Request for Approval of Modification(s) to Program

Southwestern Oklahoma State University

First Name: Trevor

Last Name: Ellis

Person ID: 705491

Email: trevor.ellis@swosu.edu

Department

Chemistry & Physics

Program Information

Official Degree Designation and Program Title

e.g. Associate in Science in Cybersecurity, Bachelor of Fine Arts in Music Performance, Master of Science in Accounting

Bachelor of Science Chemistry - Professional

Program Code

Please list the 3-digit OSRHE program code.

106

This program has approved options

No

Is this program part of a cooperative agreement?

No

Does this change impact an embedded certificate?

No

Does the CIP Code for this program need to be updated?

No

Type of Request(s)

Program Suspension?

No

Electronic Delivery of Existing Program

NOTE: Electronic delivery is recognized at the program level. If the existing program has options that are offered via electronic delivery and the program meets State Regents' policy for electronic delivery, the program MUST be approved for electronic delivery.

No

Option Additions?

No

Option Deletion?

No

Option Name Change?

No

Program Requirement Change(s)?

Yes

Explanation of changes

Please provide a brief summary of changes being made.

In the Electives and Advanced Chemistry Section we would like to add a note that at least one of the electives selected must be CHEM 4223 Polymer Chemistry or CHEM 4353 Materials Chemistry.

Total Credit Hour Change?

No

Justification for program requirement changes*

Please provide a brief summary of the reason for the program requirement changes.

This change is being made to comply with the macromolecular, supramolecular aggregate and meso- or nanoscale (MSN) requirement for degree/program accreditation by the American Chemical Society (ACS).

Program Reinstatement?

No

Program Name Change?

No

Degree Designation Change?

Changes formerly classified as substantive and non-substantive will now be combined as program requirement changes. (e.g. course credit hour changes, changes in courses required for graduation, changing credit hours required for electives, course prefix changes, course title changes, removing courses from list of electives)

No

Documents

If applicable, submit any documentation related to the requested action.

BACHELOR OF SCIENCE
CHEMISTRY – PROFESSIONAL (CHEMPRO.BS)

GENERAL EDUCATION (Min. 40 hours)

Bolded courses are required. *Italicized courses are recommended.*

Communication **9**

ENGL	**1113**	**English Composition I**
ENGL	**1213**	**English Composition II**
COMM	**1313**	**Introduction to Public Speaking** OR
TECH	3143	Technical Presentations (if permitted by degree program)

Quantitative Reasoning **3**

Select one course.

MATH	1143	Mathematical Concepts
MATH	1153	Mathematical Applications
MATH	1193	Elementary Statistics
MATH	1313	Functions and Modeling
MATH	**1513**	**College Algebra**

or a higher numbered math course

U. S. History **3**

Select one course.

HIST	1043	U.S. History to 1877
HIST	1053	U.S. History since 1877

American Government **3**

POLSC	**1103**	**American Government & Politics**

Science **7-8**

Select one course from Life Science and one course from Physical Science. One Science course must be a lab science.

Life Science **3-4**

BIOL	1004	Biological Concepts w/Lab
BIOL	1013	Current Issues in Biology
BIOL	1054	Principles of Biology I w/Lab

Physical Science **3-4**

ASTRO	1904	Astronomy
CHEM	**1004**	**General Chemistry w/Lab or a higher numbered chemistry or physics course**
GEOL	1934	Physical Geology w/Lab
PHY	1044	Basic Physics I w/Lab
PHY	1063	General Physics (or a higher numbered chemistry or physics course)
SCI	1501	Concepts of Physical Science Lab
SCI	1513	Conc of Phy Science (can be taken w/wo lab)

Humanities and Social Science **12**

Select one course from each sub-category ***and one additional course*** *from any subcategory below.*

Humanities **3**

GEOG	1103	World Cultural Geography
HIST	1003	Early World History
HIST	1023	Modern World History
HUM	1103	Introduction to Humanities

Fine Arts **3**

ART	1223	Art Survey
COMM	1263	Introduction to Theatre
LIT	2333	Introduction to Film
LIT	2413	Introduction to Literature
MUSIC	1013	Introduction to Music I
MUSIC	1103	Music and Culture (Music majors only)
MUSIC	1123	History of Rock-n-Roll
PHILO	1453	Introduction to Philosophy

Social and Human Sciences **3**

ASL	2163	American Sign Language I
ECONO	2263	Intro to Macroeconomics
ECONO	2363	Intro to Microeconomics
ENTRP	1123	Intro to Business
FINAN	2113	Personal Financial Planning
ITAL	1004	Elementary Italian I
KINES	1133	Wellness Conc & Exercise Applications
LATIN	1054	Elementary Latin I (or higher number)
PSYCH	1003	General Psychology
SOCIO	1003	Introduction to Sociology
SPAN	1054	Elementary Spanish I (or higher number)
TECH	1223	Technology and Society

Computer Proficiency **0-3**

COMSC 1023 Computers and Info Access or the SWOSU Proficiency Exam, or HS course clearly defined to meet our goals.

GE Elective **0-3**

Students who meet the computer proficiency by exam or HS course must choose an additional GE course from any category.

CHEMISTRY MAJOR (B.S. Professional)

Required Courses **52-54**

CHEM	4900	Seminar Attendance (enroll each semester)
CHEM	1203	General Chemistry I
CHEM	1252	General Chemistry I Lab
CHEM	1303	General Chemistry II
CHEM	1352	General Chemistry II Lab
CHEM	2112	Structure and Bonding
CHEM	2612	Principles of Laboratory Safety
CHEM	3015	Organic Chemistry I
CHEM	3124	Quantitative Analysis
CHEM	3233	Inorganic Chemistry
CHEM	3211	Inorganic Chemistry Lab
CHEM	3343	Physical Chemistry I
CHEM	4001-4	Chemistry Research (min 2 hrs)
CHEM	4115	Organic Chemistry II
CHEM	4124	Biochemistry
CHEM	4234	Instrumental Analysis
CHEM	4455	Physical Chemistry II
CHEM	3901	Seminar in Chemistry I
CHEM	4901	Seminar in Chemistry II

Students with 8 hours each of General and/or Organic Chemistry and changing majors to Chemistry may make up the hours by taking one of the chemistry electives below.

Electives and Advanced Chemistry (chosen from this list) **8**

CHEM	4011-4	Sem in Chem. Spec. Topics (when offered)
CHEM	4223	Polymer Chemistry*
CHEM	4313	Advanced Organic Synthesis
CHEM	4353	Materials Chemistry*
CHEM	4554	Advanced Organic Spectroscopy
CHEM	4673	Advanced Metabolism

Secondary Requirements **22**

MATH	1834	Calculus I
MATH	2834	Calculus II
MATH	3834	Calculus III
PHY	2145	General Physics I
PHY	2155	General Physics II

TOTAL HOURS **122-124**

REGULATIONS PERTAINING TO GRADUATION

Minimum credit hours for graduation........ 122
Minimum credit hours in the liberal arts & sciences........ 55
Minimum credit hours in upper-division (3000/4000 courses)........ 40
Minimum credit hours (3000/4000 courses) in major completed at SWOSU 8
Minimum credit hours at SWOSU (15 of the last 30)........ 30
Minimum Grade Point Average in all coursework........ 2.00
Minimum Grade Point Average in major........ 2.00
Minimum Grade Point Average in minor........ 2.00

BACHELOR OF SCIENCE
CHEMISTRY – PROFESSIONAL (CHEMPRO.BS)

GENERAL EDUCATION (Min. 40 hours)

Bolded courses are required. *Italicized courses are recommended.*

Communication 9

ENGL 1113 English Composition I
ENGL 1213 English Composition II
COMM 1313 Introduction to Public Speaking OR
TECH 3143 Technical Presentations (if permitted by degree program)

Quantitative Reasoning 3

Select one course.

MATH 1143 Mathematical Concepts
MATH 1153 Mathematical Applications
MATH 1193 Elementary Statistics
MATH 1313 Functions and Modeling
MATH 1513 College Algebra
or a higher numbered math course

U. S. History 3

Select one course.

HIST 1043 U.S. History to 1877
HIST 1053 U.S. History since 1877

American Government 3

POLSC 1103 American Government & Politics

Science 7-8

Select one course from Life Science and one course from Physical Science. One Science course must be a lab science.

Life Science 3-4

BIOL 1004 Biological Concepts w/Lab
BIOL 1013 Current Issues in Biology
BIOL 1054 Principles of Biology I w/Lab

Physical Science 3-4

ASTRO 1904 Astronomy
CHEM 1004 General Chemistry w/Lab or a higher numbered chemistry or physics course
GEOL 1934 Physical Geology w/Lab
PHY 1044 Basic Physics I w/Lab
PHY 1063 General Physics (or a higher numbered chemistry or physics course)
SCI 1501 Concepts of Physical Science Lab
SCI 1513 Conc of Phy Science (can be taken w/wo lab)

Humanities and Social Science 12

Select one course from each sub-category ***and one additional course*** *from any subcategory below.*

Humanities 3

GEOG 1103 World Cultural Geography
HIST 1003 Early World History
HIST 1023 Modern World History
HUM 1103 Introduction to Humanities

Fine Arts 3

ART 1223 Art Survey
COMM 1263 Introduction to Theatre
LIT 2333 Introduction to Film
LIT 2413 Introduction to Literature
MUSIC 1013 Introduction to Music I
MUSIC 1103 Music and Culture (Music majors only)
MUSIC 1123 History of Rock-n-Roll
PHILO 1453 Introduction to Philosophy

Social and Human Sciences 3

ASL 2163 American Sign Language I
ECONO 2263 Intro to Macroeconomics
ECONO 2363 Intro to Microeconomics
ENTRP 1123 Intro to Business
FINAN 2113 Personal Financial Planning
ITAL 1004 Elementary Italian I
KINES 1133 Wellness Conc & Exercise Applications
LATIN 1054 Elementary Latin I (or higher number)
PSYCH 1003 General Psychology
SOCIO 1003 Introduction to Sociology
SPAN 1054 Elementary Spanish I (or higher number)
TECH 1223 Technology and Society

Computer Proficiency 0-3

COMSC 1023 Computers and Info Access or the SWOSU Proficiency Exam, or HS course clearly defined to meet our goals.

GE Elective 0-3

Students who meet the computer proficiency by exam or HS course must choose an additional GE course from any category.

CHEMISTRY MAJOR (B.S. Professional)

Required Courses 52-54

CHEM 4900 Seminar Attendance (enroll each semester)
CHEM 1203 General Chemistry I
CHEM 1252 General Chemistry I Lab
CHEM 1303 General Chemistry II
CHEM 1352 General Chemistry II Lab
CHEM 2112 Structure and Bonding
CHEM 2612 Principles of Laboratory Safety
CHEM 3015 Organic Chemistry I
CHEM 3124 Quantitative Analysis
CHEM 3233 Inorganic Chemistry
CHEM 3211 Inorganic Chemistry Lab
CHEM 3343 Physical Chemistry I
CHEM 4001-4 Chemistry Research (min 2 hrs)
CHEM 4115 Organic Chemistry II
CHEM 4124 Biochemistry
CHEM 4234 Instrumental Analysis
CHEM 4455 Physical Chemistry II
CHEM 3901 Seminar in Chemistry I
CHEM 4901 Seminar in Chemistry II

Students with 8 hours each of General and/or Organic Chemistry and changing majors to Chemistry may make up the hours by taking one of the chemistry electives below.

Electives and Advanced Chemistry (chosen from this list) 8

*Students must complete either CHEM 4223 or CHEM 4353 to satisfy the ACS MSN requirements.**

CHEM 4011-4 Sem in Chem. Spec. Topics (when offered)
CHEM 4223 Polymer Chemistry*
CHEM 4313 Advanced Organic Synthesis
CHEM 4353 Materials Chemistry*
CHEM 4554 Advanced Organic Spectroscopy
CHEM 4673 Advanced Metabolism

Secondary Requirements 22

MATH 1834 Calculus I
MATH 2834 Calculus II
MATH 3834 Calculus III
PHY 2145 General Physics I
PHY 2155 General Physics II

TOTAL HOURS 122-124

REGULATIONS PERTAINING TO GRADUATION

Minimum credit hours for graduation 122
Minimum credit hours in the liberal arts & sciences 55
Minimum credit hours in upper-division (3000/4000 courses) 40
Minimum credit hours (3000/4000 courses) in major completed at SWOSU 8
Minimum credit hours at SWOSU (15 of the last 30) 30
Minimum Grade Point Average in all coursework 2.00
Minimum Grade Point Average in major. 2.00
Minimum Grade Point Average in minor 2.00

Macromolecular, Supramolecular, and Nanoscale (MSN) Systems in the Curriculum

Context

Much of the traditional undergraduate curriculum in chemistry focuses on the synthesis and characterization of small discrete molecules. But many types of materials are not well-described from this perspective. These include macromolecules (whether synthetic or biological), supramolecular systems and nano/mesoscale systems. In some of these materials, the boundaries between discrete molecular and bulk behavior are blurred, which impacts the ways that we can describe and characterize their structure and physical properties. In others, though the molecular boundaries may be clear, understanding key behaviors relies on understanding the role of non-covalent and intramolecular interactions. Recognizing the differences between small molecule vs. larger systems is key to understanding many important materials that are pervasive in our society and in modern chemistry. Because of the importance of these large scale chemical systems, the ACS guidelines require that exposure to aspects of MSN chemistry be included in the undergraduate curriculum.

The 2015 ACS guidelines state that students be exposed to MSN content covering three broad areas: 1) structure, synthesis and/or preparation, 2) characterization, and 3) physical properties. Coverage of at least two types of MSN systems, such as synthetic polymers, biological macromolecules, supramolecular aggregates, and/or meso- or nanoscale materials is required. To be counted towards the requirement, MSN material must focus on aspects in which large scale chemical systems are significantly different than small molecules. Contrasting examples include:

- Simply referencing the types of condensation or addition reactions that can be used to synthesize polymers does not address their unique properties.; but the requirement could be met by discussing the impacts of these synthetic routes on the properties of the final polymer, the high extents of reaction (>99%) necessary to achieve high molecular weight polymers by condensation polymerization or the impact of various types of addition polymerization reactions on molecular weight distribution, stereochemistry, etc.
- Studying the kinetics of an enzyme catalyzed reaction where only the catalytic impact of the enzyme is covered would not contribute to student’s understanding of MSN systems; inclusion of the impact of the tertiary structure on its catalytic role would.
- Superconductors composed of solid state oxides are not supramolecular systems; metal-organic frameworks (MOFs) are valid examples of MSN systems.
- Laboratories that utilize polymeric systems, such as polysiloxanes, epoxies, or other polymers without covering the relationship of the properties of these systems do not fulfill

the MSN requirement; labs which focus specifically on the synthesis, characterization, or evaluation of properties that are uniquely related to MSN materials would. It is expected that laboratories used for the MSN requirement include related background, either in lecture courses or significant pre-lab assignments to ensure that the students have a solid understanding of the MSN aspects of the laboratory content.

Some chemistry programs provide coverage of this material in polymer chemistry, materials chemistry, and/or supramolecular chemistry courses which may be used to satisfy the MSN requirement. However*, IT IS NOT NECESSARY FOR DEPARTMENTS TO DEVELOP A SEPARATE COURSE*, as it is equally acceptable to introduce these concepts into existing foundation and in-depth courses across the curriculum. While MSN content may be incorporated into any of the standard subdisciplines, it is not required that the exposure spans *every* subdiscipline.

If not covered through a stand-alone course(s), the combined coverage of these topics should be the equivalent of approximately one-fourth of a standard semester course distributed through the required curriculum, where the coverage of any single type of MSN system will be counted for no more than half of the MSN coverage. This supplement suggests ways to introduce these concepts in either a distributed or stand-alone format throughout the chemistry curriculum.

Conceptual Topics

Three general subject areas in MSN chemistry are recommended for meeting the MSN requirement. While some content from all three general subject areas is expected, CPT recognizes that most approved curricula will not cover all of the topics suggested below.

Structure, synthesis, reactions, and preparation of MSN materials

- Basic synthetic approaches for the preparation of MSN materials such as synthetic polymers, biological macromolecules, inorganic polymers, framework materials, and nanoparticles.
    - Step growth (condensation) polymerizations - molecular weight dependence on extent of conversion (Carothers Equation), reaction kinetics, broad MW distributions, branching
    - Chain growth (radical, ionic, or coordination) polymerizations – reaction kinetics, catalysts, living polymerization, MW control, stereochemistry
    - Nanostructures - top-down milling (e.g., milling, e-beam patterning, chemical etching), bottom-up synthesis (solution synthesis of nanoscale particles, sol-gel growth, pyrolysis, vapor phase growth, e-beam deposition))
    - Quantum dots – solution phase synthesis
    - Supramolecular inclusion complexes (e.g., cyclodextrins, curcuribitils, etc.)
    - Endohedral complexes
    - Metal organic frameworks

- Polymer composition (homo vs copolymer) structure (linear, branched, star, crosslinked/network) and morphology (amorphous, semi-crystalline), and the role of covalent and non-covalent interactions in determining molecular interactions
- Isolation, purification and size separation techniques for synthetic and biopolymers (solubility, size exclusion, etc.).
- Nanoparticle structure - single component, core-shell

Characterization of macromolecules and mesoscale structures

- Structure and characterization of polymers/macromolecules:
    - Techniques for determining molecular weight and molecular weight distributions (steric exclusion chromatography, light scattering, MALDI-MS)
    - Identification of phases (amorphous, microcrystalline) and phase changes including glass transition, crystalline melting, and degree of crystallinity
    - Network formation and degree of crosslinking
    - Thermo-mechanical properties such as toughness, yield strength, stress-strain behavior, and degradation temperature
    - Electrical properties of conjugated systems
- Structure and characterization of biopolymers:
    - Gel electrophoresis
    - Nucleotide melting
    - Circular dichroism/thermal melts
- Structure and characterization of nanoparticles
    - Particle size and electronic properties of nanoparticles by UV/Vis spectroscopy
    - Particle size and morphology by SEM, TEM, and AFM
    - Particle size distribution by aerosol MS
    - XRD for crystallinity, chemical composition, and particle size
    - Mobility measurements by zeta potential
    - Particle size and morphology by light microscopy and optical spectroscopy
    - Elemental profiling by XPS, EDX, or nano-SIMS

Physical properties of MSN systems

- Impacts of size on the evolution of properties as MSN materials grow larger on:
    - Mechanical properties: impacts of entanglements, new phase changes (glass, microcrystalline and liquid crystalline transitions), strength-to-weight ratio, thermoformability, durability, etc.
    - Optical properties: impact of polymer morphology
    - Thermal properties: glass transition temperature, segmental motion, relationship of backbone structure and aromaticity on thermal stability
    - Electrical properties
    - Surface plasmon resonance in metal nanoparticles
- Impact of non-covalent interactions in determining key properties and behaviors
    - Intra-molecular interactions and relationship of structure and function (especially for biopolymers)

    - Impact of stereoregularity on crystallization and material properties for synthetic and biopolymers
    - Impact of chain ordering on optical and electrical properties
- Properties of solutions and mixtures
    - Thermodynamics of mixtures/phase separation of macromolecules
    - Thermodynamics of solution formation and rheology, non-Newtonian behaviors
    - Behaviors of composite material and alloys, and the impact of length scale
- Biocompatible and biodegradable polymers and their applications

Practical Topics

MSN can be used to illustrate a myriad of principles throughout the classroom and laboratory components of the chemistry curriculum. The brief listing below provides examples appropriate for each subdiscipline.

Analytical Chemistry

- Size exclusion chromatography – determination of synthetic polymer molecular weight and molecular weight distribution
- Study of structural stability, phase changes, morphology by DSC
- Stability, gas absorption capacity using thermogravimetry (TGA)
- Molecular weight by functional-group titration
- Size determination by light scattering methods
- Determination of copolymer composition by pyrolysis gas chromatography
- Determination of additive levels using ultraviolet or infrared spectroscopy
- Determination of structure, long-range order in framework materials by X-ray methods
- Determination of nano/mesoscale structure and composition by microscopies and scanning probe methods

Biochemistry

- Structure, stabilizing factors, folding and biosynthesis of key biopolymers including proteins, carbohydrates, cellulose, RNA, and DNA
- Influence of molecular bonding on structure and properties (carbohydrates vs cellulose, crosslinking of lignin, DNA, etc.)
- Impact of intramolecular interactions on protein structure, folding, influence on biological function
- Intermolecular interactions of biopolymers and influence of polymer primary, secondary, and tertiary structure (DNA, RNA, proteins, etc.)
- Determination of molecular weight and structure for natural polyamides
- Self-assembly of large-scale biological systems (lipids, cell walls, etc.)
- Natural, modified natural and synthetic macromolecules used for bioactive applications
- Purification of proteins: size exclusion, solubility (precipitation via salt or molecular crowding); laser light scattering (aggregation state, pre-crystallization conditions)
- Thermodynamics of protein folding and superstructure organization

- Allosteric regulation of proteins; e.g., hemoglobin
- Intrinsically disordered protein domains
- Protein aggregation polymerization, e.g., prions, actin, sickle cell, protein aggregation and disease
- Heteropolysaccharides (cartilage) and homopolymer saccharides (gelation etc.)
- Secondary/quaternary structure without ternary structure
- Supramolecular structure of collagen
- Lipid bilayer viscoelastic properties

Inorganic Chemistry

- Coordination – catalyst formation, metalloenzyme structure, structure of metal-organic frameworks (MOFs), control of porosity and framework size, control of gas adsorption properties
- Ziegler-Natta, metallocene catalysts for olefin polymerization – impact on industrial/materials development
- Structure/bonding/property relationships in silicon or phosphorous based polymers and semiconductors, including backbone flexibility, conductivity, and molecular orbital and band theory compared to C based analogs
- Utilization of X-ray and calorimetry to determine percent crystallinity
- Polymer/inorganic natural systems such as chitin/calcium carbonate composites
- Absorption properties of metal nanoparticles (e.g., colloidal gold used to color stained glass windows)
- Quantum dots – effect of size on optical properties, electrical properties, effect of core-shell structures

Organic Chemistry

- Step growth polymerizations including common types of polymers (nylon, PET, polycarbonate, polyurethane, etc.)
- Types of chain growth polymerization (radical, cationic, anionic, and coordination) and common types of polymers (polyethylene, polypropylene, PVC, polystyrene, etc.)
- Ring-opening polymerizations
- Living polymerizations and control of molecular weight/distribution
- Biocompatible materials (e.g., glycolic acid/lactic acid polyesters as absorbable sutures, bone scaffolding, etc.)
- Green chemistry, sustainability, materials from renewable biosources
- Role of hydrophobic/hydrophilic interactions in governing self-assembly processes (latex polymerizations, surfactant behavior)
- Role of π-stacking in self-assembly
- Properties of extended conjugated systems (polyacetylene, graphite, graphene)

Physical Chemistry

- Polymerization kinetics by various synthetic methods and impact on polymer structure and polydispersity

- Thermodynamics of polymer/solvent and polymer/polymer solutions with respect to phase separation and solution properties – comparison to small molecule/ideal analogs
- Dilute solution viscometry – determination of polymer molecular weight, hydrodynamic radius, chain branching, solvent interactions/ideal solutions
- Non-Newtonian properties of polymer melts and solutions
- Thermomechanical properties including differential scanning calorimetry (DSC) – observation of phase changes, determination of percent crystallinity, dynamic mechanical analysis (DMA) – determination of viscoelastic properties of elastomers, and thermogravimetric analysis (TGA) – determination of thermal stability/degradation
- Influence of linearity, stereochemistry, tacticity on polymer crystallinity and density
- Kinetic vs thermodynamic aspects of nanocrystal growth and morphology, and impact on physical properties
- Optoelectronic properties of nanostructures such as surface plasmon resonance and surface enhanced Raman scattering (SERS)

References

Below is a list of references that may be useful in incorporating macromolecular content:

- M.M. Coleman and P.C. Painter, "Fundamentals of Polymer Science: An Introductory Text", 2nd Ed., Technomic Publishing/CRC Press LLC, Boca Raton, FL, 1997.
  [An excellent elementary text that can function as a source of material to augment/ enhance/ increase interest in any foundational chemistry course.]
- C.S. Brazel and S.L. Rosen, "Fundamental Principles of Polymeric Materials", 3rd Ed., John Wiley and Sons, Inc., Hoboken, N.J., 2012.
  [A classic beginning textbook.]
- H.R. Allcock, F.W. Lampe and J.E. Mark, "Contemporary Polymer Chemistry", 3rd Ed. Prentice Hall, 2003.
  [A classic textbook that may be at a slightly higher level than desired for foundation courses, but is good for in-depth courses and a good reference for instructors]
- H.A. Wittcoff, B.E. Reuben and J.S. Plotkin, "Industrial Organic Chemicals", 3rd Ed., John Wiley and Sons, Inc., Hoboken, N.J., 2013.
  [An outstanding textbook which not only treats polymeric materials but places them in context as to origin, prominent place in the chemical industry, and importance to societal well-being.]
- J.A. Tyrell, "Fundamentals of Industrial Chemistry", John Wiley and Sons, Inc., Hoboken, N.J., 2014, Ch. 7-9.
  [Provides a brief overview of polymeric materials in chapters 7-9, which can be drawn on to provide supplemental material for any foundational course.]
- B.A. Howell, Ed., "Introduction of Macromolecular Science/Polymeric Materials into the Foundational Course in Organic Chemistry", American Chemical Society (Symposium Series 1151), Washington, D.C., 2013.

[This volume contains several chapters illustrating how polymeric materials are currently being incorporated into the beginning organic course. It is a wonderful source of material/approaches for any organic instructor.]

- Sandler, S.R; Karo, W.; Bonesteel, J.; Pearce, E.M. *Polymer Synthesis and Characterization: A Laboratory Manual*; Academic Press: San Diego, CA, 1998.
  [Laboratory manual for polymer synthesis and characterization]
- Steed, J. W.; Atwood, J. L. *Supramolecular Chemistry;* 2nd Ed., Wiley and Sons: New York, 2009.
  [This text focuses on the main categories of supramolecular systems.]
- Steed, J.W.; Gale, P.A. *Supramolecular Chemistry: From Molecules to Nanomaterials*; Wiley and Sons: New York, 2012
  [An eight-volume reference work covering supramolecular and nanoscale materials, including tutorial articles]
- Diederich, F.; Stang, P.J.; Tykwinski, R.R., Eds. *Modern Supramolecular Chemistry: Strategies for Macrocycle Synthesis*; Wiley and Sons: New York, 2008
  [Covers experimental procedures for most major classes of supramolecular compounds]

Literature articles on supramolecular systems:

- Nguyen, S. T.; Gin, D. L.; Hupp, J. T.; Zhang, X. “Supramolecular chemistry: Functional structures on the mesoscale,” *PNAS* **2001**, *98*, 11849.
- Smith, D. K. “A Supramolecular Approach to Medicinal Chemistry: Medicine Beyond the Molecule,” *J. Chem. Educ.* **2005**, *82*, 393.
- Breslow, R. “Bioorganic Chemistry: A Natural and Unnatural Science,” *J. Chem. Educ.* **1998**, *75*, 705
- Diederich, F. “Molecular Recognition in Aqueous Solution,” *J. Chem. Educ.* **1990**, *67*, 813.
- Hamliton, A. D. “Molecular Recognition,” *J. Chem. Educ.* **1990**, *67*, 821.

Approved January 2017

2023 ACS Guidelines for Undergraduate Chemistry Programs

Approved January 2023

(Updated March 12, 2024)

Table of Contents

Section 1: ACS Program Approval

The American Chemical Society (ACS) is committed to fostering excellence in chemistry education and developing the next generation of dynamic chemistry leaders. One mechanism by which these efforts are promoted is through the approval of baccalaureate chemistry programs. Through the Committee of Professional Training, ACS authorizes the chair of any ACS-approved program to certify bachelor's degree graduates who meet the ACS guidelines.

Section 1.1: Goals of the ACS Approval Program

- To communicate and establish standards for training bachelor's level chemists.
- To promote and support the development of bachelor's-level chemists who are competitive in the global economy.
- To publicly recognize excellence and exemplary practice in chemical education and to highlight opportunities and benefits that the program provides for students.
- While graduates who earn a certified degree often must complete requirements that exceed those of the degree-granting institution, an ACS-certified degree signifies that a student has completed an integrated program that emphasizes the development of skills necessary to be competitive in a global economy.
- Students attending ACS-approved institutions have exposure and access to a comprehensive chemistry curriculum and access to a well-maintained infrastructure.

Section 1.3: Program Approval Requirements

ACS recognizes the changing landscape of higher education as well as the diversity of institutions and students that embody the chemical enterprise. Thus, these guidelines provide approved programs with opportunities to develop chemistry degree tracks that are appropriate to the educational missions of their institutions.

The guidelines are organized into nine (9) Sections. Each section groups the guidelines into three categories: ***critical requirements for approval, normal expectations, and markers of excellence***. These indicators are not meant to be prescriptive or an all-inclusive checklist but represent the values of the American Chemical Society and its vision for continued excellence in chemistry education.

- **Critical Requirements:** Departments/programs must meet these requirements to obtain or maintain ACS approval.
- **Normal Expectations:** Guidelines in this category reflect the expected values and activities of an ACS approved program.
- **Markers of Excellence:** The guidelines in this category reflect departmental and institutional practices characteristic of an exemplary chemistry program that supports innovation and inclusive education.

Section 2: Institutional Environment

Long term excellence in undergraduate chemistry education relies on a substantial institutional commitment to support the instructional needs and interests of the faculty and students. The following requirements reflect the institutional and programmatic attributes that support and maintain excellence in chemistry education.

Critical Requirements	Normal Expectations	Markers of Excellence
The institution must - Have the ability and will to make a financial commitment to the program at a level commensurate with the resources of the institution and its educational mission. - Provide sustainability through inevitable changes in faculty, leadership, and funding levels Program must - Be accredited by a regional accreditation body. - Graduate, on average, 2 students per year - Have reasonable influence over - Budget - Faculty selection - Tenure & promotion - Curriculum development - Teaching assignments	Programs should normally: - Be organized as an independent unit - Have sufficient breadth to offer a range of educational experiences - Have both academic and non-academic staff and resources that provide - Administrative support services - Administration of stockrooms and teaching assistants - Instrument and equipment maintenance - Be able to ensure that equipment and supplies needed for modern laboratory instruction are available - Ensure that students and faculty have access to modern chemical information resources - Have regular institutional support for maintaining and upgrading institutional technology - Provide regular support for the professional development of all faculty, including instructional and tenure-track faculty - Provide regular support for faculty and student travel to professional meetings - Have access to regularized resources for capital equipment acquisition and replacement	- Support is available to assist with grant application and administration. - Regularized program of sabbatical leave exists and is utilized by faculty. - The program provides advisors to transfer students, and engages in activities to encourage matriculation of transfer students.

Section 3: Faculty & Staff

Faculty members are responsible for defining and executing the goals of the undergraduate program, supporting and facilitating both student learning of content knowledge and the development of professional skills, which together constitute an undergraduate chemistry education. An energetic, accomplished, and diverse faculty (in gender, race, ethnic, sexuality, and ability) is essential to an excellent undergraduate program. An approved program therefore has mechanisms in place to recruit and retain a qualified and diverse faculty, maintain the professional competence of its faculty, provide faculty development and mentoring opportunities, and provide regular feedback regarding faculty performance.

Critical Requirements	Normal Expectations	Markers of Excellence
Number of faculty ● Five full-time permanent faculty ● Wholly dedicated to chemistry program ● 75% must have a terminal degree in chemistry or an adjacent field. **Situational Variance** ● Faculty are active-duty military on assignment to a service academy **Use of Teaching Assistants** Graduate and, or undergraduate teaching assistants must be properly trained and supervised.	**Faculty involved in instruction** ● Courses needed for certification are taught by permanent faculty without excessive reliance on temporary or part-time faculty ● Where faculty contracts are renewed on a regular basis, the positions hold the expectation for long-term and full-time employment ● Expertise of faculty reflects the breadth of the five distinct areas of chemistry (ABIOP) ● Faculty are diverse in terms of gender, race, and ethnic background (for more details see DEIR section). **Institutions should provide** ● Opportunity and resources for scholarly activities of faculty ● Opportunities and resources for faculty professional development through sabbaticals, participation in meetings, and other professional activities ● Enough academic and non-academic support staff to allow the program and its faculty to conduct academic and scholarly activities ● A mechanism for counting supervision of undergraduate research in the normal faculty	● Faculty contact hours are substantially less than the maximum permitted as outlined above ● Faculty have a professional development plan that is reviewed and updated regularly ● Faculty are engaged in external organizations, outreach, and promotion of a DEIR climate ● More than five full-time permanent faculty members are wholly committed to the chemistry department ● Formal mechanisms exist by which established faculty members mentor junior colleagues
<u>**Contact Hours**</u> (60 minutes = 1 contact hour) **General rule:** All faculty regardless of rank or title must have 15 or fewer contact hours per semester/quarter. Faculty with >15 contact hours in a single semester/quarter are compliant if: ● No single semester/quarter exceeds 18 contact hours		

● AND one or more of the following situational variances is met:	workload	
Situational Variances ● They are covering for family or medical leave; or under unusual circumstances (resignation, death, etc) ● The faculty member is a lab manager/ coordinator/temporary faculty member with no service or research responsibilities ● The department must be compliant with a union contract (if the number of contact hours is $\leq$ 18 in any given semester)		

Other variances
● For instructors teaching **non-major courses** with
  ○ duplicate course offerings OR
  ○ no research or admin duties OR
  ○ no expectations for additional course development OR
  ○ no expectation for lab set up
● For instructors teaching **majors courses** with
  ○ duplicate course assignments
  ○ courses previously taught by instructor
  ○ modified service, research, or admin duties
  ○ additional assistance from graders, TAs, etc.		

Section 4: Infrastructure

A modern and comprehensive infrastructure is essential to a vigorous undergraduate program. Infrastructure includes physical laboratory spaces for teaching and research consistent with safety guidelines outlined in Section 7, state of the art instrumentation, access to appropriate information resources including journal access, databases, and computational software. Modern laboratories and infrastructure ensure that students can be properly trained across the spectrum of chemical sciences, and that such training can occur safely and with minimal environmental impact.

Critical Requirements	Normal Expectations	Markers of Excellence
Laboratories ● Research and instructional laboratories are suitable for their purposes, safe, properly maintained, and meet all applicable government regulations. ● Fume hoods are present and regularly tested/inspected. ● Provides sufficient space and management for hazardous waste storage and disposal. **Instrumentation & Computational Resources** ● A functioning NMR (or reliable access to a functioning NMR that students use). ● Instrumentation from four out of five of the following: ○ Optical Molecular Spectroscopy ○ Optical Atomic Spectroscopy ○ Mass Spectrometry ○ Chromatography and Separations ○ Electrochemistry ● The program must maintain an additional complement of instruments adequate to support the curriculum and undergraduate research.	**Laboratories & Classrooms** ● Classroom, teaching, laboratory, dedicated research, office, and common space that is modern and well-equipped. ● Dedicated facilities for research and teaching should exist, which are appropriate for the work conducted in them. ● Chemistry classrooms, labs, storage areas, and faculty offices should be in close proximity. ● The number of students supervised by a faculty member or by a TA in an instructional lab should not exceed 25. ● The facilities should permit experiments to be maintained for extended periods of time. ● The program should have access to support facilities needed for their research efforts, including machine, electronic, and glass fabrication. ● Classrooms adhere to modern standards for lighting, ventilation, comfort with proper demo facilities, projection capabilities, internet access. ● Ensure that laboratory courses are scheduled such that sufficient time is	● Programs have functioning instrumentation from all 5 categories noted in Critical Requirements. ● Programs have a plan and institutional support for regular replacement of instrumentation. ● Teaching and research spaces are continuously reviewed and improved, with capital funding available for upgrades. ● Availability of collaborative student workspaces and/or study spaces. **Journal and Information Access** ● Access that reflects substantial depth in multiple subdisciplines.

● The institution must maintain the instrumentation in good working order.
● The program must have access to computational chemistry software.
 	
Journal and Information Access
● Immediate access to a minimum of *9 peer reviewed journals* in the chemical sciences.
  ○ 3 general focus
  ○ At least one in each area ABIOP
  ○ At least one chemical education
● The library must provide timely access to publications not immediately available through a mechanism such as Interlibrary Loan (ILL).
● Access-available to technical databases including structure-based searching.
	available to address chemical preparation, chemical waste, and equipment needs.
	
	Instrumentation & Computational Resources
	● The field strength and capabilities of NMR should support the instructional and research needs of the program.
	● The program should have access to computing facilities.
	
	Support and Resources for Transfer Students
	● The program should be aware of educational backgrounds and challenges facing transfer students.
	● A curricular framework for transfer student success should be provided.
	
	Journal and Information Access
	● Immediate access to a minimum of 14-peer reviewed journals in the chemical sciences.
	  ○ 3 general focus
	  ○ At least one in each area ABIOP
	  ○ At least one chemical education
	● Access is available to multiple technical databases including structure-based searching.	

Section 5.1: Coursework

The curriculum of an approved program provides both a broad background in chemical principles and in-depth study of chemistry or chemistry-related areas that build on this background. Student learning progresses from beginner to expert knowledge and comprises introductory, foundation, and in-depth experiences. Foundation experiences are designed to provide students with an intellectual framework that covers the breadth of modern chemistry. In-depth experiences are designed to provide students with deeper development of critical thinking and problem-solving.

<table>
<tr><th>Critical Requirements</th><th>Normal Expectations</th><th>Markers of Excellence</th></tr>
<tr>
<td>Course Frequency
Foundation Course Frequency
● Programs must teach at least
○ (Semester) 4 foundation courses each academic year covering 4/5 ABIOP.
○ (Quarters) 6 foundation courses each academic year covering ⅘ ABIOP
● Each foundation course must be taught at least once in any 2-year period. If all foundation courses are not taught annually, then programs must ensure that students can complete the degree in 4 years.
○ If one of the foundation courses is taught by faculty outside of chemistry, then the chemistry faculty must teach the other 4 courses annually

In-Depth Course Frequency
● Programs must teach
○ (Semester): Three, 3-credit, in-depth courses annually, exclusive of research.
○ (Quarters) Five, 3-credit, in-depth courses, exclusive of research.
● Frequency of in-depth courses must allow students to graduate in 4 years.

Coursework</td>
<td>● Five foundation courses taught annually
● The curriculum includes the operation and theory of modern instruments and their use to solve chemical problems.
● The curriculum includes two semesters of calculus-based physics with lab.
● Undergraduate research opportunities are available within the curriculum

Green Chemistry & Sustainability
● Case studies are used to demonstrate to students the interplay of chemical, environmental health, regulatory, and business considerations that dictate chemical processes and product design.</td>
<td>● Offer a variety of in-depth courses. Some examples could include catalysis, environmental chemistry, green/sustainable chemistry, materials science, or toxicology.
● Curriculum includes integrative experiences that require students to synthesize the knowledge and skills introduced across the curriculum. These integrative experiences could be provided in an existing upper-level, designated capstone course (e.g., senior seminar) or distributed among several courses taught in the chemistry department.
● Students have opportunities to develop expertise at the interface of chemistry to help them solve problems that span scientific disciplines.
● Mentored opportunities exist for undergraduate students to integrate their knowledge and skills through peer instruction.
● The curriculum includes cognate courses beyond the critical requirement expectation.
Green Chemistry & Sustainability</td>
</tr>
</table>

- Prior to beginning foundation-level course work, students must have an introductory chemistry experience that addresses basic chemical concepts such as stoichiometry, states of matter, atomic structure, molecular structure and bonding, thermodynamics, equilibria, and kinetics. **Foundation Courses** **Definition:** Foundation courses must require an introductory chemistry prerequisite, use textbooks or other specialized materials that are beyond the introductory chemistry experience. Course content and exams should reflect coverage at a higher level than general chemistry - Courses in other disciplines with a chemical perspective (atomic/molecular-level perspective, rely on the tools of chemical measurement and analysis, and have a prerequisite of a full year of introductory chemistry) could be considered as an in-depth course. - Seminar classes **cannot count** towards foundation or in-depth coursework. **Number of courses required:** Students must complete at least (Semester) 5, one-semester courses of at least 3 credits each (Quarter) 8 one-quarter courses **Coverage:** The foundation courses must cover all areas of ABIOP, either as stand-alone courses or with content distributed across courses **In-depth Courses** **Definition:** In-depth courses - Must require a foundation or in-depth course prerequisite.		- Students are given the opportunity to assess chemical products and processes and design greener alternatives when appropriate. - Students understand and can evaluate the environmental, social, and health impacts of a chemical product over the life cycle of the product, from synthesis to disposal

○ Course content and exams include coverage at a higher level than foundation courses, with a focus on critical thinking and problem-solving skills ● **Number of courses required:** Students who wish to have a certified degree must take a minimum of ○ (Semester) 4 courses that add to at least 12 credits. ○ (Quarter) 6 courses that correspond to at least 18 credits. ● **Undergraduate research** (on or off campus) can satisfy one in-depth course for students who wish to have a certified degree. (See Section 6 - Undergraduate Research for more details). ● **Lab Courses as In-Depth Courses:** For a laboratory course to be considered as one of the four in-depth courses, ○ It must represent an advanced laboratory experience that includes the integration of student skills and builds on the foundation laboratory experiences. ○ In these courses, students are typically in the laboratory for at least six hours a week. ○ *A lab associated with a lecture course, even if it has a separate course number, is not considered a separate in-depth course*. **MSN Requirement** ● Coverage of synthetic polymers, biological macromolecules, supramolecular aggregates, meso- or nanoscale materials (MSN) must be part of the curriculum, using either a dedicated course(s) or within a distributed model. For the latter, coverage of MSN should constitute roughly		

15 hours within a standard semester course. This instruction must cover the preparation, characterization, and physical properties of such systems. At least two of the four types of systems must be covered. **Green Chemistry & Sustainability** ● The curriculum must provide students with a working knowledge of the Twelve Principles of Green Chemistry. **Cognates** ● Must complete the equivalent of 2 semesters of math including calculus I and a second math course, such as calculus II, linear algebra, statistics, or data science. The second math course may not be a prerequisite for Calculus I. ● Must complete the equivalent of 2 semesters of physics with labs.		

Section 5.2: Laboratory - Curriculum & Skills

See each individual subsection to provide feedback on this section.

Science is a process of discovery. In the laboratory, students conduct experiments, solve problems, and use the scientific method. Collectively, a laboratory experience should be experiential with students gaining breadth and depth in their scientific skills. The laboratory program is experiential in nature and should be designed at a curricular level and structured so that skills increase with complexity as students progress through the curriculum. The figure below represents the overarching outcomes of laboratory experiences and their defining attributes.

Section 5.2.1: Policy on Remote Laboratory Experiences

Virtual/at-home/simulated labs can supplement but not replace in person experiences for the foundational and in-depth courses.

- Chemistry is an empirical science that requires the safe and effective physical manipulation of materials, equipment, and instrumentation. This first person experiential expertise cannot be developed solely through simulations.

Remote Lab Experiences

- One introductory laboratory course (prior to the foundational courses) may be conducted remotely or outside of the University laboratory environments.
- Kitchen chemistry experiments can supplement in person experience in non-major and introductory chemistry sequences.
- Kitchen chemistry- remote labs involve the manipulation. Kitchen chemistry involves using everyday items that you can find in your kitchen or local discount store to explore basic chemistry. As always, consider appropriate safety precautions.

Equity for students with disabilities

Core value to provide access to a high-quality chemical education to all students. Whenever possible, programs should do their best to reasonably accommodate student needs by modifying laboratory experiments or environments. In general, programs should avoid offering fully virtual laboratory experiences in place of in-person experiences as accommodations

<table>
<tr><th colspan="3">Section 5.2.2: Laboratory Course Requirements</th></tr>
<tr><td>Critical Requirements</td><td>Normal Expectations</td><td>Markers of Excellence</td></tr>
<tr><td>Lab Hours and Structure
Students completing the requirements for a certified degree must complete a minimum of 350 hours of in person lab work that builds on, but does not include, introductory experiences.
● 220 hours of lab must be from courses taught in the chemistry program beyond the introductory courses (general chemistry).
● Undergraduate research or chemistry adjacent laboratory courses (on or off campus) can account for up to 130 of the required 350 laboratory hours.
● A student using research to meet the 350 hours must prepare a well- written, comprehensive, and well-documented research report, including safety considerations where appropriate and thorough and current references to peer-reviewed literature.
● No more than 25% of lab work can be in computational chemistry.</td><td>Lab Hours and Structure
● A program should provide students with the opportunity to complete approximately 400 hours of lab work that builds on introductory, in class laboratory experiences.
● Undergraduate research or chemistry adjacent courses (on or off campus) can account for up to 180 of the required 400 laboratory hours.
● Lab experiences reflect current standards and practices in the chemical science.
● Programs should evaluate and update their lab curricula on a regular basis to reflect modern questions and techniques in chemistry.</td><td>Lab Hours and Structure
● Instructors develop or adapt new approaches or practices that enhance student skills and disseminate them to the larger community.</td></tr>
<tr><td>Breadth of Student Laboratory Experiences
Laboratory courses must:
● Include experiences in a minimum of 4 of the 5 areas of ABIOP
● Provide experiences with
○ synthesis and production
○ purification
○ preparation of samples for analysis
○ qualitative analysis</td><td>Breadth of Student Laboratory Experiences
● Gain experiences with at least 4 classes of chemical compounds (small organic molecules, small inorganic molecules, biological macromolecules, polymers, supramolecular systems, meso- or nanoscale materials, or extended solids)</td><td>Breadth of Student Laboratory Experiences
● Students gain laboratory experience in all 5 areas of ABIOP.
● Instruction is provided so that students gain experience with one or more of the following: programming, data analytics, and, or, informatics.</td></tr>
</table>

○ quantitative analysis ○ measurement of chemical properties ○ structure determination, and ○ modeling		
Depth of Student Laboratory Experiences ● Laboratory experiences must build on practical techniques developed in earlier lab courses. ● Laboratory skills are structured so that the complexity of tasks increase as students progress through the curriculum ● As they progress, students must encounter some lab experiences that are open-ended or incompletely defined questions or unfamiliar situations. ● Students must have regular hands-on experience with modern instrumentation	**Depth of Student Laboratory Experiences** ● Students regularly have lab experiences that are open-ended or incompletely defined questions or unfamiliar situations. ● Students participate in multi-week laboratory experiences where they can revise ideas and build on prior findings. ● Lab experiences relate to modern research problems ● Students participate in a CURE or research experience during their undergraduate career. ● Students should have opportunities to have hands-on experiences instruments from 4 of 5 of the instrumental categories (atomic spectroscopy, molecular spectroscopy, separations and chromatography, electrochemistry, and mass spectrometry).	**Depth of Student Laboratory Experiences** ● Students work on problems that contribute new knowledge to the discipline. ● Most students participate in Classroom Undergraduate Research Experiences (CURE) or undergraduate research experiences. ● Students should have in depth experience with instrumentation and understand how to troubleshoot instrumental problems. ● Students have comprehensive exposure to all instrument categories.
Experimental Design Laboratory experiences must be developed in such a way that students regularly: ● make predictions and develop hypotheses ● design experiments to answer scientific questions	**Experimental Design** Laboratory experiences are developed in such a way that students regularly execute experiments that they design and evaluate the effectiveness of their experimental design.	**Experimental Design** Laboratory experiences are developed in such a way that students regularly use the iterative design process to advance scientific inquiry.

Section 5.2.3 - Student Skills Learned in Laboratory Courses		
Critical Requirements	**Normal Expectations**	**Markers of Excellence**
Connect Experiment to Theory Students must ● use accepted scientific theories to explain their data and analyses ● develop or select appropriate models for their systems ● understand the limitation of models and theories	**Connect Experiment to Theory** Students should ● develop proficiency with modeling software, ideally allowing them hands-on experience in directly comparing theory and experiment	**Connect Experiment to Theory**
Construct Scientific Explanations & Arguments Students must ● construct explanations of their results ● use evidence to support the interpretation of their results ● use mathematics and computational thinking	**Construct Scientific Explanations & Arguments** Students should ● Have multiple opportunities to develop arguments using different types of data (structural, statistical, etc.)	**Construct Scientific Explanations & Arguments** Students in these programs develop compelling arguments using multiple pieces of supporting evidence
Data & Analysis Skills Students must be able to ● maintain an effective laboratory notebook/record ● analyze data using appropriate statistical methods and software ● understand uncertainties in experimental measurements ● assess experimental errors and draw appropriate conclusions	**Data & Analysis Skills** Students should ● be introduced to modern laboratory record-keeping tools including laboratory information management systems (LIMS) and electronic laboratory notebooks (ELNs). ● use best practices for data storage, access, sharing, and archiving.	**Data & Analysis Skills** Students in these programs ● Understand data compliance and integrity issues within a regulatory context. ● Work with partners to ensure students have appropriate documentation, data analysis, and data management skills necessary to make them marketable in their areas. ● develop programming skills.
Computational Skills Students must be	**Computational Skills** Students should	**Computational Skills** Students

• Exposed to computational chemistry and chemical dynamics simulation packages.	• use of computational chemistry and chemical dynamics simulation packages. • have experience writing code in standard software packages	• are proficient with computational chemistry and chemical dynamics simulation packages. •
Representation and Visualization of Data Students must be able to • Present data in graphs and tables • Draw 2-D and 3-D structures using appropriate software.	**Representation and Visualization of Data** Students should be able to • Effectively present data in graphs and tables. • Draw effective 2-D and 3-D structures.	**Representation and Visualization of Data** • Students are aware of multiple methods for representing data and can select the most appropriate method.

Section 5.3: Pedagogy

An approved program should use effective pedagogies in classroom and laboratory course work. Programs should teach their courses in a challenging, engaging, and inclusive manner that accommodates a variety of teaching styles. Additionally, a program should provide opportunities for faculty to maintain their knowledge of effective practices in chemistry education and modern theories of learning and cognition in science. An approved program should regularly review its pedagogical approaches to ensure that they promote student learning and build the skills needed to be an effective professional.

Critical Requirements	Normal Expectations	Markers of Excellence
• Provide opportunities for faculty to maintain and improve their knowledge of evidence-based practices in chemical education and modern theories of learning, cognition, and social psychology in science. • **Regularly** review its pedagogical approaches to ensure that they promote student learning and build the skills necessary to be an effective professional. • **Regularly** evaluate its curriculum and pedagogy, faculty development opportunities and infrastructure needs relative to the program's teaching and research mission.	**Approved programs should** • Use effective pedagogies in classroom and laboratory course work. • Teach their courses in a challenging, engaging, and inclusive manner that helps improve learning for all students. **Faculty should** • Incorporate pedagogies that have been shown to be effective in undergraduate chemistry education and address the cognitive, affective, and social aspects of learning. Examples include, but are not limited to, problem- or inquiry- based learning, peer-led instruction, learning communities, technology-aided instruction such as the use of personal response systems and hybrid classes, and classes where active-learning is the dominant in class instructional mode.	• Data are collected in a way that allows for a continuous process of evaluation, analysis, and improvement. • Thoughtful and thorough self-evaluation has led to improved or modernized course content or pedagogy identification of areas in which the curriculum may be strengthened, and student outcomes improved. • Program evaluation provided a strong infrastructure to support the educational and scientific missions of the program.

Section 6: Undergraduate Research*

***Guidelines pertain to institutions that require undergraduate research to meet the lab hour requirement or when a student uses research as an in-depth course.**

Undergraduate research allows students to integrate and reinforce chemistry knowledge from their formal course work, to further develop their scientific and professional skills, and to create new scientific knowledge. Conducting undergraduate research in close collaboration with a faculty mentor allows a student to draw on faculty expertise. Such research should be well-defined, stand a reasonable chance of completion in the allotted time, apply and develop an understanding of in-depth concepts, use a variety of instrumentation and methods, promote awareness of advanced scientific practice, and be thoroughly grounded in the chemical literature. Overall, the research project should be viewed as a component of a publication in a peer-reviewed journal.

Critical Requirements	Normal Expectations	Markers of Excellence
● Research must be well-defined, apply and develop understanding of in-depth concepts, promote awareness of safety, be grounded in literature, and contribute new knowledge to the discipline. ● For programs where research is required, all students must prepare a well-written, comprehensive, and well-documented research report that has been evaluated by department faculty. ○ The report must include safety considerations where appropriate and thorough and current references to peer-reviewed literature. ● Students must prepare a written report for summer/off-campus work to count towards student certification	● Research should be envisioned as a component of a publication in a peer-reviewed journal or technical report ● Research progress would be presented at an institutional or local meeting. ● Programs should have a standard rubric for assessing undergraduate research reports	● Research contributions would result in a co-authorship of a peer-reviewed publication ● Research would be presented at a regional or national chemistry meeting ● A research project involves multiple semesters or years with students gaining increasing independence and scientific sophistication.

Section 7: Creating a Safety Culture

The preparation and development of undergraduate chemistry majors should reflect learning in both the classroom and laboratory and occur in a supportive and safe culture. Key aspects of the culture include a safety-first mindset, respect for chemical processes, and safe laboratory experimentation. A safety culture requires appropriate administrative support, infrastructure, curriculum, and instructor training, as well as commitment from all constituencies. Students must be trained to plan for potential safety incidents and how to resolve them for processes they and their colleagues are performing. The goal is the safe practice of our profession.

The guidelines outlined below reflect the need for students to work in a safe laboratory environment and to develop the knowledge and skills necessary to-work safely in their future careers. Institutions, faculty, and staff must understand their roles in educating students about safety and in supporting a culture of safety through shared responsibility.

<table>
<tr><th>Critical Requirements</th><th>Normal Expectations</th><th>Markers of Excellence</th></tr>
<tr>
<td>
Safety Culture

Program must be conducted in a safe environment & promote a safety culture

Regulations and Infrastructure

Program must have a written chemical hygiene plan which is:

consistent with OSHA/state regulations,
included in the teaching and research activities of the program
recognizes hazards encountered in teaching and research activities
Includes hazardous waste management

Properly functioning and appropriate fume hoods, safety showers, eyewashes, first aid kits, and fire extinguishers must be readily available

Eyewash and shower stations must be regularly tested and inspected

</td>
<td>
Safety Culture

Programs should work with administrators on an annual basis to establish institutional support and an adequate budget to maintain safety infrastructure, education, training, and regulatory compliance.

Regulations and Infrastructure

Safety plans for each space need to recognize the hazards encountered in the instructional and research activities within that space.
Chemistry classrooms, labs, storage areas, and faculty offices should be in close proximity.
The number of students supervised by a faculty member or by a teaching assistant in an instructional lab should not exceed 25. Many laboratories require smaller numbers for safe and effective instruction.

</td>
<td>
Safety Culture

Students recognize that safety is a community endeavor, and every community member plays a role in maintaining a safe environment.

Regulations and Infrastructure

Programs provide students with instruction about state and federal safety regulations and compliance.

Training and Education

Students have access to a course in chemical safety and / or toxicology.
Programs seek reduction of chemical use and hazardous waste generation and embrace green chemistry principles.
The program establishes a system to promote safety in an institution or department that encompasses electronic communications, printed materials, special seminars, or events discussing or promoting

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○ Labs must meet applicable OSHA safety regulations ○ Appropriate PPE must be readily available to students, staff, and faculty ● The program establishes and maintains an incident reporting system, an incident investigation system, and an incident database reviewed by the safety committee. **Training and Education** ● Programs must instruct students, faculty and staff in the aspects of modern chemical safety appropriate to their educational level and scientific needs ○ The promotion of safety awareness and skills must begin during the first laboratory experience and should be incorporated into each lab experience thereafter ○ Students must undergo general safety instruction as well as lab-specific instruction before beginning undergraduate research ○ Safety understanding and skills must be developed and assessed throughout the curriculum. ● Programs must provide students with training that allows them to ○ carry out responsible disposal techniques for both chemicals and damaged glassware ○ comply with safety regulations ○ properly use personal protective equipment to minimize exposure to hazards	● Periodic spot observations of chemical users' safety behaviors in teaching and research laboratories. **Training and Education** ● Programs provide students with instruction ○ That allows them to properly select and use personal protective equipment to minimize exposure to hazards ○ In responsible disposal techniques ● Students learn RAMP (**R**ecognize hazards, **A**ssess the risks of hazards, **M**inimize the risks of hazards, and **P**repare for Emergencies) analyses. As the program progresses, students should learn to conduct these analyses. ○ Programs include a RAMP analysis in the development of all new teaching lab experiments.	safety / safety moments, a recognition system for good safety performance, and a process to solicit, review, and act on suggestions for improving safety and identifying safety issues. ● Students actively participate in aspects of the safety program (such as the safety committee). ● The administration is actively involved in the safety program. ● Incidents are discussed within the program.

○ understand the categories of hazards associated with chemicals (health, physical, and environmental) ○ use Safety Data Sheets (SDSs) and other standard printed and online safety reference materials ○ recognize chemical and physical hazards in laboratories, assess the risks from these hazards, know how to minimize the risks, and prepare for emergencies such as fires, explosions, chemical exposures, injuries, and chemical spills. ○ properly use emergency equipment (e.g., fire extinguishers, eyewash stations, safety showers, spill kits, first aid kits, fire alarms, and fire blankets)		

Section 8: Professional Skills & Competencies

Preparing students for the modern workplace requires more than technical skills. Surveys of employers consistently indicate the importance of interpersonal skills such as complex communication, social skills, teamwork, cultural sensitivity, and dealing with diversity for success in a wide range of areas. Effective departments must train students to communicate effectively, including using relevant technology and information management, work collaboratively, and engage in the ethical conduct of science. The Chemical Professional's Code of Conduct outlines the obligations of the professional chemist to the public, colleagues, employers, students, the profession, the environment, and the science of chemistry. The professional conduct of scientists must be an intentional part of the instruction in a chemistry program. Furthermore, students must know that science is a collaborative endeavor and requires the collective, equitable, and fair participation of everyone in the scientific community. Since faculty serve as role models, they must exemplify responsible conduct in their teaching, research, and all other professional activities. Successful chemistry programs, by way of their example, instruction, and assessment must prepare their students for the global chemical enterprise by developing strong professional skills and competencies.

Critical Requirements	Normal Expectations	Markers of Excellence
Communication Skills ● The chemistry curriculum must include writing and speaking opportunities that allow students to learn how to communicate technical information: (1) clearly and concisely, (2) in a scientifically appropriate style for the intended audience including non-technical audiences, (3) ethically and accurately, and (4) utilizing relevant technology. ● Instruction must demonstrate the importance of including effective visual representations of models and datasets in scientific communication. ● Communication skills must be explicitly assessed to determine the level of student competency in both written and oral scientific communication.	**Communication Skills** ● Communication skills are developed across the curriculum with multiple opportunities for practice and evaluative feedback.	**Communication Skills** ● Because chemistry is a global enterprise, knowledge of more than one language or an international experience can be an asset to chemistry students and add greatly to a student's ability to communicate with chemists worldwide. ● The program offers opportunities that go beyond coursework for students to engage with the broader institutional, local, or scientific community.

Information Retrieval, Evaluation, & Management

- Students receive instruction in effective methods for performing and assessing the quality of searches using keywords, authors, abstracts, citations, patents, and structures/substructures.
- Students can use chemical identifiers (e.g., chemical name, CAS registry number, molecular formula) to locate physical and chemical properties in handbooks and databases.
- Students' ability to conduct effective searches and then read, analyze, interpret, and cite the chemical literature as applied to answering chemical questions is assessed across the curriculum.

Teamwork and Collaboration

- Programs must incorporate team experiences into classroom and laboratory components of the chemistry curriculum, thus providing opportunities for students to learn to interact effectively in a group to solve scientific problems and work productively with a diverse group of peers.

Information Retrieval, Evaluation, & Management

- Instruction is provided in data management and archiving, record keeping (electronic and otherwise), and managing citations and related information.
- Students are trained in strategies for assessing the quality of sources of scientific information.

Teamwork and Collaboration

- Approved programs should incorporate effective measures to assess the performance of both team leaders and members across the curriculum.

Information Retrieval, Evaluation, & Management

- Students demonstrate knowledge of intellectual property issues associated with scientific publications including author's rights, the use of copyrighted materials in research and instruction, the peer review process, and publication in and access to open-access journals.

Teamwork and Collaboration

- Leadership development involves providing instruction and assessment of a range of skills including effective coordination, direction, and engagement of team members; experience in persuasion and negotiation to accomplish goals and meet deadlines; and ability to resolve conflicts and critically evaluate team members.
- The effectiveness of team members is enhanced through opportunities to build strong communication skills and initiative, respect for the views of other team members, and reliability and commitment to the task at hand.

Professional Conduct of Scientists ● Approved programs must train their students to: ○ follow appropriate experiment documentation and data integrity practices ○ treat data responsibly, ○ cite the work of others' properly, ○ abstain from act(s) of plagiarism, and ○ maintain the scholastic standards that pertain to the publication of scientific results. ● Programs address multiple aspects of professional conduct, including sustainability, bias, policy/regulation, professional growth, and limitations of knowledge.	**Professional Conduct of Scientists** ● Successful programs prepare their students to recognize the impact of their work on individuals in society. ● Students have opportunities to learn to treat individuals with respect and fairness in all aspects of the scientific process – ○ establishing collaborations, partnerships, and mentoring relationships. ○ designing and conducting research projects. ○ writing and reviewing manuscripts and proposals; presenting research findings at conferences, etc.	**Professional Conduct of Scientists** ● Assessment of professional conduct goes beyond evaluating student reports or laboratory notebooks. ● Programs provide multiple opportunities for students to engage in self-reflection and discussion of the role of sustainability, bias, policy/regulation, professional growth, limitations of knowledge in the practice of science.
● Instruction and coursework should demonstrate that the interconnection of chemistry with other disciplines is necessary to develop a comprehensive view of how physical, chemical, and biological systems behave, interact, and affect one another.	**Systems Thinking** ● Students should be made aware that solutions to problems in the world around us require decision-making that takes into consideration chemical knowledge as well as social, economic, political, moral, or environmental factors.	**Systems Thinking** ● Students work through problems that bring in chemical knowledge, as well as social, economic, political, moral, or environmental factors.

Section 9: Diversity, Equity, Inclusion, and Respect (DEIR)

<table>
<tr><th colspan="3">9.1 DEIR Experience & Training</th></tr>
<tr><th>Critical Requirements</th><th>Normal Expectations</th><th>Markers of Excellence</th></tr>
<tr><td>Faculty & Staff involved with
Teaching
Academic Advising
Mentoring
are experienced or trained in making their practices inclusive, equitable, and accessible to persons with diverse backgrounds and identities.</td><td>Provide training opportunities or support for students interested in developing DEI competencies.
DEIR training is part of the evaluation criteria for personnel involved in teaching, academic, advising, or mentoring.
Require DEI training for anyone serving on admissions and/or search committees.</td><td>Provide evidence that all constituents (faculty, staff, students)
Understand elements of DEIR
Know how these elements are operationalized within the department or program
Know how violations of these elements are acknowledged and addressed
Promote engagement by students, faculty, and staff in DEIR activities through rewards and performance evaluations.</td></tr>
<tr><th colspan="3">9.2 Recruitment and Retention</th></tr>
<tr><th>Critical Requirements</th><th>Normal Expectations</th><th>Markers of Excellence</th></tr>
<tr><td>Have a long-term strategy for recruitment & retention of
Faculty
Staff
Students
from diverse backgrounds and underrepresented groups.</td><td>Support professional development on culturally responsive and inclusive pedagogies and practices for faculty and staff who engage in searching, recruiting, and retaining individuals (faculty, staff, students) from underrepresented groups.
Support faculty, staff, and student engagement with affinity organizations (e.g. NOBCChE, SACNAS, oSTEM, etc.) and interdisciplinary programs that prioritize topics related to DEIR and access.</td><td>Use evidence-based practices to define strategies for recruitment of faculty, staff, and students from diverse backgrounds.
Ensure working and learning environments are inclusive and accessible for faculty, staff, and students.</td></tr>
</table>

	• Support/Encourage faculty and staff interested in participation in a broader array of conferences and workshops that foster the success of students from underrepresented groups
	• Ensure that learning environments are inclusive for students
	    ○ Minimize stereotype threat and social stigma
	    ○ Recognize and value contributions from all students, including those from underrepresented groups
	    ○ Welcome and provide access for students with different abilities	

9.3 Retention - Chemistry Majors		
Critical Requirements	**Normal Expectations**	**Markers of Excellence**
• Establish mechanisms for supporting learning & retention of chemistry majors from diverse backgrounds and underrepresented groups	• Include aspects of DEIR in pedagogies used to train chemistry majors. Promote DEIR in their curriculum and highlight achievements and contributions of scientists from underrepresented groups and diverse backgrounds. • Encourage the formation of student led groups that engage with DEIR activities and provide them with counter spaces.	• Ensure that funds are available to provide access of opportunities for chemistry majors, including those from underrepresented groups. • Establish metrics for evaluating the mechanisms for supporting learning and retention of chemistry majors from underrepresented groups.
9.4 Policies and Procedures		
Critical Requirements	**Normal Expectations**	**Markers of Excellence**

• Have institutional, or departmental policies to investigate and address issues of
    ○ Discrimination
    ○ Bias
    ○ (micro)aggressions
    ○ prejudice
    ○ harassment
	• Have procedures and tools for observing & documenting inclusive classroom practices.
	• Communicate and clearly articulate criteria for personnel whose evaluation include DEIR criteria
	• Track department demographics (faculty, staff, students)
	• Conduct or participate in departmental/institutional climate surveys
		• Make curricular goals related to DEIR available on a public forum. Include both
		    ○ Evaluation of curriculum
		    ○ Revision of curriculum
		• Establish metrics for evaluating policies used to address issues of **discrimination bias**, **(micro)aggressions**, prejudice,

		and **harassment** in the working and learning environments. ● Communicate effective practices in faculty, staff, and student recruitment and retention ● Have a strategic plan to communicate about and advance access to learning environments, including laboratories, for students with different abilities.

9.5 Review, Revise, and Communicate Policies		
Critical Requirements	**Normal Expectations**	**Markers of Excellence**
	● Periodically review, revise, and communicate policies ● Provide evidence that constituents perceive that the elements of DEIR have been operationalized in earnest and without patronage.	● Has a standing committee that includes faculty, staff, students dedicated to DEIR issues, including accessibility ● There is an evaluation of the program's ability to achieve uniform and effective DEIR practices ● There is a mechanism to receive student anonymous feedback on DEIR practices and accessibility.

Glossary

Ability and Ableism: **Ability** refers to one's physical and cognitive capabilities whereas **ableism** is a system that places value on societally constructed ideas of normalcy, favoring those with abilities and resulting prejudice or discrimination against people with disabilities.

ABIOP: Analytical, Biochemistry, Inorganic, Organic, Physical Chemistry

Access and accessibility: **Access** refers to the conditions that enable people with permanent or temporal disabilities to participate equitably in all societal activities whereas **accessibility** describes the degree to which one has access to all rights, benefits, and responsibilities in the living, working, and learning environments.

Affinity group/organizations: A group or organization formed based on the shared ideas, interests, and goals of the individuals.

Bias: Disproportionately favoring or not favoring a person, group, entity, or idea in a way that is unfair, prejudice, or discriminatory.

Counter spaces: A system of support structures and resources, formal or informal, that support the psychological health of individuals from marginalized, minoritized, and disadvantaged groups.

Culturally responsive and inclusive pedagogies: Culturally responsive pedagogies incorporate students' identities and cultural references into the curriculum whereas inclusive pedagogies address students' learning styles, abilities, and background.

DEIR: Diversity, equity, inclusion, and respect.

Discrimination: The mistreatment of individuals or groups of individuals based on their identity (e.g., race, ethnicity, culture, sexual orientation, gender, socioeconomic background)

Diversity: Representing individuals having a range of identities (e.g., race, ethnicity, culture, sexual orientation, gender, socioeconomic background, body size)

Equity: Ensuring that everyone in each environment has the same resources, opportunities, treatment, and experience

Evidence-based practices: Strategies having a demonstrated efficacy and outcomes backed by empirical data

Harassment: To inflict hostile, prejudice, or intimidating behaviors on another individual

Inclusion: Ensuring that all individuals have access to a space or opportunity.

Micro-aggression: subtle verbal, behavioral, or environmental instances that are directly or indirectly intended to be degrading, dismissive, intimidating, belittling, or contemptuous towards an individual or group, particularly those from a marginalized or disadvantaged group.

Prejudice: A judgment or opinion about an individual or group that seeks to marginalize or cast aspersions on that individual or group based on their identity or other characteristics (e.g., academic pedigree or marital status).

Respect: A positive or esteemed disposition towards another individual.

Stereotype threat: An individual's fear of confirming a negative belief about their identity regardless of if the belief is founded. Such fear often manifests through low performance, despite the person's ability, and isolating behaviors.

Underrepresented groups: A subset of the population whose presence or participation in a space is significantly smaller than the whole.

Appendix 1: Natural Disaster and Emergency Guidelines

Natural disasters and other emergencies have disrupted education practices worldwide, including ACS-approved programs offering bachelor's degrees in chemistry. These events may temporarily change how programs train their students. The ACS Committee on Professional Training (CPT) has developed guidelines addressing student training if an institution is impacted by a natural disaster or other emergency and needs to temporarily pivot to virtual instruction.

The goals of this policy are to ensure that:

1. Chemistry majors can continue to receive training that prepares them for a successful career,
2. Chemistry majors do not extend their graduation time,
3. Programs offering bachelor degrees in chemistry have the flexibility to continue their pursuit for sustained academic excellence, and
4. Programs return to in person laboratory experiences as soon as emergency conditions have passed.

Lab Skills

Participative laboratory skills are an essential skill for chemists because of the manipulative and problem solving skills that students develop. Furthermore, practical lab experiences help students develop greater awareness of working in a laboratory environment and laboratory safety. Through communication with the broader chemistry community, CPT has compiled a list of the laboratory skills typically covered in the undergraduate curriculum that require physical presence in a laboratory. Programs should develop a plan to develop these skills, typically taught in-person that are typically covered in the undergraduate curriculum. In addition to complying with emergency-related OSHA and CDC requirements, best practices for laboratory safety, as described in the Guidelines for Chemical Laboratory Safety in Academic Institutions, should be employed.

Virtual Labs

Safety is a core value of the American Chemical Society and as such the health and well-being of students, staff, and faculty members in the community is paramount. The use of virtual labs will be allowed for institutions that must move all instruction online as a result of an emergency and will not affect the approval status of a program. Once face-to-face instruction is possible, or laboratories on campus can be occupied, all laboratory experiences must be performed face-to-face as well.

"Kitchen" Laboratory Experiences

In general, institutional decisions surrounding the best way to offer laboratory experiences when face-to-face instruction is not possible should comply with all safety regulations and be focused on safe and effective student learning. These types of activities would not affect your approval status unless they were used after face-to-face instruction resumed.

Certification

Department chairs can certify students who were on the path to completing the approved curriculum if the emergency impacts coursework due to a move to virtual instruction.

Pass/Fail Grading

Some institutions may enact a pass/fail grading policy as part of the response to the emergency. Students currently on a path to complete an approved curriculum who graduate with pass/fail grades can still be certified by the department chairperson. The department's ACS approval will not be affected.

Our concern is for the health and safety of students, staff, and faculty at approved institutions and understand that emergencies increase the stress on faculty, staff, and students. Please let us know if there is anything else that can be done to assist the program and feel free to reach out to us at cpt@acs.org.

Package History

Date	User	Action
9/27/2024 1:39:34 PM	Ellis, Trevor	Added attachment '1-Guidelines-APPROVED-Jan2023.pdf'
9/27/2024 1:39:34 PM	Ellis, Trevor	Added attachment 'macromolecular-supramolecular-nanoscale-supplement.pdf'
9/27/2024 1:39:34 PM	Ellis, Trevor	Submitted 'Program Modification'
9/27/2024 1:39:52 PM	Johnson, Jason	Received
9/27/2024 2:37:44 PM	Ellis, Trevor	Received
9/27/2024 2:37:44 PM	Johnson, Jason	Decision Returned to a previous user on step 'FLOW-Deans'
9/29/2024 1:53:06 PM	Ellis, Trevor	Added attachment 'Current CHEMPRO_BS Degree Program.pdf'
9/29/2024 1:53:15 PM	Ellis, Trevor	Added attachment 'Proposed CHEMPRO_BS Degree Program.pdf'
9/29/2024 1:53:30 PM	Ellis, Trevor	Decision Submitted on step 'Start'
9/29/2024 1:53:54 PM	Johnson, Jason	Received
9/29/2024 3:00:44 PM	Johnson, Jason	Decision Approved on step 'FLOW-Deans'
9/29/2024 3:00:57 PM	FLOW-Provost's Executive Assistant	Received