling the thesis defense date with his/her supervisor and committee members. It is advisable that the student submits a final copy of the thesis to the thesis committee members at least two weeks prior the defense date.

Non-Thesis Option

Research requirement: A minimum of 6 credits of directed research credits (MSE 299) is required. Summer internship credits may be used to fulfill the research requirement provided that the summer internship is research-based. Summer internships are subject to approval by the student's academic advisor.

Students must complete the remaining credits through one or a combination of the options listed below:

- **Two Courses:** Any two 3-credit graduate-level courses in any program at KAUST.
- **Non-technical Broadening Experience Courses:** 6 credits of courses that broaden a student's M.S. experience.

- **Ph.D.-Level Courses:** 6 credits of MSE courses numbered 300 or greater. Any course in the Ph.D. core requirements that is passed with a minimum grade of B– may be used towards meeting the core Ph.D. requirements of the MSE program if the student chooses to continue for a Ph.D. degree in MSE at KAUST.
- **Internship:** 6 credits of research-based summer internship (administered as directed research, MSE 299)

It should be noted that a student may also mix and match courses to satisfy the six-credit requirement. For example, a student could take one Ph.D.-level course and one graduate-level course in another program. A student may not enroll in two summer internships.

Degree of Doctor of Philosophy

In accordance with KAUST regulations, the Ph.D. program in MSE includes the following requirements:

1. Successful completion of Ph.D. coursework;
2. Designating a research advisor;
3. Passing a subject-comprehensive examination;
4. Obtaining candidacy status;
5. Preparing and submitting a doctoral dissertation and successfully defending it.

Coursework

Students may be accepted to the Ph.D. program in MSE either directly after earning a B.S. degree or after earning an M.S. degree. Degree requirements differ depending on when the student is accepted.

B.S. to Ph.D.

Students entering the Ph.D. program with an applicable B.S. degree will be awarded the Ph.D. degree upon the successful completion of 96 credit, of which 36 credits are for coursework and 60 credits are for dissertation research. The required credits are as follows:

- 1) 3 Core courses
- 2) 8 Elective courses from MSE or other interdisciplinary programs
- 3) 1 Course on mathematical methods
- 4) 60 credit hours of dissertation research

Students are expected to attend seminars offered by MSE or other programs whose focus complements the student's dissertation research or directed research activities. Seminar attendance is required, but no credit shall be given, and a pass/fail mark for seminar attendance will be recorded. The minimum number of semesters of required seminars for B.S. to Ph.D. students is 6.

Up to six directed research credits may replace two courses if approved by the student's advisor.

M.S. to Ph.D.

Students entering the Ph.D. program with a master's degree either from KAUST or another university are expected to take a minimum of 12 credits in MSE courses. In addition, the student is required to enroll in 60 credits of dissertation research. The total number of credits required is 72.

Students are expected to attend seminars offered by MSE or other programs whose focus complements the student's dissertation research or directed research activities. Seminar attendance is required, but no credit shall be given, and a pass/fail mark for seminar attendance will be recorded. The number of semesters of required seminars for M.S. to Ph.D. students is four.

Up to six directed research credits may replace two classes if approved by the student's advisor.

Designation of a Research Advisor

The Ph.D. dissertation advisor can be any MSE faculty member. The student may also select an advisor who is a faculty member in another program at KAUST. In this case, the student must seek the approval of the MSE Program prior to commencing research.

Examinations

After completion of core course requirements, the student must successfully complete the required Ph.D. examinations. These include a written exam, called the written subject examination, and an oral exam, called the oral dissertation proposal examination.

Students entering the Ph.D. program with an M.S. degree must pass the written subject examination some time in the first year of their Ph.D. program. Students entering the Ph.D. program with a B.S. degree must pass the written subject examination some time in the first two years at KAUST.

The following rules and procedures pertain to the written subject examination:

- The written examination will cover the content of the Core Courses. The three selected core courses may vary from student to student. The student will be tested on the content of the three core courses in which they received credit.
- The written exam will be held on one day. Three core courses will be covered in three separate sessions divided by breaks. The written examination will be offered twice per year (January and June) and on an as-needed basis as determined by MSE faculty.
- The students must declare their intent to take the exam 3 months before the exam date.

The following rules and procedures pertain to the oral dissertation proposal examination:

- The student's dissertation committee members must attend the oral dissertation proposal examination.
- The content of the oral dissertation proposal examination is based on the student's proposed dissertation research project
- This part of the exam can be attended by other students and faculty
- The student is responsible for scheduling the oral proposal examination with her/his advisor and faculty members
- The dissertation proposal examination can be taken only after the written subject examination has been passed

There are three possible outcomes for students who take the written subject exam or the oral dissertation proposal exam:

- (1) Pass
- (2) Fail with option to retake
- (3) Fail without option to retake

The decision to allow (or deny) a student to retake an exam shall be made by dissertation committee on a case-by-case basis. Students allowed to retake the Ph.D. examinations (written or oral) do not have to retake the entire exam. For example, if the student passes the written subject exam but fails the oral part, only the oral exam must be retaken. In the case that a student is allowed to retake the written qualifying exam, the student is expected to retake only the section(s) that he or she failed.

Students who fail one or the other exam a second time will be terminated from the program

Candidacy Status

A Ph.D. student is officially considered a Ph.D. Candidate after he/she passes both the written subject examination and the oral dissertation proposal examination. Students entering the program with a B.S. degree are expected to complete the requirements of Ph.D. candidacy no later than 4 semesters after enrolling in the Ph.D. program at KAUST. Students entering the program with an M.S. degree are expected to become Ph.D. candidates within 1 year of starting at KAUST.

Dissertation

The Ph.D. dissertation must result from original research work and be written in English.

Dissertation Defense

The Dissertation Defense is the final exam of the program. It is a public presentation that consists of an oral presentation followed by questions. As a general rule, the research advisor (dissertation supervisor) is appointed to chair the defense committee, which consists of five faculty members, three of whom must be MSE faculty members. One of the non-MSE members should be from another program at KAUST and is responsible for making sure that the process is run in accordance with University requirements. The fifth member of the

dissertation committee should preferably be from outside KAUST. It is the responsibility of the student to inform the dissertation committee of his/her progress, deadlines for submitting graduation forms, the defense date, etc. It is advisable that the student submits her/his dissertation six weeks prior the defense date in order to receive feedback from the committee members in a timely manner. The public defense of the dissertation may last a maximum of three hours. The agreement of the committee to pass the student must be unanimous.

Additional Program Information

Required Training Sessions

Every student in MSE must pass required training sessions in:

- 1) Laboratory safety and practices
- 2) Responsible conduct of research
- 3) Cultural differences and acceptance

Core and Elective Courses

CORE COURSES

- MSE 301 Crystallography and Diffraction
- MSE 302 Electronic Properties of Materials
- MSE 303 Statistical Thermodynamics and Equilibrium Processes
- MSE 304 Applied Quantum Mechanics
- MSE 305 Kinetics and Phase Transformations

ELECTIVE COURSES

- MSE 200 Advanced Engineering Mathematics
- MSE 201 Fundamentals of Materials Science and Engineering

- MSE 307 Materials Characterization
- MSE 309 Materials Modeling
- MSE 311 Soft Materials
- MSE 313 Functional Ceramics
- MSE 315 Thin Film Science and Engineering
- MSE 317 Mechanical Behavior of Engineering Materials
- MSE 319 Polymeric Materials
- MSE 321 Optical Properties of Materials
- MSE 306 Electrochemistry & Corrosion
- MSE 308 Biomaterials
- MSE 310 Materials for Energy
- MSE 312 Engineering Alloys
- MSE 314 Ab-initio Computational Methods
- MSE 316 Magnetic Materials
- MSE 318 Nanomaterials
- MSE 320 Solar Cell Materials and Devices

MSE 322 Semiconductor Materials
MSE 323 Surface Chemistry

MSE 297 MS Thesis Research
MSE 299 Directed Research- MS

MSE 392 Advanced Topics in Materials Science I
MSE 393 Advanced Topics in Materials Science II
MSE 394 Advanced Topics in Materials Science III
MSE 398 Graduate Seminar
MSE 397 PhD Dissertation Research
MSE 399 Directed Research- PhD

MATERIALS SCIENCE AND ENGINEERING PROGRAM COURSE DESCRIPTIONS

MSE 200. Advanced Engineering Mathematics (3-0-3)

This course presents basic mathematical methods for engineers including: differentiation and integration, Taylor's expansion, linear systems resolution and matrix formalism, partial differential equations, Laplace, Fourier and Legendre transforms, statistics and probability.

MSE 201. Fundamentals of Materials Science and Engineering (3-0-3)

This course is intended for students who do not have a materials science and engineering background. The course will cover four major topics including: fundamental concepts, microstructure development and phase equilibria, material properties and fabrication methods and applications. The course will cover atomic structure, atomic bonding, crystal structures, defects, and diffusion in materials. It also will cover phase transformations and phase equilibria and how they impact microstructure development. The electrical, magnetic, optical, thermal, and mechanical properties of materials will also be reviewed. The course will also highlight modern fabrication technologies and applications of metals, ceramics, semiconductors, and polymers.

MSE 301. Crystallography and Diffraction (3-0-3)

The objective of this course is to present the basic concepts needed to understand the crystal structure of materials. Fundamental concepts including lattices, symmetries, point groups, and space groups will be discussed and the relationship between crystal symmetries and physical properties will be addressed. The theory of X-ray diffraction by crystalline matter along with the experimental x-ray methods used to determine the crystal structure of materials will be covered. Application of X-ray diffraction to proteins, electron diffraction and neutron diffraction will be briefly discussed.

MSE 302. Electronic Properties of Materials (3-0-3)

This course offers an overview of the electronic, optical, magnetic and thermal properties of materials, not limited to solid state. It covers the fundamental concepts of band structure and bonding of materials, electrical and thermal conduction in metals, semiconductors and dielectric. The interaction between light and matter will be addressed and important concepts such as excitons will be introduced. Finally magnetism will be introduced.

MSE303. Statistical Thermodynamics & Equilibrium Processes (3-0-3)

Prerequisite: Advanced Engineering Mathematics MSE 200 (Students might attend this course as co-requisite). The course offers a modern fundamental understanding to the main concepts and practical applications of thermodynamics in materials science. The following major topics are discussed within the frame of this course: review of basic laws of classical thermodynamics, an introduction to phase equilibria including the theory of solutions, chemical reaction and surface and interfacial phenomena. Additionally, an introduction to statistical thermodynamics of gases and condensed matter is provided.

MSE 304. Applied Quantum Mechanics (3-0-3)

Prerequisite: Advanced Engineering Mathematics MSE200. Introduction to non-relativistic quantum mechanics. Summary of classical mechanics and electrodynamics. Postulates of quantum mechanics, wave functions, and operator formalism. Stationary state problems, including quantum wells. Harmonic oscillator. Angular momentum and spin. Atoms, molecules, and band theory of solids. Time evolution, Approximation methods for time-independent as well as time-dependent interactions, including electromagnetism. Scattering theory. Modern applications.

MSE 305. Kinetics and Phase Transformations (3-0-3)

Prerequisite: MSE 303. The course offers a modern and fundamental understanding to the main concepts and practical applications of Kinetics and Phase Transformations in materials science. The following major topics are discussed within the frame of this course: kinetics of homogenous chemical reactions, thermodynamics of irreversible processes including an introduction to the Onsager postulates, mathematical description of Diffusion in Materials (Fick's Laws and an atomistic description via random-walk process). Basic concepts of phase transformation theories, including homogeneous and heterogeneous nucleation and growth, spinodal decomposition and Landau theory of phase transformation.

MSE 306. Electrochemistry and Corrosion (3-0-3)

This course offers, in a first part, an overview of the fundamentals of electrochemistry including thermo-dynamics, nonequilibrium systems and Electrode/Electrolyte interfaces followed by an Introduction to modern applications of electrochemistry such as synthesis of nanoparticles, nanowires and thin films; as well as electrochemical means of energy conversion and

storage. The second part deals with Corrosion phenomena: types of corrosion cells and damages, thermodynamics and kinetics, uniform corrosion, passivity, localized corrosion, atmospheric and high temperature corrosion, environmentally induced cracking. Prevention of corrosion using electrochemical and surface engineering means. Corrosion mechanisms and protection of materials of practical interest.

MSE 307. Materials Characterization (3-0-3)

This course will introduce the basic principles of materials characterization and the common characterization techniques available at KAUST. It will cover the following topics: Diffraction methods: basic principles, interaction of radiation and particle beams with matter, XRD, scattering techniques; Spectroscopic methods; Imaging: optical including confocal microscopy, scanning, transmission electron, scanning tunneling and field ion microscopy; Microanalysis and Tomography: energy dispersive, wavelength dispersive, Auger Processes, Electron, Ion and Atom Probe Tomography, SIMS, photoelectron spectroscopy; thermal analysis: DTA, DSC. Lab visits and demonstrations will be scheduled to the class to discuss some case studies.

MSE 308. Biomaterials (3-0-3)

This course offers a basic understanding of the concepts underlying the design and selection of materials for use in biological applications. It focuses on both hard and soft tissue materials. The class addresses modern topics including biosensors, surface and interface functionalization. Further topics include: A brief introduction to relevant tissue types: anatomy, biochemistry and physiology; concepts of biocompatibility, host response, material degradation, testing and selection criteria; an overview of current research on biomechanics and its relevance to prosthesis design and tissue engineering; basic concepts of drug delivery and molecular biomechanics.

MSE 309. Materials Modeling (3-0-3)

Introduction to the theory and application of materials modeling techniques. Advantages of modeling to the engineer. Principles and methods of programming. Data requirements and structuring. Comparison of analytical and numerical methods. Introduction to basic numerical algorithms. Modeling approaches for different length scales from atomistic to continuum.

MSE 310. Materials for Energy (3-0-3)

This course emphasizes materials engineering aspects and the role they play in important energy related technologies such as energy harvesting approaches, super capacitors and energy storage media, batteries, fuel cells, bio-energy, nuclear energy, solar and wind based power generation, thermoelectricity, and Hydrogen generation.

MSE 311. Soft Materials (3-0-3)

This course covers chemical and physical aspects of soft materials such as gels, polymers, lipids, surfactants and colloids; physical chemistry of soft materials; phase transformations and self-assembly; the role of intermolecular and surface forces in determining morphology and hierarchy. Membranes, catalysis, drug delivery, flexible and stretchable materials and devices.

MSE 312. Engineering Alloys (3-0-3)

This course offers a basic understanding of materials requirements of alloys for various applications. Topics covered include: the trade-off between properties (e.g., strength and toughness) and micro-structure; the impact of alloy composition on the micro-structure; property differences and design philosophy in steels, nickel-, titanium- and aluminum- based alloys, focusing on construction, aerospace and automotive applications; alloy evolution and production routes.

MSE 313. Functional Ceramics (3-0-3)

Fundamental concepts relevant to functional ceramics will be reviewed, including defect chemistry and reactions, Brouwer diagrams, Ellingham diagrams, Heckman diagrams, ionic and electronic transport, and tensor notation. The physics, materials, and applications for the following classes of functional ceramics will be covered: linear dielectrics, ferroelectrics and multiferroics, piezoelectrics, pyroelectrics, electrooptics, thermoelectrics, and semiconducting oxides. Selected technological applications will be reviewed including varistors, sensors, MEMs, capacitors, memories, transistors, night vision systems, positive temperature coefficient resistors, and electro-optic devices.

MSE 314. Ab-Initio Computational Methods (3-0-3)

Prerequisite: Applied Quantum Mechanics (MSE 304). Band structure approaches for crystalline solids. Fundamentals and advanced applications of density functional theory. Introduction into classical and quantum molecular dynamics. Application and use of commercial and freeware computer packages.

MSE 315. Thin Film Science & Engineering (3-0-3)

Thin films and coatings are the material building blocks of many modern and pervasive technologies ranging from electronics to optics and photovoltaics, and from anticounterfeiting to glazings and hard coatings. The fundamentals and atomistics of thin film growth are discussed in detail. Deposition techniques for thin films and coatings are presented, including physical and chemical vapor depositions, molecular beam epitaxy, atomic layer deposition, and low-pressure plasma processes. Organic thin film deposition. Solution-processing and printing of inorganic, and hybrid organic-inorganic thin films. Artificially structured and chemically modulated layered and nanocomposite materials. Ex situ/in situ characterization of thin films and coatings.

MSE 316. Magnetic Materials (3-0-3)

This course introduces fundamental concepts in modern magnetic materials together with the electronic properties of magnetic hybrid structures. (i) Diamagnetism, paramagnetism, ferromagnetism and antiferromagnetism will be introduced and the microscopic origin of magnetism will be addressed (metals, semiconductors, oxides, insulators, etc.). (ii) Experimental techniques to investigate magnetism and magnetic behavior will be mentioned (X-ray dichroism, Magneto-Optical Kerr effect, etc...). (iii) Advanced applications of modern magnetic materials will be presented and the electronic properties as well as magnetization dynamics of magnetic hybrid structures will be covered.

MSE 317. Mechanical Behavior of Composite Materials (3-0-3)

(Same as ME 343) Response of composite materials (fiber and particulate reinforced materials) to static, cyclic, creep and thermomechanical loading. Manufacturing process-induced variability and residual stresses. Fatigue behavior, fracture mechanics and damage development. Role of the reinforcement-matrix interface in mechanical behavior. Environmental effects. Dimensional stability and thermal fatigue. Application to polymer, metal, ceramic and carbon matrix composites.

MSE 318. Nanomaterials (3-0-3)

This course describes the most recent advances in the synthesis, fabrication and characterization of nanomaterials. Topics to be covered: Zero-dimensional nanomaterials, including nanoparticles, quantum dots and nanocrystals; one dimensional materials including nanowires and nanotubes; two-dimensional materials: including self-assembled monolayers, patterned surfaces and quantum well; three-dimensional nanomaterials: including nanoporosity, nanocomposites, block copolymers, and supra-crystals. Emphasis on the fundamental surface and size-related physical and chemical properties of nanomaterials; and their applications in biosensing, nanomedicine, catalysis, photonics, and nanoelectronics.

MSE 319. Polymeric Materials (3-0-3)

This course describes polymerization processes; polymer solutions (Flory-Huggins model and application to polymer blends); polymer chain conformations; calculation of end-to-end distribution function $W(r)$ for short range interacting chains; rotational isomeric state scheme and temperature dependence; chain with long range interactions (excluded volume effect); radius of gyration; the crystalline and amorphous states of polymers; the glass transition (configurational entropy model); mechanical, electrical and optical properties and characterization of polymers.

MSE 320. Solar Cell Materials and Devices (3-0-3)

This course will provide the students with an up-to-date basic knowledge of the physical and chemical principles of materials used in solar cells of various kinds including but not limited to technologies such as: 1) silicon-based solar cells, 2)

CIGS, CIS and other inorganic thin film solar cells, 3) multijunction solar cells, 4) nanoparticles and quantum dots solar cells, 5) organic and hybrid solar cells and 6) thermal and concentrator solar power generation.

MSE 321. Optical Properties of Materials (3-0-3)

Prerequisite: basic knowledge of quantum mechanics, electromagnetism, and solid state physics. Introduction to optical coefficients and optical materials, classical propagation of light, Interband absorption processes and photodetectors, excitons, light emission including photoluminescence and electroluminescence, quantum confined structures, free electrons and plasmons, optical properties of molecules and polymers, color centers, phonons, polaritons, polarons and inelastic light scattering, introduction to nonlinear optical properties of materials including second and third order nonlinearities.

MSE 322. Advanced Semiconductor Materials (3-0-3)

The course covers the physico-chemical and electronic properties of advanced semiconductor materials other than Si and GaAs. The materials that will be covered include elemental semiconductors such as Ge and carbon (in the form of carbon nanotubes and graphene), compound semiconductors such as III-V and II-VI compounds, and wide-band gap semiconductors such as carbides and nitrides. Special classes of semiconductors such as oxides, chalcogenides, and polymeric semiconductors will be included. In each material category, the material processing and fabrication of select devices will be discussed including 1-dimensional and 2-dimensional devices. Measurement protocols for the devices will be presented.

MSE 323. Surface Chemistry (3-0-3)

(same as CBE 313) Surface tension and surface free energy (theory and measurement methods); Surface films on liquid substrates (surface potential, monomolecular films, Langmuir-Blodgett layers); Electrical aspects of surface chemistry (electrical double layer, zeta potential, DLVO theory); Solid-liquid interface, stability of dispersions, stabilization of suspensions, steric stabilization of colloids; Contact angle (theory and measurement methods); Emulsions, foams and aerosols; Wetting of surfaces by liquids, Lotus effect; Flotation, aggregation and flocculation; Detergency, surfactants, self-assembly, micelles and vesicles; Friction, lubrication and adhesion; Adsorption (Langmuir, BET); Characterization of colloidal particles; Applications of colloid and surface science in petroleum recovery, coating and painting, food, pharmaceutical and cosmetic industry; Methods of surface characterization (AFM, STM, SIMS, XPS, LEED, GISAXS)

MSE 298. Graduate Seminar (variable credit) Master's-level seminar focusing on special topics within the field

MSE 299. Directed Research (variable credit) Master's-level supervised research.

MSE 392. Advanced Topics in Materials Science I (variable credit) Lecture-based class.

MSE 393. Advanced Topics in Materials Science II (variable credit) Lecture-based class.

MSE 393. Advanced Topics in Materials Science III (variable credit) Lecture-based class.

MSE 397. Dissertation (variable credit)

MSE 398. Graduate Seminar (variable credit) Doctoral-level seminar focusing on special topics in the field.

MSE 399. Directed Research (variable credit) Doctoral-level supervised research.