2020 Polymer Science

Mississippi Department of Education

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Direct inquiries to:

Instructional Design Specialist
Research and Curriculum Unit
P.O. Drawer DX
Mississippi State, MS 39762
662.325.2510

Program Coordinator
Office of Career and Technical Education
Mississippi Department of Education
P.O. Box 771
Jackson, MS 39205
601.359.3461

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Research and Curriculum Unit
Mississippi State University
Mississippi State, MS 39762

The Research and Curriculum Unit (RCU), located in Starkville, as part of Mississippi State University (MSU), was established to foster educational enhancements and innovations. In keeping with the land-grant mission of MSU, the RCU is dedicated to improving the quality of life for Mississippians. The RCU enhances intellectual and professional development of Mississippi students and educators while applying knowledge and educational research to the lives of the people of the state. The RCU works within the contexts of curriculum development and revision, research, assessment, professional development, and industrial training.

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Standards

Standards are superscripted in each unit and are referenced in the appendices. Standards in the polymer science curriculum framework and supporting materials are based on the following:

Society of the Plastics Industry (SPI) Standards

Founded in 1937, SPI is the plastics industry trade association representing the third-largest manufacturing industry in the United States. SPI's member companies represent the entire plastics industry supply chain, including processors, machinery and equipment manufacturers, and raw materials suppliers. plasticsindustry.org

Applied Academic Credit Benchmarks

The *Mississippi Polymer Science Curriculum Framework* is aligned to the Chemistry course in the 2018 *Mississippi College- and Career-Readiness Standards for Science*. An alignment crosswalk can be viewed at the end of this document.

National Educational Technology Standards for Students

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21st Century Skills and Information and Communication Technologies Literacy Standards

In defining 21st century learning, the Partnership for 21st Century Skills has embraced five content and skill areas that represent the essential knowledge for the 21st century: global awareness; civic engagement; financial, economic, and business literacy; learning skills that encompass problem-solving, critical-thinking, and self-directional skills; and information and communication technology (ICT) literacy.

Preface

Secondary CTE programs in Mississippi face many challenges resulting from sweeping educational reforms at the national and state levels. Schools and teachers are increasingly being held accountable for providing applied learning activities to every student in the classroom. This accountability is measured through increased requirements for mastery and attainment of competency as documented through both formative and summative assessments. This document provides information, tools, and solutions that will aid students, teachers, and schools in creating and implementing applied, interactive, and innovative lessons. Through best practices, alignment with national standards and certifications, community partnerships, and a hands-on, student-centered concept, educators will be able to truly engage students in meaningful and collaborative learning opportunities.

The courses in this document reflect the statutory requirements as found in Section 37-3-49, *Mississippi Code of 1972*, as amended (Section 37-3-46). In addition, this curriculum reflects guidelines imposed by federal and state mandates (Laws, 1988, Ch. 487, §14; Laws, 1991, Ch. 423, §1; Laws, 1992, Ch. 519, §4 eff. from and after July 1, 1992; Carl D. Perkins Vocational Education Act IV, 2007; and Every Student Succeeds Act, 2015).

Mississippi Teacher Professional Resources

The following are resources for Mississippi teachers:

Curriculum, Assessment, Professional Learning

Program resources can be found at the RCU's website, rcu.msstate.edu.

Learning Management System: An Online Resource

Learning management system information can be found at the RCU's website, under Professional Learning.

Should you need additional instructions, call 662-325-2510.

Executive Summary

Pathway Description

Polymer science is an instructional pathway that introduces an individual to the field of plastics and polymer materials manufacturing. The pathway allows an individual to prepare for employment or continued education in the occupations of plastics and polymer materials manufacturing. The pathway is designed to provide students with hands-on experiences related to the application of polymer science concepts in the workplace. Students will develop academic and technical skills, 21st century skills, and human relations competencies that accompany technical skills for job success and lifelong learning. Students who complete the pathway will be better prepared to enter and succeed in related programs offered by Mississippi community colleges and institutions of higher education.

Industry Certification

Two national certifications are associated with the polymer science industry, the Certified Composites Technician (CCT) and the National Certification in Plastics (NCP).

Assessment

The latest assessment blueprint for the curriculum can be found at rcu.msstate.edu/Curriculum/CurriculumDownload.

Student Prerequisites

In order for students to experience success in the program, the following prerequisites are suggested:

1. C or Higher in a physical science or biology

or

1. Instructor approval

Applied Academic Credit

The latest academic credit information can be found at mdek12.org/ESE/Approved-Course-for-the-Secondary-Schools.

Teacher Licensure

The latest teacher licensure information can be found at mdek12.org/OTL/OEL/career&technical.

Professional Learning

If you have specific questions about the content of any of the training sessions provided, please contact the RCU at 662.325.2510.

Course Outlines

Option 1—Four 1-Carnegie Unit Courses

This curriculum consists of four 1-credit courses, which should be completed in the following sequence:

1. **Introduction to Polymer Science I—Course Code: 994502**
2. **Introduction to Polymer Science II—Course Code: 994503**
3. **Advanced Topics in Polymer Science—Course Code: 994504**
4. **Careers in Polymer Science—Course Code: 994505**

Course Description: Introduction to Polymer Science I

This course orients the students to the polymer science program and lab. During this course, students learn computer applications relevant to polymer science. They are also introduced to chemistry concepts and the structures and properties of polymers.

Course Description: Introduction to Polymer Science II

This course teaches students the processing techniques associated with polymers and the methods and benefits of plastics recycling.

Course Description: Advanced Topics in Polymer Science

This is a comprehensive course that focuses on polymer synthesis, surface coatings, and composite materials.

Course Description: Careers in Polymer Science

This course explores the job opportunities available for individuals in this area. The course also teaches job application and workplace skills and offers a potential for job shadowing.

Introduction to Polymer Science I—Course Code: 994502

Unit	Unit Name	Hours
1	Orientation, Safety, and Information Media	40
2	Recycling	30
3	Introduction to Chemistry	70
Total		140

Introduction to Polymer Science II—Course Code: 994503

Unit	Unit Name	Hours
4	Chemistry of Polymers	80
5	Introduction to Polymer Processing	40
Total		120

Advanced Topics in Polymer Science—Course Code: 994504

Unit	Unit Name	Hours
6	Polymer Safety and Concepts Review	20
7	Advanced Polymer Processing	40
8	Materials Science	50
Total		110

Careers in Polymer Science—Course Code: 994505

Unit	Unit Name	Hours
9	Surface Coatings	30
10	Composite Materials, Processing, and Applications	50
11	School to Work	50
Total		130

Option 2 – Two 2-Carnegie Unit Courses

This curriculum consists of two 2-credit courses, which should be completed in the following sequence:

1. **Polymer Science I – Course Code: 994500**
2. **Polymer Science II – Course Code: 994501**

Course Description: Polymer Science I

This course introduces the course and lab. During the course, students learn computer applications relevant to polymer science, and they are also introduced to chemistry concepts and the structures and properties of polymers. Students are also taught the processing techniques associated with polymers and the methods and benefits of plastics recycling.

Course Description: Polymer Science II

This is a comprehensive course that focuses on polymer synthesis, surface coatings, and composite materials. It explores the job opportunities available for individuals in this area, and it also teaches job application and workplace skills as well as offers a potential for job shadowing.

Polymer Science I – Course Code: 994500

Unit	Unit Name	Hours
1	Orientation, Safety, and Information Media	40
2	Recycling	30
3	Introduction to Chemistry	70
4	Chemistry of Polymers	80
5	Introduction to Polymer Processing	40
Total		260

Polymer Science II – Course Code: 994501

Unit	Unit Name	Hours
6	Polymer Safety and Concepts Review	20
7	Advanced Polymer Processing	40
8	Materials Science	50
9	Surface Coatings	30
10	Composite Materials, Processing, and Applications	50
11	School to Work	50
Total		240

Research Synopsis

Introduction

The Polymer career pathway will target careers at the professional and technical levels in polymer science. Students enrolled in these courses should be better prepared to pursue degrees at the community college and four-year college level.

Needs of the Future Workforce

Data for this synopsis were compiled from the Mississippi Department of Employment Security (2019). Employment opportunities for each of the occupations are listed below.

Table 1.1: Current and Projected Occupation Report

Description	Jobs, 2016	Projected Jobs, 2026	Change (Number)	Change (Percent)	Average Hourly Earning
Chemical Engineers	80	90	10	12.5%	$51.39
Chemical Technicians	320	340	20	6.3%	$22.97
Chemists	300	330	30	10.0%	$35.51
Materials Engineers	130,110	120	10	9.1%	$43.03

Source: Mississippi Department of Employment Security; mdes.ms.gov (2019).

Perkins IV Requirements

The polymer science curriculum meets Perkins IV requirements of high-skill, high-wage, and/or high-demand occupations by introducing students to and preparing students for such occupations. It also offers students a program of study that includes secondary, postsecondary, and institutions of higher learning (IHL) courses that will prepare them for occupations in the polymer science field. Additionally, the polymer science curriculum is integrated with academic standards and articulated to the organic chemistry course in the *2010 Mississippi Science Framework*. The polymer science curriculum focuses on ongoing and meaningful professional development for teachers as well as building relationships with industry. The curriculum is written in accordance with the 2006 Society of the Plastics Industry Standards. Lastly, students will be assessed using the Mississippi Career Planning and Assessment System 3 (MS-CPAS3).

Curriculum Content

Summary of Standards

The standards to be included in the polymer science curriculum are the Society of the Plastics Industry Standards, 21st Century Skills, Common Core State Standards (CCSS), the National Educational Technology Standards (NETS) for Students, and the Mississippi Academic Framework Chemistry Standards. Combining these standards to create this document will result in highly skilled, well-rounded students who are prepared to enter postsecondary education or the workforce.

Industry Certifications

Two national certifications are associated with the polymer science industry, the Certified Composites Technician (CCT) and the National Certification in Plastics (NCP).

Academic Infusion

The polymer science curriculum integrates science, mathematics, and language arts to guide students as they learn about polymer science. Students apply mathematical processes to solve scientific problems such as creating compounds. Various literacy strategies are present in this curriculum to increase literacy and communication skills. This curriculum also integrates 21st century skills to prepare students for the 21st century workforce.

Transition to Postsecondary Education

The latest articulation information for secondary to postsecondary can be found at the Mississippi Community College Board (MCCB) website, mccb.edu.

Dual Enrollment

At the present time, there are no options for dual enrollment with polymer science.

Best Practices

Innovative Instructional Technologies

Recognizing that today's students are digital learners and the increasing role of technology is industry, the classroom should be equipped with tools using the latest technology to best prepare students for the workforce. The polymer science curriculum includes teaching strategies that incorporate current, state-of-the-art technology. Each classroom houses approximately 20 desktop student computers, one teacher laptop, an interactive white board, and a projector. Teachers are also encouraged to teach using a content delivery system that allows increased student access, lesson customization, and assessment and grading automation. Teachers are encouraged to use project-based instruction to increase problem-solving and 21st century skills and foster critical thinking.

Differentiated Instruction

Students learn in a variety of ways. Some are visual learners, needing only to read information and study it to succeed. Others are auditory learners, thriving best when information is read aloud to them. Still, others are tactile learners, needing to participate actively in learning experiences. Add the student's background, emotional health, and circumstances, and a very unique learner emerges. To address these issues, the polymer science curriculum is written to include several instructional methods designed to lead students to a deeper understanding of course material and provide them multiple opportunities to succeed in different ways. Many activities are graded by rubrics that allow students to choose the type of product they will produce. By providing various teaching and assessment strategies, students with various learning styles can succeed.

Career and Technical Education Student Organizations

At the current time, there are no state or national career and technical education student organizations that support the polymer science curriculum. The University of Southern Mississippi, however, has partnered with the secondary polymer science programs to host an annual student competition. For more information, please refer to the University of Southern Mississippi Polymer Science department, usm.edu/polymer.

~~**Conclusions**~~

~~Based on the previous information, the Mississippi polymer science curriculum will be filled with opportunities to teach and learn using current and relevant workplace technology. Literacy, mathematics, and science is embedded throughout this curriculum to prepare students for college and/or the workforce. Other widely used teaching strategies such as cooperative learning, problem-based learning, and demonstration will also be included to prepare students for the hands-on instruction they will likely receive upon entering the workforce.~~

Professional Organizations

Society of Plastics Engineers
4spe.org

SPI: The Plastics Industry Trade Association
plasticsindustry.org

Using This Document

Suggested Time on Task

This section indicates an estimated number of clock hours of instruction that should be required to teach the competencies and objectives of the unit. A minimum of 140 hours of instruction is required for each Carnegie unit credit. The curriculum framework should account for approximately 75–80% of the time in the course. The remaining percentage of class time will include instruction in non-tested material, review for end-of-course testing, and special projects.

Competencies and Suggested Objectives

A competency represents a general concept or performance that students are expected to master as a requirement for satisfactorily completing a unit. Students will be expected to receive instruction on all competencies. The suggested objectives represent the enabling and supporting knowledge and performances that will indicate mastery of the competency at the course level.

Integrated Academic Topics, 21st Century Skills and Information and Communication Technology Literacy Standards, ACT College Readiness Standards, and Technology Standards for Students

This section identifies related academic topics as required in the Subject Area Testing Program in Algebra I, Biology I, English II, and U.S. History from 1877, which are integrated into the content of the unit. Research-based teaching strategies also incorporate ACT College Readiness standards. This section also identifies the 21st Century Skills and Information and Communication Technology Literacy skills. In addition, national technology standards for students associated with the competencies and suggested objectives for the unit are also identified.

References

A list of suggested references is provided for each unit. The list includes some of the primary instructional resources that may be used to teach the competencies and suggested objectives. Again, these resources are suggested, and the list may be modified or enhanced based on needs and abilities of students and on available resources.

Unit 1: Orientation, Safety, and Information Media

Competencies and Suggested Objectives

1. Evaluate the local program and explore how personality traits and learning styles can impact success in the classroom and workplace. DOK1
   a. Examine the local student handbook and program, establishing rules and guidelines.
   b. Examine how understanding personality and learning styles can impact learning and workplace performance.
      - True Colors
      - Animal communications
      - Myers-Briggs
      - Learning styles inventories
      - Multiple intelligence assessments
   c. Describe student organizations (including SkillsUSA and Technology Student Association) activities and participate in a polymer skills competition.

2. Examine the history and development of the polymer and material science industries/professions. DOK1
   a. Trace the development of polymer and material science technologies/industries from beginning through present day (e.g., Materials Through the Ages timeline, polymer development timeline).
   b. Research and describe career opportunities, including educational requirements, earnings potential, etc. for polymer and materials related fields.

3. Describe and demonstrate safe laboratory practices and environmental responsibility when working with laboratory equipment, chemicals, and processing equipment commonly encountered in polymer-related industries. DOK2
   a. Apply safety rules/guidelines, colors, and symbols for the lab and workplace, and establish how to use safety equipment properly (e.g. Flinn safety test/contract).
   b. Investigate how industrial, governmental, and environmental organizations impact safe operations in polymer-related industries.
      - OSHA
      - EPA
      - CSB
      - ACS
      - ANSI
      - FDA
   c. Identify basic laboratory equipment and functions while correctly and safely using selected pieces of equipment.
   d. Detail safe practices related to the operation of equipment in polymer-related laboratories and manufacturing facilities.
      - Lockout tags

- Safety zones and floor markings
- Emergency stop buttons

e. Evaluate the resources available for the safe handling and disposal of chemicals.

- DOT placards
- NFTA safety diamond
- SDS documents

4. Demonstrate the ability to manage a computer operating system in relation to plastics and polymer applications. DOK2

a. Create files and transfer them between directories and subdirectories.

b. Produce and utilize graphics in relation to research for plastics design and production.

c. Produce quality word processing and multimedia documents related to polymer science topics.

d. Create an e-portfolio to include all relevant materials.

Note: All safety competencies and objectives are to be implemented throughout the course.

Unit 2: Recycling

Competencies and Suggested Objectives

1. Relate plastics recycling/conservation principles and their effects on the environment. DOK2,
   a. Classify the different types of plastics and their recycling codes.
      - PETE
      - HDPE
      - V
      - LDPE
      - PP
      - PS
      - Other plastics
   b. Research and describe the various sorting and recycling methods (e.g. primary, secondary, and tertiary recycling, or the three Rs).
   c. Debate the cost of using recycled polymers versus virgin polymers in manufacturing.
   d. Examine the human issues related to recycling for the different types of plastics, including e-waste and ocean pollution.

Enrichment:

1. Implement additive and subtractive techniques to repurpose or reuse recyclable materials.
2. Investigate recycling and repurposing strands within the maker, tinker, and/or fab movements.

Unit 3: Introduction to Chemistry

Competencies and Suggested Objectives

1. Apply inquiry-based and problem-solving processes and skills to scientific investigations. DOK3
   a. Use current technologies to explore current research related to a specific topic.
   b. Clarify research questions and design laboratory investigations.
   c. Demonstrate the use of scientific inquiry and methods to formulate, conduct, and evaluate laboratory investigations.
      - Hypothesis
      - Experimental design
      - Observations
      - Data analyses
      - Interpretations
      - Theory development
   d. Organize data to construct graphs (e.g., plot points, label the x- and y-axis, and create appropriate titles and legends for circle, bar, and line graphs), draw conclusions, and make inferences.
   e. Evaluate the procedures, data, and conclusions to critique the scientific validity of research.
   f. Formulate and revise scientific explanations and models using logic and evidence (data analysis).
   g. Collect, analyze, and draw conclusions from data to create a formal presentation using available technology (e.g., computers, calculators, Smart Board, computer-based learning's, lab interfaces, etc.).

Note: This competency should be implemented throughout the entire course.

2. Demonstrate an understanding of the atomic model of matter by explaining atomic structure. DOK2
   a. Describe and classify matter based on physical and chemical properties and the interactions between molecules of atoms (e.g., Classify properties such as boiling point, melting point, density, mass, volume, flammability, etc. as being physical or chemical; and describe each state of matter in terms of internal energy, molecular motion, and the phase transitions within and between them.).
   b. Classify matter as pure substances or mixtures, including homogeneous and heterogeneous mixtures and solution saturations, and investigate the conditions that impact mixture formation and stability (e.g., heat, agitation, solute-solvent compatibility, etc.).
   c. Develop a model of atomic and nuclear structure based on theory and knowledge of the fundamental particles including protons, neutrons, and electrons.
   d. Describe the properties and interactions of the three fundamental particles of the atom and explain the laws of conservation of mass, constant composition, definite proportions, and multiple proportions.
   e. Use atomic numbers and mass numbers to calculate the number of protons, neutrons, and electrons in individual isotopes and ions.

3. Develop an understanding of the periodic table. DOK2
   a. Analyze patterns and trends and make predictions regarding the organization of elements in the periodic table and compare their relationships to their positions in the table (e.g., atomic number, atomic mass, metal and non-metal character, electronegativity, and reactivity).
   b. Following the Aufbau principle, write electron configurations and Lewis diagrams of elements and ions.

4. Investigate the way the atomic structure and arrangement in matter impact bonding and chemical reaction. DOK2
   a. Use Lewis dot structures and periodic trends to predict and draw compound structures and formulas.
   b. Compare the properties of compounds according to their types of bonding, including metallic, ionic, and covalent bonding (e.g., non-polar and polar covalent bonds, single and multiple bonds [double and triple], and intermolecular forces including hydrogen bonding and van der Waals forces).
   c. Classify reactions by type (synthesis, decomposition, single displacement, double displacement, combustion, and redox reactions), and identify reactants and the products involved in reaction, explaining how the electrons of reacting species interact to make these changes possible.
   d. Balance equations for chemical reactions, representing the connection between the microscopic (particles) and macroscopic (moles and bulk properties) levels of matter.

5. Identify common organic molecules and relate their structures to chemical and physical properties. DOK3
   a. Construct models and illustrate structures for aliphatic, aromatic, and cyclic hydrocarbons, applying prior bonding knowledge.
   b. Apply IUPAC nomenclature for simple organic structures and derivatives (i.e., functional groups such as alcohols, amines, aldehydes, ketones, carboxylic acids, esters, amides, ethers, etc.).
   c. Describe how functional groups affect properties for simple organic molecules.

Enrichment:

1. Research and explain the critical contributions and experiments of John Dalton, J. J. Thomson, Robert Millikan, Ernest Rutherford, Louis de Broglie, Erwin Schrödinger, and others in order to describe how each discovery contributed to the current model of atomic and nuclear structure.
2. Discuss the development of the periodic table and the contributions of Johannes Döbereiner, John Newlands, Dmitri Mendeleev, Henry Mosely, etc.
3. Use Lewis structures to predict molecular geometries (shapes and bond angles), polarities, hybridization, and intermolecular forces.
4. Using given reactants, predict possible reaction products.
5. Write and classify common reactions for aliphatic, aromatic, and cyclic hydrocarbons.

Unit 4: Chemistry of Polymers

Competencies and Suggested Objectives

1. Relate small molecule chemistry to the production of polymers compounds. DOK3
   - Polyethylene
   - Polypropylene
   - Polystyrene
   - Polytetrafluoroethylene
   - Polyvinyl chloride
   - Polyvinyl alcohol
   - Polyvinyl acetate
   - Polymethyl methacrylate
   - Polybutadiene
   - Families of compounds such as polyamides, polyurethanes, and polyesters

   a. Using models, demonstrate the structure of monomers.

   b. Using models, demonstrate the structure and synthesis of homopolymers.

   c. Using models, demonstrate the structure and synthesis of various types of copolymers and terpolymers.

2. Recognize and differentiate natural and synthetic polymers. DOK2

   a. Describe natural polymers.
      - Cellulose
      - DNA/RNA
      - Natural rubber
      - Starches
      - Proteins

   b. Describe synthetic polymers.
      - Plastics
      - Thermoplastics
      - Thermosets
      - Fiber
      - Films
      - Elastomers
      - Adhesives

   c. Differentiate between the properties of natural and synthetic polymers, including polydispersity, degree of polymerization, and molecular weight.

3. Explore how the chemistry of polymer preparation affects performance properties. DOK2

   a. Describe and demonstrate different types of polymer syntheses to include condensation and addition polymerization.

   b. Communicate the relationship that exists between polymerization type (step-growth and chain-growth) and graphical representations of growth rates.

c. Explore the effects of molecular weight, molecular weight distribution, branching, tacticity, and cross-linking on polymer properties.
4. Relate rheology and viscosity to polymer properties and processing. DOK2 a. Explain the importance of rheology and viscosity. b. Demonstrate polymer melt rheology.
Enrichment: 1. Research the history of rheology and viscosity.

Unit 5: Introduction to Polymer Processing

Competencies and Suggested Objectives
1. Explain how basic manufacturing techniques are used to convert polymer feedstock into plastic products, and manufacture plastic parts using each processing technique. DOK4 a. Describe and demonstrate single-step polymer processing techniques. • Extrusion • Injection molding • Thermoforming/vacuum-forming • Rotational molding • Open- and closed-cell foam processing • Fiber formation
2. Identify acceptable and unacceptable products for each single-step processing technique. DOK1 a. Identify short-shots, flashing, and warped parts. b. Troubleshoot various processing techniques to create good parts.
3. Apply the principles of computer-aided design and drafting (CADD) to create designs and prototypes for plastic parts. DOK3 a. Interpret and apply basic CADD symbols to create, edit, and print parts and drawings in preparation for making plastic parts. b. Demonstrate the importance of wall thickness, draft angles, ribs, fillets, and rounds in part design. c. Design, create, edit, and produce a rapid prototyped part from 2-D and 3-D prints/plots according to specifications. d. Compare and contrast additive and subtractive 2-D and 3-D manufacturing techniques in making quality parts.
Enrichment: 1. Demonstrate the ability to read and interpret a basic blueprint. a. Demonstrate the ability to read the various parts of a blueprint. b. Demonstrate the ability to interpret the different views of a blueprint.

Unit 6: Polymer Safety and Concepts Review

Competencies and Suggested Objectives
1. Re-evaluate the local program and explore how personality traits and learning styles can impact success in the classroom and workplace. DOK1 a. Re-examine the local student handbook and program, establishing rules and guidelines. b. Re-examine how understanding personality and learning styles can impact learning and workplace performance, such as True Colors, animal communications, Meyers-Briggs, learning styles inventories, multiple intelligence assessments, etc. c. Describe student organizations (including SkillsUSA and TSA) activities and participate in a polymer skills competition.
2. Describe and demonstrate safe laboratory practices and environmental responsibility when working with laboratory equipment, chemicals, and processing equipment commonly encountered in polymer-related industries. DOK2 a. Apply safety rules/guidelines, colors, and symbols for the lab and workplace and establish how to use safety equipment properly (e.g., Flinn safety test/contract). b. Investigate how industrial, governmental, and environmental organizations impact safe operations in polymer-related industries (e.g., OSHA, EPA, CSB, ACS, ANSI, FDA, etc.). c. Identify basic laboratory equipment and functions while correctly and safely using selected pieces of equipment. d. Detail safe practices related to the operation of equipment in polymer-related laboratories and manufacturing facilities (e.g., lockout tags, safety zones and floor markings, emergency stop buttons, etc.). e. Evaluate resources available for safe handling and disposal of chemicals (e.g., DOT placards, NFTA safety diamond, SDS documents).

Unit 7: Advanced Polymer Processing

Competencies and Suggested Objectives
1. Explain how additives affect the properties of a polymeric material. DOK2 a. Explain how compounding and formulation changes the properties and processing of polymers by using additives or modifiers.
2. Explain how advanced or multi-step manufacturing techniques are used to convert polymer feedstock into plastic products, and manufacture plastic parts using each processing technique. DOK3 a. Describe and demonstrate advanced manufacturing processes. • Blow molding (extrusion and injection) • Blown film extrusion • Casting • Expanded bead molding • Dip coating • Calendering • Compression molding
3. Differentiate between acceptable and unacceptable products for each advanced processing technique. DOK3 a. Troubleshoot the various processing techniques to create good parts.

Unit 8: Materials Science

Competencies and Suggested Objectives
1. Demonstrate a foundational understanding of the properties and processing for metals and related materials. DOK3 a. Analyze the properties of metals as compared to other materials, including alloys, ceramics, and composites. b. Assess the importance of, describe the processes used, and apply various methods of reduction to obtain metals from their ores as it pertains to industrial metals production. c. Relate the macroscopic properties of metallic substances to crystalline metal microstructures. d. Perform conditioning processes to harden, temper, and anneal metal.
2. Demonstrate a foundational understanding of the properties and processing for ceramics and related materials. DOK3 a. Analyze the relationship between the metallic ores, metals, and ceramic materials arising from the oxidation of metallic materials. b. Assess how chemical bonding and the observable properties of ceramic materials give rise to a wide variety of ceramic uses in our society. c. Analyze the amorphous structure and properties of glass (also known as the special ceramic). d. Examine and perform ceramic processing techniques, including Raku.
Enrichment: 1. Use materials testing to analyze the macroscopic properties of metals and other materials that arise from processing and work hardening stresses. 2. Examine and demonstrate glass batching and other glass processing techniques.

Unit 9: Surface Coatings

Competencies and Suggested Objectives
1. Describe the production of various types of surface coatings. DOK2 a. Differentiate between the types of coatings (e.g., architectural [DIY], OEM [original equipment manufacturer], and specialty purpose coatings), their properties, and their uses in industry. b. Research and communicate the development of coatings through the years, including binder type advancements (from drying oils through high solids coatings). c. Illustrate the synthesis of waterborne binders for surface coatings (i.e., emulsions). d. Identify legislation that influences the push for low to no VOC coatings and discuss industry responses.
2. Demonstrate the properties of coatings. DOK3 a. Expand understanding of the use of additives with regards to coatings formulations to influence performance properties. b. Evaluate application suitability of surface coatings using various properties (e.g., impact, adhesion, hardness, flexibility, etc.).

Unit 10: Composite Materials, Processing, and Applications

Competencies and Suggested Objectives
1. Examine composite materials and their configurations in final parts to determine how each affects the finished properties of a composite structure. DOK2 a. Evaluate possible matrix and reinforcement materials in terms of chemistries and forms (e.g., particulate, fiber-reinforced, or laminar). b. Assess how composite performance is influenced by various structural configurations of reinforcements (e.g., stressed skin, oriented fibers, tubes vs. rods, etc.).
2. Investigate different composite processing methods and composite applications. DOK3 a. Research and communicate how advanced needs and technologies have influenced the development of composites materials and processing (e.g. Portland cement, aerocrete, fiberoptic concrete, aerogels, plywood, glulam, particle board, carbon fiber, and graphene). b. Evaluate various composites processing techniques (e.g., hand lay-up, spray lay-up, VARTM, vacuum bagging, filament winding, pultrusion, etc.), emphasizing their influences on finished products.

Unit 11: School to Work

Competencies and Suggested Objectives

1. Explain and demonstrate employability skills over the course of the program. DOK3
   a. Perform a self-evaluation and compare it to traits of a quality employee (e.g., integrity, loyalty, responsibility, etc.).
   b. Create an educational and/or career-track plan for a selected job in materials science.
   c. Prepare a résumé containing essential information for polymer specific careers.
   d. Complete a job application.
   e. Describe and demonstrate the procedures for a job interview.
   f. Explain personnel law, requirements of Title IX law, and employment procedures as related to plastics and polymer manufacturing.

2. Explain and demonstrate the role human relations, teamwork, and leadership play in plastics and polymer manufacturing. DOK2
   a. Describe and practice the qualities of an effective leader (i.e., positive attitude, image, decisiveness, communication skills, and being knowledgeable).
   b. Prepare a project management methodology and use it consistently.
   c. Research and/or participate in personal development seminars, leadership conferences, and national/international exchange programs, or research/participate in student organizations, competitions, and related activities.

Enrichment:

1. Apply the skills needed to be a viable member of the workforce. DOK4
   a. Prepare a description of and demonstrate the technical skills to be developed in the supervised work experience program.
   b. Demonstrate human relationship skills in the supervised work experience program.
2. Work with an instructor and/or employer to develop, assess, and document the performance of written occupational objectives to be accomplished during a polymer-related internship and/or simulated polymer industry. DOK3
   a. Develop and follow a set of written guidelines for the supervised work experience program.
   b. Perform written occupational objectives in the supervised work experience program.
   c. Prepare a daily written assessment of the accomplishment of the objectives.
   d. Present weekly written reports of activities performed and objectives accomplished to the instructor.
   e. Prepare and finalize an electronic portfolio to include all relevant materials.

Student Competency Profile

Student's Name: _____

This record is intended to serve as a method of noting student achievement of the competencies in each unit. It can be duplicated for each student, and it can serve as a cumulative record of competencies achieved in the course.

In the blank before each competency, place the date on which the student mastered the competency.

Unit 1: Orientation, Safety, and Information Media		
	1.	Evaluate the local program and explore how personality traits and learning styles can impact success in the classroom and workplace.
	2.	Examine the history and development of the polymer and material science industries/professions.
	3.	Describe and demonstrate safe laboratory practices and environmental responsibility when working with laboratory equipment, chemicals, and processing equipment commonly encountered in polymer-related industries.
	4.	Demonstrate the ability to manage a computer operating system in relation to plastics and polymer applications.
Unit 2: Recycling		
	1.	Relate plastics recycling/conservation principles and their effects on the environment.
Unit 3: Introduction to Chemistry		
	1.	Apply inquiry-based and problem-solving processes and skills to scientific investigations.
	2.	Demonstrate an understanding of the atomic model of matter by explaining atomic structure, its contributions to chemical structures, and chemical bonding.
	3.	Develop an understanding of the periodic table.
	4.	Investigate the compositions and properties of various mixtures and the conditions that impact mixture formation and stability.
	5.	Identify common organic molecules and relate their structures to chemical and physical properties.
Unit 4: Chemistry of Polymers		
	1.	Relate small molecule chemistry to the production of polymers (e.g., compounds such as polyethylene, polypropylene, polystyrene, polytetrafluoroethylene, polyvinyl chloride, polyvinyl alcohol, polyvinyl acetate, polymethyl methacrylate, polybutadiene, or families of compounds such as polyamides, polyurethanes, and polyesters).
	2.	Recognize and differentiate natural and synthetic polymers.

	3.	Explore how the chemistry of polymer preparation affects performance properties.
	4.	Relate rheology and viscosity to polymer properties and processing.
Unit 5: Introduction to Polymer Processing		
	1.	Explain how basic manufacturing techniques are used to convert polymer feedstock into plastic products, and manufacture plastic parts using each processing technique.
	2.	Identify acceptable and unacceptable products for each single-step processing technique.
	3.	Apply the principles of computer-aided design and drafting (CADD) to create designs and prototypes of plastic parts.
Unit 6: Polymer Safety and Concepts Review		
	1.	Re-evaluate the local program and explore how personality traits and learning styles can impact success in the classroom and workplace.
	2.	Describe and demonstrate safe laboratory practices and environmental responsibility working with laboratory equipment, chemicals, and processing equipment commonly encountered in polymer-related industries.
Unit 7: Advanced Polymer Processing		
	1.	Explain how additives affect the properties of a polymeric material.
	2.	Explain how advanced or multi-step manufacturing techniques are used to convert polymer feedstock into plastic products, and manufacture plastic parts using each processing technique.
	3.	Differentiate between acceptable and unacceptable products for each advanced processing technique.
Unit 8: Materials Science		
	1.	Demonstrate a foundational understanding of materials science and materials processing for the four major classes of materials (metals, ceramics, polymers, and composites).
	2.	Analyze the relationship between metallic ores, metals, and the ceramic materials arising from the oxidation of metallic material.
Unit 9: Surface Coatings		
	1.	Describe the production of various types of surface coatings.
	2.	Demonstrate the properties of coatings.
Unit 10: Composite Materials, Processing, and Applications		
	1.	Examine composite materials to determine how such materials affect the finished properties of a composite structure.
	2.	Demonstrate different composite processing methods and composite applications.

~~Unit 11: School to Work~~		
	~~1.~~	~~Explain and demonstrate the role human relations, teamwork, and leadership play in plastics and polymer manufacturing.~~
	~~2.~~	~~Explain and demonstrate employability skills over the course of the program.~~

Appendix A: Industry Standards

Society of the Plastics Industry Standards

Crosswalk for Polymer Science												
	Units	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11
SPI-I. Essential Knowledge		*	*	*	*	*	*	*	*	*	*	*
SPI-II. Extrusion Process					*	*		*	*			
SPI-III. Major Components of the Injection Molding Process						*		*				
SPI-IV. Material and Product Handling/Storage		*	*		*		*			*		
SPI-V. Measurement, Analysis, and Response			*							*		
SPI-VI. Safety Components		*					*					

Appendix B: 21st Century Skills[1]

21st Century Crosswalk for Polymer Science												
	Units	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11
21st Century Standards												
CS1		*	*				*					*
CS2			*									*
CS3			*									*
CS4			*	*	*	*		*	*	*	*	
CS5			*	*	*	*		*	*	*	*	
CS6												*
CS7			*	*	*	*		*	*	*	*	*
CS8												*
CS9		*					*					*
CS10		*					*					*
CS11		*					*					*
CS12		*					*					*
CS13		*	*				*					*
CS14		*	*				*					*
CS15				*	*	*		*	*	*	*	*
CS16		*	*				*					*

CSS1 21st Century Themes

CS1 Global Awareness

1. Using 21st century skills to understand and address global issues
2. Learning from and working collaboratively with individuals representing diverse cultures, religions, and lifestyles in a spirit of mutual respect and open dialogue in personal, work, and community contexts
3. Understanding other nations and cultures, including the use of non-English languages

CS2 Financial, Economic, Business, and Entrepreneurial Literacy

1. Knowing how to make appropriate personal economic choices
2. Understanding the role of the economy in society
3. Using entrepreneurial skills to enhance workplace productivity and career options

CS3 Civic Literacy

1. Participating effectively in civic life through knowing how to stay informed and understanding governmental processes
2. Exercising the rights and obligations of citizenship at local, state, national, and global levels
3. Understanding the local and global implications of civic decisions

CS4 Health Literacy

1. Obtaining, interpreting, and understanding basic health information and services and using such information and services in ways that enhance health

[1] *21st century skills.* (n.d.). Washington, DC: Partnership for 21st Century Skills.

2. Understanding preventive physical and mental health measures, including proper diet, nutrition, exercise, risk avoidance, and stress reduction
3. Using available information to make appropriate health-related decisions
4. Establishing and monitoring personal and family health goals
5. Understanding national and international public health and safety issues

CS5 Environmental Literacy

1. Demonstrate knowledge and understanding of the environment and the circumstances and conditions affecting it, particularly as relates to air, climate, land, food, energy, water, and ecosystems.
2. Demonstrate knowledge and understanding of society's impact on the natural world (e.g., population growth, population development, resource consumption rate, etc.).
3. Investigate and analyze environmental issues, and make accurate conclusions about effective solutions.
4. Take individual and collective action toward addressing environmental challenges (e.g., participating in global actions, designing solutions that inspire action on environmental issues).

CSS2 Learning and Innovation Skills

CS6 Creativity and Innovation

1. Think Creatively
2. Work Creatively with Others
3. Implement Innovations

CS7 Critical Thinking and Problem Solving

1. Reason Effectively
2. Use Systems Thinking
3. Make Judgments and Decisions
4. Solve Problems

CS8 Communication and Collaboration

1. Communicate Clearly
2. Collaborate with Others

CSS3 Information, Media and Technology Skills

CS9 Information Literacy

1. Access and Evaluate Information
2. Use and Manage Information

CS10 Media Literacy

1. Analyze Media
2. Create Media Products

CS11 ICT Literacy

1. Apply Technology Effectively

CSS4 Life and Career Skills

CS12 Flexibility and Adaptability

1. Adapt to change
2. Be Flexible

~~**CS13 Initiative and Self-Direction**~~

1. ~~Manage Goals and Time~~
2. ~~Work Independently~~
3. ~~Be Self-directed Learners~~

~~**CS14 Social and Cross-Cultural Skills**~~

1. ~~Interact Effectively with others~~
2. ~~Work Effectively in Diverse Teams~~

~~**CS15 Productivity and Accountability**~~

1. ~~Manage Projects~~
2. ~~Produce Results~~

~~**CS16 Leadership and Responsibility**~~

1. ~~Guide and Lead Others~~
2. ~~Be Responsible to Others~~

Appendix C: College and Career Readiness Standards

Reading Standards for Literature (11-12)
College and Career Readiness Anchor Standards for *Reading Literature*
Key Ideas and Details

RL.11.1. Cite strong and thorough textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text, including determining where the text leaves matters uncertain.

RL.11.2. Determine two or more themes or central ideas of a text and analyze their development over the course of the text, including how they interact and build on one another to produce a complex account; provide an objective summary of the text.

RL.11.3. Analyze the impact of the author's choices regarding how to develop and relate elements of a story or drama (e.g., where a story is set, how the action is ordered, how the characters are introduced and developed).

Craft and Structure

RL.11.4. Determine the meaning of words and phrases as they are used in the text, including figurative and connotative meanings; analyze the impact of specific word choices on meaning and tone, including words with multiple meanings or language that is particularly fresh, engaging, or beautiful. (Include Shakespeare as well as other authors.)

RL.11.5. Analyze how an author's choices concerning how to structure specific parts of a text (e.g., the choice of where to begin or end a story, the choice to provide a comedic or tragic resolution) contribute to its overall structure and meaning as well as its aesthetic impact.

RL.11.6. Analyze a case in which grasping point of view requires distinguishing what is directly stated in a text from what is really meant (e.g., satire, sarcasm, irony, or understatement).

Integration of Knowledge and Ideas

RL.11.7. Analyze multiple interpretations of a story, drama, or poem (e.g., recorded or live production of a play or recorded novel or poetry), evaluating how each version interprets the source text. (Include at least one play by Shakespeare and one play by an American dramatist.)

RL.11.8. (Not applicable to literature)

RL.11.9. Demonstrate knowledge of eighteenth-, nineteenth- and early-twentieth-century foundational works of American literature, including how two or more texts from the same period treat similar themes or topics.

Range of Reading and Level of Text Complexity

RL.11.10. By the end of grade 11, read and comprehend literature, including stories, dramas, and poems, in the grades 11–CCR text complexity band proficiently, with scaffolding as needed at the high end of the range.
By the end of grade 12, read and comprehend literature, including stories, dramas, and poems, at the high end of the grades 11–CCR text complexity band independently and proficiently.

Reading Standards for Informational Text (11-12)
College and Career Readiness Anchor Standards for *Informational Text*

Key Ideas and Details

RI.11.1. Cite strong and thorough textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text, including determining where the text leaves matters uncertain.

RI.11.2. Determine two or more central ideas of a text and analyze their development over the course of the text, including how they interact and build on one another to provide a complex analysis; provide an objective summary of the text.

RI.11.3. Analyze a complex set of ideas or sequence of events and explain how specific individuals, ideas, or events interact and develop over the course of the text.

Craft and Structure

RI.11.4. Determine the meaning of words and phrases as they are used in a text, including figurative, connotative, and technical meanings; analyze how an author uses and refines the meaning of a key term or terms over the course of a text (e.g., how Madison defines faction in Federalist No. 10).

RI.11.5. Analyze and evaluate the effectiveness of the structure an author uses in his or her exposition or argument, including whether the structure makes points clear, convincing, and engaging.
RI.11.6. Determine an author's point of view or purpose in a text in which the rhetoric is particularly effective, analyzing how style and content contribute to the power, persuasiveness, or beauty of the text.

Integration of Knowledge and Ideas

RI.11.7. Integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a question or solve a problem.

RI.11.8. Delineate and evaluate the reasoning in seminal U.S. texts, including the application of constitutional principles and use of legal reasoning (e.g., in U.S. Supreme Court majority

opinions and dissents) and the premises, purposes, and arguments in works of public advocacy (e.g., The Federalist, presidential addresses).

RI.11.9. Analyze seventeenth-, eighteenth-, and nineteenth-century foundational U.S. documents of historical and literary significance (including The Declaration of Independence, the Preamble to the Constitution, the Bill of Rights, and Lincoln's Second Inaugural Address) for their themes, purposes, and rhetorical features.

Range of Reading and Level of Text Complexity

RI.11.10. By the end of grade 11, read and comprehend literary nonfiction in the grades 11–CCR text complexity band proficiently, with scaffolding as needed at the high end of the range.

By the end of grade 12, read and comprehend literary nonfiction at the high end of the grades 11–CCR text complexity band independently and proficiently.
College and Career Readiness Anchor Standards for *Writing*

Text Types and Purposes

W.11.1. Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.

a. Introduce precise, knowledgeable claim(s), establish the significance of the claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that logically sequences claim(s), counterclaims, reasons, and evidence.

b. Develop claim(s) and counterclaims fairly and thoroughly, supplying the most relevant evidence for each while pointing out the strengths and limitations of both in a manner that anticipates the audience's knowledge level, concerns, values, and possible biases.

c. Use words, phrases, and clauses as well as varied syntax to link the major sections of the text, create cohesion, and clarify the relationships between claim(s) and reasons, between reasons and evidence, and between claim(s) and counterclaims.

d. Establish and maintain a formal style and objective tone while attending to the norms and conventions of the discipline in which they are writing.

e. Provide a concluding statement or section that follows from and supports the argument presented.

W.11.2. Write informative/explanatory texts to examine and convey complex ideas, concepts, and information clearly and accurately through the effective selection, organization, and analysis of content.

a. Introduce a topic; organize complex ideas, concepts, and information so that each new element

builds on that which precedes it to create a unified whole; include formatting (e.g., headings), graphics (e.g., figures, tables), and multimedia when useful to aiding comprehension.

b. Develop the topic thoroughly by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples appropriate to the audience's knowledge of the topic.

c. Use appropriate and varied transitions and syntax to link the major sections of the text, create cohesion, and clarify the relationships among complex ideas and concepts.

d. Use precise language, domain-specific vocabulary, and techniques such as metaphor, simile, and analogy to manage the complexity of the topic.

e. Establish and maintain a formal style and objective tone while attending to the norms and conventions of the discipline in which they are writing.

f. Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).

W.11.3. Write narratives to develop real or imagined experiences or events using effective technique, well-chosen details, and well-structured event sequences.

a. Engage and orient the reader by setting out a problem, situation, or observation and its significance, establishing one or multiple point(s) of view, and introducing a narrator and/or characters; create a smooth progression of experiences or events.

b. Use narrative techniques, such as dialogue, pacing, description, reflection, and multiple plot lines, to develop experiences, events, and/or characters

c. Use a variety of techniques to sequence events so that they build on one another to create a coherent whole and build toward a particular tone and outcome (e.g., a sense of mystery, suspense, growth, or resolution).

d. Use precise words and phrases, telling details, and sensory language to convey a vivid picture of the experiences, events, setting, and/or characters.

e. Provide a conclusion that follows from and reflects on what is experienced, observed, or resolved over the course of the narrative.

Production and Distribution of Writing

W.11.4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. (Grade-specific expectations for writing types are defined in standards 1–3 above.)

W.11.5. Develop and strengthen writing as needed by planning, revising, editing, rewriting, or

trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. (Editing for conventions should demonstrate command of Language standards 1–3 up to and including grades 11–12 on page 54.)

W.11.6. Use technology, including the Internet, to produce, publish, and update individual or shared writing products in response to ongoing feedback, including new arguments or information.

Research to Build and Present Knowledge

W.11.7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

W.11.8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

W.11.9. Draw evidence from literary or informational texts to support analysis, reflection, and research.

a. Apply grades 11–12 Reading standards to literature (e.g., "Demonstrate knowledge of eighteenth-, nineteenth- and early-twentieth-century foundational works of American literature, including how two or more texts from the same period treat similar themes or topics").

b. Apply grades 11–12 Reading standards to literary nonfiction (e.g., "Delineate and evaluate the reasoning in seminal U.S. texts, including the application of constitutional principles and use of legal reasoning [e.g., in U.S. Supreme Court Case majority opinions and dissents] and the premises, purposes, and arguments in works of public advocacy [e.g., The Federalist, presidential addresses]").

Range of Writing

W.11.10. Write routinely over extended time frames (time for research, reflection, and revision) and shorter time frames (a single sitting or a day or two) for a range of tasks, purposes, and audiences.

College and Career Readiness Anchor Standards for *Speaking and Listening*

Comprehension and Collaboration

SL.11.1. Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 11–12 topics, texts, and issues,

building on others' ideas and expressing their own clearly and persuasively.

a. Come to discussions prepared, having read and researched material under study; explicitly draw on that preparation by referring to evidence from texts and other research on the topic or issue to stimulate a thoughtful, well-reasoned exchange of ideas.

b. Work with peers to promote civil, democratic discussions and decision-making, set clear goals and deadlines, and establish individual roles as needed.

c. Propel conversations by posing and responding to questions that probe reasoning and evidence; ensure a hearing for a full range of positions on a topic or issue; clarify, verify, or challenge ideas and conclusions; and promote divergent and creative perspectives.

d. Respond thoughtfully to diverse perspectives; synthesize comments, claims, and evidence made on all sides of an issue; resolve contradictions when possible; and determine what additional information or research is required to deepen the investigation or complete the task.

SL.11.2. Integrate multiple sources of information presented in diverse formats and media (e.g., visually, quantitatively, orally) in order to make informed decisions and solve problems, evaluating the credibility and accuracy of each source and noting any discrepancies among the data.

SL.11.3. Evaluate a speaker's point of view, reasoning, and use of evidence and rhetoric, assessing the stance, premises, links among ideas, word choice, points of emphasis, and tone used.

Presentation of Knowledge and Ideas

SL.11.4. Present information, findings, and supporting evidence, conveying a clear and distinct perspective, such that listeners can follow the line of reasoning, alternative or opposing perspectives are addressed, and the organization, development, substance, and style are appropriate to purpose, audience, and a range of formal and informal tasks.

SL.11.5. Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

SL.11.6. Adapt speech to a variety of contexts and tasks, demonstrating a command of formal English when indicated or appropriate. (See grades 11–12 Language standards 1 and 3 on page 54 for specific expectations.)

College and Career Readiness Anchor Standards for *Language*

Conventions of Standard English

L.11.1. Demonstrate command of the conventions of standard English grammar and usage when

writing or speaking.

a. Apply the understanding that usage is a matter of convention, can change over time, and is sometimes contested.

b. Resolve issues of complex or contested usage, consulting references (e.g., Merriam-Webster's Dictionary of English Usage, Garner's Modern American Usage) as needed.

L.11.2. Demonstrate command of the conventions of standard English capitalization, punctuation, and spelling when writing.

a. Observe hyphenation conventions.

b. Spell correctly.

Knowledge of Language

L.11.3. Apply knowledge of language to understand how language functions in different contexts, to make effective choices for meaning or style, and to comprehend more fully when reading or listening.

a. Vary syntax for effect, consulting references (e.g., Tufte's Artful Sentences) for guidance as needed; apply an understanding of syntax to the study of complex texts when reading.

Vocabulary Acquisition and Use

L.11.4. Determine or clarify the meaning of unknown and multiple-meaning words and phrases based on grades 11–12 reading and content, choosing flexibly from a range of strategies.

a. Use context (e.g., the overall meaning of a sentence, paragraph, or text; a word's position or function in a sentence) as a clue to the meaning of a word or phrase.

b. Identify and correctly use patterns of word changes that indicate different meanings or parts of speech (e.g., conceive, conception, conceivable).

c. Consult general and specialized reference materials (e.g., dictionaries, glossaries, thesauruses), both print and digital, to find the pronunciation of a word or determine or clarify its precise meaning, its part of speech, its etymology, or its standard usage.

d. Verify the preliminary determination of the meaning of a word or phrase (e.g., by checking the inferred meaning in context or in a dictionary).

L.11.5. Demonstrate understanding of figurative language, word relationships, and nuances in word meanings.

a. Interpret figures of speech (e.g., hyperbole, paradox) in context and analyze their role in the

text.

b. Analyze nuances in the meaning of words with similar denotations.

L.11.6. Acquire and use accurately general academic and domain-specific words and phrases, sufficient for reading, writing, speaking, and listening at the college and career readiness level; demonstrate independence in gathering vocabulary knowledge when considering a word or phrase important to comprehension or expression.

Reading Standards for Literacy in History/Social Studies (11-12)

Key Ideas and Details

RH.11.1 Cite specific textual evidence to support analysis of primary and secondary sources, connecting insights gained from specific details to an understanding of the text as a whole.

RH.11.2. Determine the central ideas or information of a primary or secondary source; provide an accurate summary that makes clear the relationships among the key details and ideas

RH.11.3. Evaluate various explanations for actions or events and determine which explanation best accords with textual evidence, acknowledging where the text leaves matters uncertain

Craft and Structure

RH.11.4. Determine the meaning of words and phrases as they are used in a text, including analyzing how an author uses and refines the meaning of a key term over the course of a text (e.g., how Madison defines faction in Federalist No. 10).

RH.11.5. Analyze in detail how a complex primary source is structured, including how key sentences, paragraphs, and larger portions of the text contribute to the whole.

RH.11.6. Evaluate authors' differing points of view on the same historical event or issue by assessing the authors' claims, reasoning, and evidence.

Integration of Knowledge and Ideas

RH.11.7. Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., visually, quantitatively, as well as in words) in order to address a question or solve a problem.

RH.11.8. Evaluate an author's premises, claims, and evidence by corroborating or challenging them with other information.

RH.11.9. Integrate information from diverse sources, both primary and secondary, into a coherent understanding of an idea or event, noting discrepancies among sources.

Range of Reading and Level of Text Complexity

RH.11.10. By the end of grade 12, read and comprehend history/social studies texts in the grades 11–CCR text complexity band independently and proficiently.

Reading Standards for Literacy in Science and Technical Subjects (11-12)

Key Ideas and Details

RST.11.1. Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

RST.11.2. Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

RST.11.3. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

Craft and Structure

RST.11.4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11–12 texts and topics.

RST.11.5. Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas.

RST.11.6. Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.

Integration of Knowledge and Ideas

RST.11.7. Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

RST.11.8. Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

RST.11.9. Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Range of Reading and Level of Text Complexity

RST.11.10. By the end of grade 12, read and comprehend science/technical texts in the grades 11–CCR text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects (11-12)

Text Types and Purposes

WHST.11.1. Write arguments focused on discipline-specific content.

a. Introduce precise, knowledgeable claim(s), establish the significance of the claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that logically sequences the claim(s), counterclaims, reasons, and evidence.

b. Develop claim(s) and counterclaims fairly and thoroughly, supplying the most relevant data and evidence for each while pointing out the strengths and limitations of both claim(s) and counterclaims in a discipline-appropriate form that anticipates the audience's knowledge level, concerns, values, and possible biases.

c. Use words, phrases, and clauses as well as varied syntax to link the major sections of the text, create cohesion, and clarify the relationships between claim(s) and reasons, between reasons and evidence, and between claim(s) and counterclaims.

d. Establish and maintain a formal style and objective tone while attending to the norms and conventions of the discipline in which they are writing.

e. Provide a concluding statement or section that follows from or supports the argument presented.

ST.11.2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
a. Introduce a topic and organize complex ideas, concepts, and information so that each new element builds on that which precedes it to create a unified whole; include formatting (e.g., headings), graphics (e.g., figures, tables), and multimedia when useful to aiding comprehension.

b. Develop the topic thoroughly by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples appropriate to the audience's knowledge of the topic.

c. Use varied transitions and sentence structures to link the major sections of the text, create cohesion, and clarify the relationships among complex ideas and concepts.

d. Use precise language, domain-specific vocabulary and techniques such as metaphor, simile,

and analogy to manage the complexity of the topic; convey a knowledgeable stance in a style that responds to the discipline and context as well as to the expertise of likely readers.

e. Provide a concluding statement or section that follows from and supports the information or explanation provided (e.g., articulating implications or the significance of the topic).

WHST.11.3. (Not applicable as a separate requirement)

Production and Distribution of Writing

WHST.11.4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

WHST.11.5. Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.

WHST.11.6. Use technology, including the Internet, to produce, publish, and update individual or shared writing products in response to ongoing feedback, including new arguments or information.

Research to Build and Present Knowledge

WHST.11.7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

WHST.11.8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

WHST.11.9. Draw evidence from informational texts to support analysis, reflection, and research.

Range of Writing

WHST.11.10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

College and Career Readiness Standards for Mathematics Crosswalk for Polymer Science

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11
CCR Math Standards											
N-Q.1		x	x	x	x		x	x	x	x	
N-Q.2		x	x	x	x		x	x	x	x	
N-Q.3		x	x	x	x		x	x	x	x	
N-VM.1			x	x	x		x			x	
N-VM.3			x		x		x			x	
N-VM.4			x		x		x			x	
A-SSE.1			x	x	x		x	x	x	x	
A-SSE.2			x	x	x		x	x	x	x	
A-CED.1			x	x						x	
A-CED.4			x	x	x		x	x		x	
A-REI.1			x	x	x		x	x	x	x	
A-REI.2			x	x	x		x	x	x	x	
A-REI.3			x	x	x		x	x	x	x	
F-IF.4			x	x	x		x	x		x	
F-IF.5			x	x	x		x	x		x	
F-IF.6			x	x	x		x	x		x	
F-IF.7			x	x	x		x	x		x	
F-LE.1			x	x	x		x	x		x	
F-LE.3			x	x	x		x	x		x	
G-CO.1	x		x	x	x						
G-CO.2	x		x		x						
G-CO.3	x		x		x						
G-CO.4	x		x		x						
G-CO.5	x		x		x						
G-SRT.5	x		x	x	x						
G-GMD.3	x		x		x		x	x		x	
G-GMD.4	x		x	x	x		x	x		x	
G-MG.1			x	x	x		x	x		x	
G-MG.2			x	x	x		x	x		x	
G-MG.3			x	x	x		x	x		x	
S-ID.1			x	x				x		x	
S-ID.2			x	x				x		x	
S-ID.3			x	x				x		x	
S-ID.4				x				x			
S-IC.5			x	x				x	x	x	
S-IC.6			x	x				x	x	x	

Mathematics (High School)

Number and Quantity

The Real Number System

N-RN.1. Explain how the definition of the meaning of rational exponents follows from extending the properties of integer exponents to those values, allowing for a notation for radicals in terms of rational exponents.

N-RN.2. Rewrite expressions involving radicals and rational exponents using the properties of exponents.

N-RN.3. Explain why the sum or product of two rational numbers is rational; that the sum of a rational number and an irrational number is irrational; and that the product of a nonzero rational number and an irrational number is irrational.

Quantities

N-Q.1. Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

N-Q.2. Define appropriate quantities for the purpose of descriptive modeling.

N-Q.3. Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

The Complex Number System

N-CN.1. Know there is a complex number i such that $i^2 = -1$, and every complex number has the form a + bi with a and b real.

N-CN.2. Use the relation $i^2 = -1$ and the commutative, associative, and distributive properties to add, subtract, and multiply complex numbers.

N-CN.3. (+) Find the conjugate of a complex number; use conjugates to find moduli and quotients of complex numbers.

N-CN.4. (+) Represent complex numbers on the complex plane in rectangular and polar form (including real and imaginary numbers), and explain why the rectangular and polar forms of a given complex number represent the same number.

N-CN.5. (+) Represent addition, subtraction, multiplication, and conjugation of complex numbers geometrically on the complex plane; use properties of this representation for

~~computation. For example, (−1 + √3 i)3= 8 because (−1 + √3 i) has modulus 2 and argument 120°.~~

~~N-CN.6. (+) Calculate the distance between numbers in the complex plane as the modulus of the difference, and the midpoint of a segment as the average of the numbers at its endpoints.~~

~~N-CN.7. Solve quadratic equations with real coefficients that have complex solutions.~~

~~N-CN.8. (+) Extend polynomial identities to the complex numbers. For example, rewrite x2+ 4 as (x + 2i)(x − 2i).~~

~~N-CN.9. (+) Know the Fundamental Theorem of Algebra; show that it is true for quadratic polynomials.~~

~~Vector and Matrix Quantities~~

~~N-VM.1. (+) Recognize vector quantities as having both magnitude and direction. Represent vector quantities by directed line segments, and use appropriate symbols for vectors and their magnitudes (e.g., v, |v|, ||v||, v).~~

~~N-VM.2. (+) Find the components of a vector by subtracting the coordinates of an initial point from the coordinates of a terminal point.~~

~~N-VM.3. (+) Solve problems involving velocity and other quantities that can be represented by vectors.~~

~~N-VM.4. (+) Add and subtract vectors~~

~~N-VM.4.a. Add vectors end-to-end, component-wise, and by the parallelogram rule. Understand that the magnitude of a sum of two vectors is typically not the sum of the magnitudes.~~

~~N-VM.4.b. Given two vectors in magnitude and direction form, determine the magnitude and direction of their sum.~~

~~N-VM.4.c. Understand vector subtraction v − w as v + (−w), where −w is the additive inverse of w, with the same magnitude as w and pointing in the opposite direction. Represent vector subtraction graphically by connecting the tips in the appropriate order, and perform vector subtraction component-wise.~~

~~N-VM.5. (+) Multiply a vector by a scalar.~~

~~N-VM.5.a. Represent scalar multiplication graphically by scaling vectors and possibly reversing their direction; perform scalar multiplication component-wise, e.g., as c(vx, vy) = (cvx, cvy).~~

~~N-VM.5.b. Compute the magnitude of a scalar multiple cv using ||cv|| = |c|v. Compute the direction of cv knowing that when |c|v ≠ 0, the direction of cv is either along v (for c > 0) or against v (for c < 0).~~

N-VM.6. (+) Use matrices to represent and manipulate data, e.g., to represent payoffs or incidence relationships in a network.

N-VM.7. (+) Multiply matrices by scalars to produce new matrices, e.g., as when all of the payoffs in a game are doubled.

N-VM.8. (+) Add, subtract, and multiply matrices of appropriate dimensions.

N-VM.9. (+) Understand that, unlike multiplication of numbers, matrix multiplication for square matrices is not a commutative operation, but still satisfies the associative and distributive properties

N-VM.10. (+) Understand that the zero and identity matrices play a role in matrix addition and multiplication similar to the role of 0 and 1 in the real numbers. The determinant of a square matrix is nonzero if and only if the matrix has a multiplicative inverse.

N-VM.11. (+) Multiply a vector (regarded as a matrix with one column) by a matrix of suitable dimensions to produce another vector. Work with matrices as transformations of vectors.

N-VM.12. (+) Work with 2 × 2 matrices as transformations of the plane, and interpret the absolute value of the determinant in terms of area.

Algebra

Seeing Structure in Expressions

A-SSE.1. Interpret expressions that represent a quantity in terms of its context.

A-SSE.1.a. Interpret parts of an expression, such as terms, factors, and coefficients.

A-SSE.1.b. Interpret complicated expressions by viewing one or more of their parts as a single entity. For example, interpret P(1+r)n as the product of P and a factor not depending on P.

A-SSE.2. Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.

A-SSE.3. Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.

A-SSE.3.a. Factor a quadratic expression to reveal the zeros of the function it defines.

A-SSE.3.b. Complete the square in a quadratic expression to reveal the maximum or minimum value of the function it defines.

A-SSE.3.c. Use the properties of exponents to transform expressions for exponential functions.

A-SSE.4. Derive the formula for the sum of a finite geometric series (when the common ratio is not 1), and use the formula to solve problems. For example, calculate mortgage payments.

Arithmetic with Polynomials and Rational Expressions

A-APR.1. Understand that polynomials form a system analogous to the integers, namely, they are closed under the operations of addition, subtraction, and multiplication; add, subtract, and multiply polynomials

A-APR.2. Know and apply the Remainder Theorem: For a polynomial p(x) and a number a, the remainder on division by x − a is p(a), so p(a) = 0 if and only if (x − a) is a factor of p(x).

A-APR.3. Identify zeros of polynomials when suitable factorizations are available, and use the zeros to construct a rough graph of the function defined by the polynomial.

A-APR.4. Prove polynomial identities and use them to describe numerical relationships.

A-APR.5. (+) Know and apply the Binomial Theorem for the expansion of (x+ y)n in powers of x and y for a positive integer n, where x and y are any numbers, with coefficients determined for example by Pascal's Triangle.

A-APR.6. Rewrite simple rational expressions in different forms; write a(x)/b(x)in the form q(x) + r(x)/b(x), where a(x), b(x), q(x), and r(x) are polynomials with the degree of r(x) less than the degree of b(x), using inspection, long division, or, for the more complicated examples, a computer algebra system.

A-APR.7. (+) Understand that rational expressions form a system analogous to the rational numbers, closed under addition, subtraction, multiplication, and division by a nonzero rational expression; add, subtract, multiply, and divide rational expressions.

Creating Equations

A-CED.1. Create equations and inequalities in one variable and use them to solve problems. Include equations arising from linear and quadratic functions, and simple rational and exponential functions.

A-CED.2. Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.

A-CED.3. Represent constraints by equations or inequalities, and by systems of equations and/or inequalities, and interpret solutions as viable or nonviable options in a modeling context. For example, represent inequalities describing nutritional and cost constraints on combinations of different foods.

A-CED.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. For example, rearrange Ohm's law V =IR to highlight resistance R.

Reasoning with Equations and Inequalities

A-REI.1. Explain each step in solving a simple equation as following from the equality of numbers asserted at the previous step, starting from the assumption that the original equation has a solution. Construct a viable argument to justify a solution method.

A-REI.2. Solve simple rational and radical equations in one variable, and give examples showing how extraneous solutions may arise.

A-REI.3. Solve linear equations and inequalities in one variable, including equations with coefficients represented by letters.

A-REI.4. Solve quadratic equations in one variable.

A-REI.4.a. Use the method of completing the square to transform any quadratic equation in x into an equation of the form (x − p)2= q that has the same solutions. Derive the quadratic formula from this form.

A-REI.4.b. Solve quadratic equations by inspection (e.g., for x2= 49), taking square roots, completing the square, the quadratic formula and factoring, as appropriate to the initial form of the equation. Recognize when the quadratic formula gives complex solutions and write them as a ± bi for real numbers a and b.

A-REI.5. Prove that, given a system of two equations in two variables, replacing one equation by the sum of that equation and a multiple of the other produces a system with the same solutions.

A-REI.6. Solve systems of linear equations exactly and approximately (e.g., with graphs), focusing on pairs of linear equations in two variables.

A-REI.7. Solve a simple system consisting of a linear equation and a quadratic equation in two variables algebraically and graphically. For example, find the points of intersection between the line y = −3x and the circle x2+y2= 3.

A-REI.8. (+) Represent a system of linear equations as a single matrix equation in a vector variable.

A-REI.9. (+) Find the inverse of a matrix if it exists and use it to solve systems of linear equations (using technology for matrices of dimension 3 × 3 or greater).

A-REI.10. Understand that the graph of an equation in two variables is the set of all its solutions plotted in the coordinate plane, often forming a curve (which could be a line).

A-REI.11. Explain why the x-coordinates of the points where the graphs of the equations y = f(x) and y = g(x) intersect are the solutions of the equation f(x) = g(x); find the solutions

approximately, e.g., using technology to graph the functions, make tables of values, or find successive approximations. Include cases where f(x) and/or g(x)
are linear, polynomial, rational, absolute value, exponential, and logarithmic functions.

A-REI.12.Graph the solutions to a linear inequality in two variables as a half plane (excluding the boundary in the case of a strict inequality), and graph the solution set to a system of linear inequalities in two variables as the intersection of the corresponding half-planes.

Functions

Interpreting Functions

F-IF.1. Understand that a function from one set (called the domain) to another set (called the range) assigns to each element of the domain exactly one element of the range. If f is a function and x is an element of its domain, then f(x) denotes the output of f corresponding to the input x. The graph of f is the graph of the equation y = f(x).

F-IF.2. Use function notation, evaluate functions for inputs in their domains, and interpret statements that use function notation in terms of a context.

F-IF.3. Recognize that sequences are functions, sometimes defined recursively, whose domain is a subset of the integers. For example, the Fibonacci sequence is defined recursively by f(0) = f(1) = 1, f(n+1) = f(n) + f(n-1) for n ≥ 1.

F-IF.4. For a function that models a relationship between two quantities, interpret key features of graphs and tables in terms of the quantities, and sketch graphs showing key features given a verbal description of the relationship. Key features include: intercepts; intervals where the function is increasing, decreasing, positive, or negative; relative maximums and minimums; symmetries; end behavior; and periodicity.

F-IF.5. Relate the domain of a function to its graph and, where applicable, to the quantitative relationship it describes. For example, if the function h(n) gives the number of person-hours it takes to assemble n engines in a
factory, then the positive integers would be an appropriate domain for the function.

F-IF.6. Calculate and interpret the average rate of change of a function (presented symbolically or as a table) over a specified interval. Estimate the rate of change from a graph.

F-IF.7. Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.

F-IF.7.a. Graph linear and quadratic functions and show intercepts, maxima, and minima.

F-IF.7.b. Graph square root, cube root, and piecewise-defined functions, including step functions and absolute value functions.
F-IF.7.c. Graph polynomial functions, identifying zeros when suitable factorizations are

available, and showing end behavior.

F-IF.7.d. (+) Graph rational functions, identifying zeros and asymptotes when suitable factorizations are available, and showing end behavior.

F-IF.7.e. Graph exponential and logarithmic functions, showing intercepts and end behavior, and trigonometric functions, showing period, midline, and amplitude.

F-IF.8. Write a function defined by an expression in different but equivalent forms to reveal and explain different properties of the function.

F-IF.8.a. Use the process of factoring and completing the square in a quadratic function to show zeros, extreme values, and symmetry of the graph, and interpret these in terms of a context.

F-IF.8.b. Use the properties of exponents to interpret expressions for exponential functions.

F-IF.9. Compare properties of two functions each represented in a different way (algebraically, graphically, numerically in tables, or by verbal descriptions). For example, given a graph of one quadratic function and an algebraic expression for another, say which has the larger maximum.

Building Functions

F-BF.1. Write a function that describes a relationship between two quantities.

F-BF.1.a. Determine an explicit expression, a recursive process, or steps for calculation from a context.

F-BF.1.b. Combine standard function types using arithmetic operations. For example, build a function that models the temperature of a cooling body by adding a constant function to a decaying exponential, and relate these functions to the model.

F-BF.1.c. (+) Compose functions. For example, if T(y) is the temperature in the atmosphere as a function of height, and h(t) is the height of a weather balloon as a function of time, then T(h(t)) is the temperature at the location of the weather balloon as a function of time.

F-BF.2. Write arithmetic and geometric sequences both recursively and with an explicit formula, use them to model situations, and translate between the two forms.

F-BF.3. Identify the effect on the graph of replacing f(x) by f(x) + k, k f(x), f(kx), and f(x + k) for specific values of k (both positive and negative); find the value of k given the graphs. Experiment with cases and illustrate an explanation of the effects on the graph using technology. Include recognizing even and odd functions from their graphs and algebraic expressions for them.

F-BF.4. Find inverse functions.

F-BF.4.a. Solve an equation of the form f(x) = c for a simple function f that has an inverse and write an expression for the inverse.
F-BF.4.b. (+) Verify by composition that one function is the inverse of another.

F-BF.4.c. (+) Read values of an inverse function from a graph or a table, given that the function has an inverse.

F-BF.4.d. (+) Produce an invertible function from a non-invertible function by restricting the domain.

F-BF.5. (+) Understand the inverse relationship between exponents and logarithms and use this relationship to solve problems involving logarithms and exponents.

Linear, Quadratic, and Exponential Models

F-LE.1. Distinguish between situations that can be modeled with linear functions and with exponential functions.

F-LE.1.a. Prove that linear functions grow by equal differences over equal intervals, and that exponential functions grow by equal factors over equal intervals.

F-LE.1.b. Recognize situations in which one quantity changes at a constant rate per unit interval relative to another.

F-LE.1.c. Recognize situations in which a quantity grows or decays by a constant percent rate per unit interval relative to another

F-LE.2. Construct linear and exponential functions, including arithmetic and geometric sequences, given a graph, a description of a relationship, or two input-output pairs (include reading these from a table).

F-LE.3. Observe using graphs and tables that a quantity increasing exponentially eventually exceeds a quantity increasing linearly, quadratically, or (more generally) as a polynomial function.

F-LE.4. For exponential models, express as a logarithm the solution to ab ct = d where a, c, and d are numbers and the base b is 2, 10, or e; evaluate the logarithm using technology.

F-LE.5. Interpret the parameters in a linear or exponential function in terms of a context.

Trigonometric Functions

F-TF.1. Understand radian measure of an angle as the length of the arc on the unit circle subtended by the angle.

F-TF.2. Explain how the unit circle in the coordinate plane enables the extension of trigonometric functions to all real numbers, interpreted as radian measures of angles traversed counterclockwise around the unit circle.

F-TF.3. (+) Use special triangles to determine geometrically the values of sine, cosine, tangent for $\pi/3$, $\pi/4$ and $\pi/6$, and use the unit circle to express the values of sine, cosine, and tangent for $\pi - x$, $\pi+x$, and $2\pi - x$ in terms of their values for x, where x is any real number.

F-TF.4. (+) Use the unit circle to explain symmetry (odd and even) and periodicity of trigonometric functions.

F-TF.5. Choose trigonometric functions to model periodic phenomena with specified amplitude, frequency, and midline.

F-TF.6. (+) Understand that restricting a trigonometric function to a domain on which it is always increasing or always decreasing allows its inverse to be constructed.

F-TF.7. (+) Use inverse functions to solve trigonometric equations that arise in modeling contexts; evaluate the solutions using technology, and interpret them in terms of the context.

F-TF.8. Prove the Pythagorean identity $\sin2(\theta) + \cos 2(\theta) = 1$ and use it to find $\sin(\theta)$, $\cos(\theta)$, or $\tan(\theta)$ given $\sin(\theta)$, $\cos(\theta)$, or $\tan(\theta)$ and the quadrant of the angle.

F-TF.9. (+) Prove the addition and subtraction formulas for sine, cosine, and tangent and use them to solve problems.

Geometry

Congruence

G-CO.1. Know precise definitions of angle, circle, perpendicular line, parallel line, and line segment, based on the undefined notions of point, line, distance along a line, and distance around a circular arc.

G-CO.2. Represent transformations in the plane using, e.g., transparencies and geometry software; describe transformations as functions that take points in the plane as inputs and give other points as outputs. Compare transformations that preserve distance and angle to those that do not (e.g., translation versus horizontal stretch).

G-CO.3. Given a rectangle, parallelogram, trapezoid, or regular polygon, describe the rotations and reflections that carry it onto itself.

G-CO.4. Develop definitions of rotations, reflections, and translations in terms of angles, circles, perpendicular lines, parallel lines, and line segments.

G-CO.5. Given a geometric figure and a rotation, reflection, or translation, draw the transformed figure using, e.g., graph paper, tracing paper, or geometry software. Specify a sequence of

~~transformations that will carry a given figure onto another.~~

~~G-CO.6. Use geometric descriptions of rigid motions to transform figures and to predict the effect of a given rigid motion on a given figure; given two figures, use the definition of congruence in terms of rigid motions to decide if they are congruent.~~

~~G-CO.7. Use the definition of congruence in terms of rigid motions to show that two triangles are congruent if and only if corresponding pairs of sides and corresponding pairs of angles are congruent.~~

~~G-CO.8. Explain how the criteria for triangle congruence (ASA, SAS, and SSS) follow from the definition of congruence in terms of rigid motions.~~

~~G-CO.9. Prove theorems about lines and angles. Theorems include: vertical angles are congruent; when a transversal crosses parallel lines, alternate interior angles are congruent and corresponding angles are congruent; points on a perpendicular bisector of a line segment are exactly those equidistant from the segment's endpoints.~~

~~G-CO.10. Prove theorems about triangles. Theorems include: measures of interior angles of a triangle sum to 180°; base angles of isosceles triangles are congruent; the segment joining midpoints of two sides of a triangle is parallel to the third side and half the length; the medians of a triangle meet at a point.~~

~~G-CO.11. Prove theorems about parallelograms. Theorems include: opposite sides are congruent, opposite angles are congruent, the diagonals of a parallelogram bisect each other, and conversely, rectangles are parallelograms with congruent diagonals.~~

~~G-CO.12. Make formal geometric constructions with a variety of tools and methods (compass and straightedge, string, reflective devices, paper folding, dynamic geometric software, etc.). Copying a segment; copying an angle; bisecting a segment; bisecting an angle; constructing perpendicular lines, including the perpendicular bisector of a line segment; and constructing a line parallel to a given line through a point not on the line.~~

~~G-CO.13. Construct an equilateral triangle, a square, and a regular hexagon inscribed in a circle.~~

~~Similarity, Right Triangles, and Trigonometry~~

~~G-SRT.1. Verify experimentally the properties of dilations given by a center and a scale factor:~~

~~G-SRT.1.a. A dilation takes a line not passing through the center of the dilation to a parallel line, and leaves a line passing through the center unchanged.~~

~~G-SRT.1.b. The dilation of a line segment is longer or shorter in the ratio given by the scale factor.~~

~~G-SRT.2. Given two figures, use the definition of similarity in terms of similarity~~

transformations to decide if they are similar; explain using similarity transformations the meaning of similarity for triangles as the equality of all corresponding pairs of angles and the proportionality of all corresponding pairs of sides.

G-SRT.3. Use the properties of similarity transformations to establish the AA criterion for two triangles to be similar.

G-SRT.4. Prove theorems about triangles. Theorems include: a line parallel to one side of a triangle divides the other two proportionally, and conversely; the Pythagorean Theorem proved using triangle similarity.

G-SRT.5. Use congruence and similarity criteria for triangles to solve problems and to prove relationships in geometric figures.

G-SRT.6. Understand that by similarity, side ratios in right triangles are properties of the angles in the triangle, leading to definitions of trigonometric ratios for acute angles.

G-SRT.7. Explain and use the relationship between the sine and cosine of complementary angles.

G-SRT.8. Use trigonometric ratios and the Pythagorean Theorem to solve right triangles in applied problems.

G-SRT.9. (+) Derive the formula A = 1/2 ab sin(C) for the area of a triangle by drawing an auxiliary line from a vertex perpendicular to the opposite side.

G-SRT.10. (+) Prove the Laws of Sines and Cosines and use them to solve problems.

G-SRT.11. (+) Understand and apply the Law of Sines and the Law of Cosines to find unknown measurements in right and non-right triangles (e.g., surveying problems, resultant forces).

Circles

G-C.1. Prove that all circles are similar.

G-C.2. Identify and describe relationships among inscribed angles, radii, and chords. Include the relationship between central, inscribed, and circumscribed angles; inscribed angles on a diameter are right angles; the radius of a circle is perpendicular to the tangent where the radius intersects the circle.

G-C.3. Construct the inscribed and circumscribed circles of a triangle and prove properties of angles for a quadrilateral inscribed in a circle.

G-C.4. (+) Construct a tangent line from a point outside a given circle to the circle.
G-C.5. Derive using similarity the fact that the length of the arc intercepted by an angle is proportional to the radius and define the radian measure of the angle as the constant of proportionality; derive the formula for the area of a sector.

Expressing Geometric Properties with Equations

G-GPE.1. Derive the equation of a circle of given center and radius using the Pythagorean Theorem; complete the square to find the center and radius of a circle given by an equation.

G-GPE.2. Derive the equation of a parabola given a focus and directrix.

G-GPE.3. (+) Derive the equations of ellipses and hyperbolas given the foci, using the fact that the sum or difference of distances from the foci is constant.

G-GPE.4. Use coordinates to prove simple geometric theorems algebraically. For example, prove or disprove that a figure defined by four given points in the coordinate plane is a rectangle; prove or disprove that the point (1, √3) lies on the circle centered at the origin and containing the point (0, 2).

G-GPE.5. Prove the slope criteria for parallel and perpendicular lines and use them to solve geometric problems (e.g., find the equation of a line parallel or perpendicular to a given line that passes through a given point).

G-GPE.6. Find the point on a directed line segment between two given points that partitions the segment in a given ratio.

G-GPE.7. Use coordinates to compute perimeters of polygons and areas of triangles and rectangles, e.g., using the distance formula.

Geometric Measurement and Dimension

G-GMD.1. Give an informal argument for the formulas for the circumference of a circle, area of a circle, volume of a cylinder, pyramid, and cone. Use dissection arguments, Cavalieri's principle, and informal limit arguments.

G-GMD.2. (+) Give an informal argument using Cavalieri's principle for the formulas for the volume of a sphere and other solid figures.

G-GMD.3. Use volume formulas for cylinders, pyramids, cones, and spheres to solve problems.

G-GMD.4. Identify the shapes of two-dimensional cross-sections of three-dimensional objects, and identify three-dimensional objects generated by rotations of two-dimensional objects.

Modeling with Geometry

G-MG.1. Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder).

G-MG.2. Apply concepts of density based on area and volume in modeling situations (e.g.,

persons per square mile, BTUs per cubic foot).

G-MG.3. Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).

Statistics and Probability

Interpreting Categorical and Quantitative Data

S-ID.1. Represent data with plots on the real number line (dot plots, histograms, and box plots).

S-ID.2. Use statistics appropriate to the shape of the data distribution to compare center (median, mean) and spread (interquartile range, standard deviation) of two or more different data sets.

S-ID.3. Interpret differences in shape, center, and spread in the context of the data sets, accounting for possible effects of extreme data points (outliers).

S-ID.4. Use the mean and standard deviation of a data set to fit it to a normal distribution and to estimate population percentages. Recognize that there are data sets for which such a procedure is not appropriate. Use calculators, spreadsheets, and tables to estimate areas under the normal curve.

S-ID.5. Summarize categorical data for two categories in two-way frequency tables. Interpret relative frequencies in the context of the data (including joint, marginal, and conditional relative frequencies). Recognize possible associations and trends in the data.

S-ID.6. Represent data on two quantitative variables on a scatter plot and describe how the variables are related.

S-ID.6.a. Fit a function to the data; use functions fitted to data to solve problems in the context of the data. Use given functions or choose a function suggested by the context. Emphasize linear, quadratic, and exponential models.

S-ID.6.b. Informally assess the fit of a function by plotting and analyzing residuals.

S-ID.6.c. Fit a linear function for a scatter plot that suggests a linear association.

S-ID.7. Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data.
S-ID.8. Compute (using technology) and interpret the correlation coefficient of a linear fit.

S-ID.9. Distinguish between correlation and causation.

Making Inferences and Justifying Conclusions

S-IC.1. Understand statistics as a process for making inferences about population parameters based on a random sample from that population.

S-IC.2. Decide if a specified model is consistent with results from a given data-generating process, e.g., using simulation. For example, a model says a spinning coin falls heads up with probability 0.5. Would a result of 5 tails in a row cause you to question the model?

S-IC.3. Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each.

S-IC.4. Use data from a sample survey to estimate a population mean or proportion; develop a margin of error through the use of simulation models for random sampling.

S-IC.5. Use data from a randomized experiment to compare two treatments; use simulations to decide if differences between parameters are significant.

S-IC.6. Evaluate reports based on data.

Conditional Probability and the Rules of Probability

S-CP.1. Describe events as subsets of a sample space (the set of outcomes) using characteristics (or categories) of the outcomes, or as unions, intersections, or complements of other events ("or," "and," "not").

S-CP.2. Understand that two events A and B are independent if the probability of A and B occurring together is the product of their probabilities and use this characterization to determine if they are independent.

S-CP.3. Understand the conditional probability of A given B as P(A and B)/P(B), and interpret independence of A and B as saying that the conditional probability of A given B is the same as the probability of A, and the conditional probability of B given A is the same as the probability of B.

S-CP.4. Construct and interpret two-way frequency tables of data when two categories are associated with each object being classified. Use the two-way table as a sample space to decide if events are independent and to approximate conditional probabilities. For example, collect data from a random sample of students in your school on their favorite subject among math, science, and English. Estimate the probability that a randomly selected student from your school will favor science given that the student is in tenth grade. Do the same for other subjects and compare the results.

S-CP.5. Recognize and explain the concepts of conditional probability and independence in everyday language and everyday situations. For example, compare the chance of having lung

cancer if you are a smoker with the chance of being a smoker if you have lung cancer.

S-CP.6. Find the conditional probability of A given B as the fraction of B's outcomes that also belong to A and interpret the answer in terms of the model.

S-CP.7. Apply the Addition Rule, P(A or B) = P(A) + P(B) – P(A and B), and interpret the answer in terms of the model.

S-CP.8. (+) Apply the general Multiplication Rule in a uniform probability model, P(A and B) = P(A)P(B|A) = P(B)P(A|B), and interpret the answer in terms of the model.

S-CP.9. (+) Use permutations and combinations to compute probabilities of compound events and solve problems.

Using Probability to Make Decisions

S-MD.1. (+) Define a random variable for a quantity of interest by assigning a numerical value to each event in a sample space; graph the corresponding probability distribution using the same graphical displays as for data distributions.

S-MD.2. (+) Calculate the expected value of a random variable; interpret it as the mean of the probability distribution.

S-MD.3. (+) Develop a probability distribution for a random variable defined for a sample space in which theoretical probabilities can be calculated; find the expected value. For example, find the theoretical probability distribution for the number of correct answers obtained by guessing on all five questions of a multiple-choice test where each question has four choices, and find the expected grade under various grading schemes.

S-MD.4. (+) Develop a probability distribution for a random variable defined for a sample space in which probabilities are assigned empirically; find the expected value. For example, find a current data distribution on the number of TV sets per household in the United States, and calculate the expected number of sets per household. How many TV sets would you expect to find in 100 randomly selected households?

S-MD.5. (+) Weigh the possible outcomes of a decision by assigning probabilities to payoff values and finding expected values.

S-MD.5.a. Find the expected payoff for a game of chance. For example, find the expected winnings from a state lottery ticket or a game at a fast-food restaurant.

S-MD.5.b. Evaluate and compare strategies on the basis of expected values. For example, compare a high-deductible versus a low-deductible automobile insurance policy using various, but reasonable, chances of having a minor or a major accident.

~~S-MD.6. (+) Use probabilities to make fair decisions (e.g., drawing by lots, using a random number generator).~~

~~S-MD.7. (+) Analyze decisions and strategies using probability concepts (e.g., product testing, medical testing, pulling a hockey goalie at the end of a game).~~

Appendix D: International Society for Technology in Education Standards (ISTE)

ISTE Standards-S Crosswalk for Polymer Science												
	Course	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11
ISTE Standards-S												
T1			x	x	x	x		x	x	x	x	x
T2		x	x	x	x	x	x	x	x	x	x	x
T3		x	x	x	x	x	x	x	x	x	x	x
T4			x	x	x	x		x	x	x	x	x
T5		x	x	x	x	x	x	x	x	x	x	x
T6		x	x	x	x	x	x	x	x	x	x	x

T1 Creativity and Innovation
T2 Communication and Collaboration
T3 Research and Information Fluency
T4 Critical Thinking, Problem Solving, and Decision Making
T5 Digital Citizenship
T6 Technology Operations and Concepts

T1 Creativity and Innovation

Students demonstrate creative thinking, construct knowledge, and develop innovative products and processes using technology. Students do the following:

a. Apply existing knowledge to generate new ideas, products, or processes.
b. Create original works as a means of personal or group expression.
c. Use models and simulations to explore complex systems and issues.
d. Identify trends and forecast possibilities.

T2 Communication and Collaboration

Students use digital media and environments to communicate and work collaboratively, including at a distance, to support individual learning and contribute to the learning of others. Students do the following:

a. Interact, collaborate, and publish with peers, experts, or others employing a variety of digital environments and media.
b. Communicate information and ideas effectively to multiple audiences using a variety of media and formats.
c. Develop cultural understanding and global awareness by engaging with learners of other cultures.
d. Contribute to project teams to produce original works or solve problems.

T3 Research and Information Fluency

Students apply digital tools to gather, evaluate, and use information. Students do the following:

a. Plan strategies to guide inquiry.
b. Locate, organize, analyze, evaluate, synthesize, and ethically use information from a variety of sources and media.
c. Evaluate and select information sources and digital tools based on the appropriateness to specific tasks.
d. Process data and report results.

T4 Critical Thinking, Problem Solving, and Decision Making

Students use critical thinking skills to plan and conduct research, manage projects, solve problems, and make informed decisions using appropriate digital tools and resources. Students do the following:

a. Identify and define authentic problems and significant questions for investigation.
b. Plan and manage activities to develop a solution or complete a project.
c. Collect and analyze data to identify solutions and/or make informed decisions.
d. Use multiple processes and diverse perspectives to explore alternative solutions.

T5 Digital Citizenship

Students understand human, cultural, and societal issues related to technology and practice legal and ethical behavior. Students do the following:

a. Advocate and practice safe, legal, and responsible use of information and technology.
b. Exhibit a positive attitude toward using technology that supports collaboration, learning, and productivity.
c. Demonstrate personal responsibility for lifelong learning.
d. Exhibit leadership for digital citizenship.

T6 Technology Operations and Concepts

Students demonstrate a sound understanding of technology concepts, systems, and operations. Students do the following:

a. Understand and use technology systems.
b. Select and use applications effectively and productively.
c. Troubleshoot systems and applications.
d. Transfer current knowledge to learning of new technologies.

Appendix E: Academic Standards

MS Chemistry Standards-Polymer Science Crosswalk											
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11
MS Chemistry Framework											
CHE.1.1	*	*	*	*	*	*	*	*	*	*	*
CHE.1.2			*	*	*		*	*	*	*	
CHE.2.3			*								
CHE.3.1			*	*			*	*	*		
CHE.3.2			*	*			*	*			
CHE.3.3			*	*				*			
CHE.4.1			*	*				*			
CHE.4.2			*	*				*			
CHE.4.3			*								
CHE.4.4			*	*							
CHE.4.5			*	*							
CHE.4.6			*	*							
CHE.4.7			*					*			
CHE.5.1			*	*			*	*	*	*	
CHE.5.2			*	*			*	*	*	*	
CHE.5.3			*	*			*	*	*	*	
CHE.6.1			*					*			
CHE.6.2			*					*			
CHE.6.3			*	*						*	
CHE.6.4			*								
CHE.6.5			*	*							
CHE.6.6			*								
CHE.6.7			*	*							
CHE.7.1			*								
CHE.7.2			*								
CHE.7.3			*					*			
CHE.8.1			*								
CHE.8.2			*								
CHE.8.3			*								
CHE.8.5			*								
CHE.8.6			*					*			
CHE.8.7			*								
CHE.8.8			*								
CHE.10.1			*	*				*			
CHE.10.2			*					*			
CHE.10.3			*								
CHE.11.2			*					*			
CHE12.1			*	*							
CHE12.2			*	*			*		*	*	
CHE12.3			*	*			*		*	*	

CHE.1 Mathematical and Computational Analysis

Conceptual Understanding: Mathematical and computational analysis is a key component of scientific investigation and prediction of outcomes. These components create a more student-centered classroom.

CHE.1 Students will use mathematical and computational analysis to evaluate problems.

CHE.1.1 Use dimensional analysis (factor/label) and significant figures to convert units and solve problems.

CHE.1.2 Design and conduct experiments using appropriate measurements, significant figures, graphical analysis to analyze data.
CHE.1.3 Enrichment: Research information from multiple appropriate sources and assess the credibility, accuracy, possible bias, and conclusions of each publication.

CHE.2 Atomic Theory
Conceptual Understanding: Atomic theory is the foundation of modern chemistry concepts. Students must be presented with a solid foundation of the atom and its components. These concepts lead to an understanding of the interactions of these components to explain macro-observations of the world.
CHE.2 Students will demonstrate an understanding of the atomic structure and the historical developments leading to modern atomic theory.
CHE.2.1 Investigate the historical progression leading to the modern atomic theory, including, but not limited to, work done by Dalton, Rutherford's gold foil experiment, Thomson's cathode ray experiment, Millikan's oil drop experiment, and Bohr's interpretation of bright line spectra.
CHE.2.2 Construct models (e.g., ball and stick, online simulations, mathematical computations) of atomic nuclei to explain the abundance weighted average (relative mass) of elements and isotopes on the published mass of elements.
CHE.2.3 Investigate absorption and emission spectra to interpret explanations of electrons at discrete energy levels using tools such as online simulations, spectrometers, prisms, flame tests, and discharge tubes. Explore both laboratory experiments and real-world examples.
CHE.2.4 Research appropriate sources to evaluate the way absorption and emission spectra are used to study astronomy and the formation of the universe.

CHE.3 Periodic Table
Conceptual Understanding: Modern chemistry is based on the predictability of atomic behavior. Periodic patterns in elements led to the development of the periodic table. Electron configuration is a direct result of this periodic behavior. The predictable behavior of electrons has led to the discovery of new compounds, elements, and atomic interactions. Predictability of atom behavior is a key to understanding ionic and covalent bonding and production of compounds or molecules.
CHE.3 Students will demonstrate an understanding of the periodic table as a systematic representation to predict properties of elements.
CHE.3.1 Explore and communicate the organization of the periodic table, including history, groups, families, family names, metals, nonmetals, metalloids, and transition metals.
CHE.3.2 Analyze properties of atoms and ions (e.g., metal/nonmetal/metalloid behavior, electrical/heat conductivity, electronegativity and electron affinity, ionization energy, and atomic/ionic radii) using periodic trends of elements based on the periodic table.
CHE.3.3 Analyze the periodic table to identify quantum numbers (e.g., valence shell electrons, energy level, orbitals, sublevels, and oxidation numbers).

CHE.4 Bonding
Conceptual Understanding: A firm understanding of bonding is necessary to further development of the basic chemical concepts of compounds and chemical interactions.
Chemistry CHE.4 Students will demonstrate an understanding of the types of bonds and resulting atomic structures for the classification of chemical compounds.

CHE.4.1 Develop and use models (e.g., Lewis dot, 3-D ball-stick, 3-D printing, or simulation programs such as PhET) to predict the type of bonding between atoms and the shape of simple compounds.
CHE.4.2 Use models such as Lewis structures and ball and stick models to depict the valence electrons and their role in the formation of ionic and covalent bonds.
CHE.4.3 Predict the ionic or covalent nature of different atoms based on electronegativity trends and/or position on the periodic table.
CHE.4.4 Use models and oxidation numbers to predict the type of bond, shape of the compound, and the polarity of the compound.
CHE.4.5 Use models of simple hydrocarbons to exemplify structural isomerism.
CHE.4.6 Use mathematical and computational analysis to determine the empirical formula and the percent composition of compounds.
CHE.4.7 Use scientific investigation to determine the percentage of composition for a substance (e.g., sugar in gum, water and/or unpopped kernels in popcorn, percent water in a hydrate). Compare results to justify conclusions based on experimental evidence.
CHE.4.8 Plan and conduct controlled scientific investigations to produce mathematical evidence of the empirical composition of a compound.

CHE.5 Naming Compounds
Conceptual Understanding: Polyatomic ions (radicals) and oxidation numbers are used to predict how metallic ions, nonmetals, and transition metals are used in naming compounds.
CHE.5 Students will investigate and understand the accepted nomenclature used to identify the name and chemical formulas of compounds.
CHE.5.1 Use the periodic table and a list of common polyatomic ions as a model to derive chemical compound formulas from compound names and compound names from chemical formulas.
CHE.5.2 Generate formulas of ionic and covalent compounds from compound names. Discuss compounds in everyday life and compile lists and uses of these chemicals.
CHE.5.3 Generate names of ionic and covalent compounds from their formulas. Name binary compounds, binary acids, stock compounds, ternary compounds, and ternary acids.

CHE.6 Chemical Reactions
Conceptual Understanding: Understanding chemical reactions and predicting products of these reactions is essential to student success.
CHE.6 Students will demonstrate an understanding of the types, causes, and effects of chemical reactions
CHE.6.1 Develop and use models to predict the products of chemical reactions (e.g., synthesis reactions; single replacement; double displacement; and decomposition, including exceptions such as decomposition of hydroxides, chlorates, carbonates, and acids). Discuss and/or compile lists of reactions used in everyday life.
CHE.6.2 Plan, conduct, and communicate the results of investigations to demonstrate different types of simple chemical reactions.
CHE.6.3 Use mathematics and computational analysis to represent the ratio of reactants and products in terms of masses, molecules, and moles (stoichiometry).

CHE.6.4 Use mathematics and computational analysis to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. Give real-world examples (e.g., burning wood).
CHE.6.5 Plan and conduct a controlled scientific investigation to produce mathematical evidence that mass is conserved. Use percent error to analyze the accuracy of results.
CHE.6.6 Use mathematics and computational analysis to support the concept of percent yield and limiting reagent.
CHE.6.7 Plan and conduct a controlled scientific investigation to produce mathematical evidence to predict and confirm the limiting reagent and percent yield in the reaction. Analyze quantitative data, draw conclusions, and communicate findings. Compare and analyze class data for validity.

CHE.7 Gas Laws

Conceptual Understanding: The comparison and development of the molecular states of matter are an integral part of understanding matter. Pressure, volume, and temperature are imperative to understanding the states of matter.
CHE.7 Students will demonstrate an understanding of the structure and behavior of gases.
CHE.7.1 Analyze the behavior of ideal and real gases in terms of pressure, volume, temperature, and number of particles.
CHE.7.2 Enrichment: Use an engineering design process to develop models (e.g., online simulations or student interactive activities) to explain and predict the behavior of each state of matter using the movement of particles and intermolecular forces to explain the behavior of matter.
CHE.7.3 Analyze and interpret heating curve graphs to explain the energy relationship between states of matter (e.g., thermochemistry-water heating from -20o C to 120o C).
CHE.7.4 Use mathematical computations to describe the relationships comparing pressure, temperature, volume, and number of particles, including Boyle's law, Charles's law, Dalton's law, combined gas laws, and ideal gas laws.
CHE.7.5 Enrichment: Use an engineering design process and online simulations or lab investigations to design and model the results of controlled scientific investigations to produce mathematical evidence that confirms the gas laws relationships.*
CHE.7.6 Use the ideal gas law to support the prediction of volume, mass, and number of particles produced in chemical reactions (i.e., gas stoichiometry).
CHE.7.7 Plan and conduct controlled scientific investigations to produce mathematical evidence that confirms that reactions involving gases conform to the law of conservation of mass.
CHE.7.8 Enrichment: Using gas stoichiometry, calculate the volume of carbon dioxide needed to inflate a balloon to occupy a specific volume. Use an engineering design process to design, construct, evaluate, and improve a simulated air bag.*

CHE.8 Solutions

Conceptual Understanding: Solutions exist as solids, liquids, or gases. Solution concentration is expressed by specifying relative amounts of solute to solvent.
CHE.8 Students will demonstrate an understanding of the nature of properties of various types of chemical solutions.
CHE.8.1 Use mathematical and computational analysis to quantitatively express the concentration of solutions using the concepts such as molarity, percent by mass, and dilution.

~~CHE.8.2 Develop and use models (e.g., online simulations, games, or video representations) to explain the dissolving process in solvents on the molecular level.~~
~~CHE.8.3 Analyze and interpret data to predict the effect of temperature and pressure on solids and gases dissolved in water.~~
~~CHE.8.4 Design, conduct, and communicate the results of experiments to test the conductivity of common ionic and covalent compounds in solution.~~
~~CHE.8.5 Use mathematical and computational analysis to analyze molarity, molality, dilution, and percentage dilution problems.~~
~~CHE.8.6 Design, conduct, and communicate the results of experiments to produce a specified volume of a solution of a specific molarity, and dilute a solution of a known molarity.~~
~~CHE.8.7 Use mathematical and computational analysis to predict the results of reactions using the concentration of solutions (i.e., solution stoichiometry).~~
~~CHE.8.8 Enrichment: Investigate parts per million and/or parts per billion as it applies to environmental concerns in your geographic region, and reference laws that govern these factors.~~

~~CHE.9 Acids and Bases (Enrichment)~~
~~CHE.9 Enrichment: Students will understand the nature and properties of acids, bases, and salt solutions.~~
~~CHE.9.1 Enrichment: Analyze and interpret data to describe the properties of acids, bases, and salts.~~
~~CHE.9.2 Enrichment: Analyze and interpret data to identify differences between strong and weak acids and bases (i.e., dissociation).~~
~~CHE.9.3 Enrichment: Plan and conduct investigations using the pH scale to classify acid and base solutions.~~
~~CHE.9.4 Enrichment: Analyze and evaluate the Arrhenius, Bronsted-Lowry, and Lewis acid-base definitions.~~
~~CHE.9.5 Enrichment: Use mathematical and computational thinking to calculate pH from the hydrogenion concentration.~~
~~CHE.9.6 Enrichment: Obtain, evaluate, and communicate information about how buffers stabilize pH in acid-base reactions.~~

~~CHE.10 Thermochemistry (Enrichment)~~
~~CHE.10 Enrichment: Students will understand that energy is exchanged or transformed in all chemical reactions.~~
~~CHE.10.1 Enrichment: Construct explanations to explain how temperature and heat flow in terms of the motion of molecules (or atoms).~~
~~CHE.10.2 Enrichment: Classify chemical reactions and phase changes as exothermic or endothermic based on enthalpy values. Use a graphical representation to illustrate the energy changes involved.~~
~~CHE.10.3 Enrichment: Analyze and interpret data from energy diagrams and investigations to support claims that the amount of energy released or absorbed during a chemical reaction depends on changes in total bond energy.~~
~~CHE.10.4 Enrichment: Use mathematical and computational thinking to solve problems involving heat flow and temperature changes, using known values of specific heat and latent heat of phase change.~~

~~CHE.11 Equilibrium (Enrichment)~~

~~CHE.11 Enrichment: Students will understand that chemical equilibrium is a dynamic process at the molecular level.~~

~~CHE.11.1 Enrichment: Construct explanations to explain how to use Le Chatelier's principle to predict the effect of changes in concentration, temperature, and pressure.~~

~~CHE.11.2 Enrichment: Predict when equilibrium is established in a chemical reaction.~~

~~CHE.11.3 Enrichment: Use mathematical and computational thinking to calculate an equilibrium constant expression for a reaction.~~

~~CHE.12 Organic Nomenclature (Enrichment)~~

~~CHE.12 Enrichment: Students will understand that the bonding characteristics of carbon allow the formation of many different organic molecules with various sizes, shapes, and chemical properties.~~

~~CHE.12.1 Enrichment: Construct explanations to explain the bonding characteristics of carbon that result in the formation of basic organic molecules.~~

~~CHE.12.2 Enrichment: Obtain information to communicate the system used for naming the basic linear hydrocarbons and isomers that contain single bonds, simple hydrocarbons with double and triple bonds, and simple molecules that contain a benzene ring.~~

~~CHE.12.3 Enrichment: Develop and use models to identify the functional groups that form the basis of alcohols, ketones, ethers, amines, esters, aldehydes, and organic acids~~

2023 Polymer Science

Program CIP: 15.0607 — Plastics and Polymer Engineering Technology/Technician

Direct inquiries to:

Instructional Design Specialist
Research and Curriculum Unit
P.O. Drawer DX
Mississippi State, MS 39762
662.325.2510

Program Supervisor
Office of Career and Technical Education
Mississippi Department of Education
P.O. Box 771
Jackson, MS 39205
601.359.3974

Published by:

Office of Career and Technical Education
Mississippi Department of Education
Jackson, MS 39205

Research and Curriculum Unit
Mississippi State University
Mississippi State, MS 39762

The Research and Curriculum Unit (RCU), located in Starkville, as part of Mississippi State University (MSU), was established to foster educational enhancements and innovations. In keeping with the land-grant mission of MSU, the RCU is dedicated to improving the quality of life for Mississippians. The RCU enhances intellectual and professional development of Mississippi students and educators while applying knowledge and educational research to the lives of the people of the state. The RCU works within the contexts of curriculum development and revision, research, assessment, professional development, and industrial training.

Table of Contents

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Ms. Rosemary G. Aultman, chair
Mr. Glen East, vice-chair
Dr. Karen Elam
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Standards

Standards and alignment crosswalks are referenced in the appendices. Depending on the curriculum, these crosswalks should identify alignment to the standards mentioned below, as well as possible related academic topics as required in the Subject Area Testing Program in Algebra I, Biology I, English II, and U.S. History from 1877, which could be integrated into the content of the units. Mississippi's CTE polymer science curriculum is aligned to the following standards:

Society of the Plastics Industry (SPI) Standards
Founded in 1937, SPI is the plastics industry trade association representing the third-largest manufacturing industry in the United States. SPI's member companies represent the entire plastics industry supply chain, including processors, machinery and equipment manufacturers, and raw materials suppliers.
plasticsindustry.org

Applied Academic Credit Benchmarks
The *Mississippi Polymer Science Curriculum Framework* is aligned to the Chemistry course in the 2018 *Mississippi College- and Career-Readiness Standards for Science*. An alignment crosswalk can be viewed at the end of this document.

National Educational Technology Standards for Students
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Next Generation Science Standards (NGSS)
NGSS Lead States. 2013. *Next Generation Science Standards: For States, By States.* Washington, DC: The National Academies Press. The NGSS were developed by educators, content experts and policymakers, using as a guiding document *A Framework for K-12 Science Education* from the National Research Council. The K-12 academic standards in science were developed by and for educators and school leaders. An alignment crosswalk can be viewed at the end of this document.

Preface

Secondary CTE programs in Mississippi face many challenges resulting from sweeping educational reforms at the national and state levels. Schools and teachers are increasingly being held accountable for providing applied learning activities to every student in the classroom. This accountability is measured through increased requirements for mastery and attainment of competency as documented through both formative and summative assessments. This document provides information, tools, and solutions that will aid students, teachers, and schools in creating and implementing applied, interactive, and innovative lessons. Through best practices, alignment with national standards and certifications, community partnerships, and a hands-on, student-centered concept, educators will be able to truly engage students in meaningful and collaborative learning opportunities.

The courses in this document reflect the statutory requirements as found in Section 37-3-49, *Mississippi Code of 1972*, as amended (Section 37-3-46). In addition, this curriculum reflects guidelines imposed by federal and state mandates (Laws, 1988, Ch. 487, §14; Laws, 1991, Ch. 423, §1; Laws, 1992, Ch. 519, §4 eff. from and after July 1, 1992; Strengthening Career and Technical Education for the 21st Century Act, 2019 [Perkins V]; and Every Student Succeeds Act, 2015).

Mississippi Teacher Professional Resources

The following are resources for Mississippi teachers:

Curriculum, Assessment, Professional Learning
: Program resources can be found at the RCU's website, rcu.msstate.edu.

Learning Management System: An Online Resource
: Learning management system information can be found at the RCU's website, under Professional Learning.

Should you need additional instructions, contact the RCU at 662.325.2510 or helpdesk@rcu.msstate.edu.

Executive Summary

Pathway Description
Polymer Science is a pathway in the polymer materials manufacturing career cluster. This program is designed for students who wish to prepare for employment or continued education in the occupations of polymer materials manufacturing. The pathway is designed to provide students with hands-on experiences related to the application of polymer science concepts in the workplace. Students will develop academic and technical skills, 21st century skills, and human relations competencies that accompany technical skills for job success and lifelong learning. Students who complete the pathway will be better prepared to enter and succeed in related programs offered by Mississippi community colleges and institutions of higher education.

College, Career, and Certifications
Two national certifications are associated with the polymer science industry, the Certified Composites Technician (CCT) and the National Certification in Plastics (NCP).

Grade Level and Class Size Recommendations
It is recommended that students enter this program as a 10th grader. Exceptions to this are a district-level decision based on class size, enrollment numbers, student maturity, and CTE delivery method. This is a hands-on, lab- or shop-based course. Therefore, a maximum of 15 students is recommended per class with only one class with the teacher at a time.

Student Prerequisites
For students to experience success in the program, the following student prerequisites are suggested:

1. C or higher in English (the previous year)
2. C or higher in high school-level math (last course taken or the instructor can specify the level of math instruction needed)
3. Instructor approval and TABE reading score (eighth grade or higher)

or

1. TABE reading and math score (eighth grade or higher)
2. Instructor approval

or

1. Instructor approval

Assessment
The latest assessment blueprint for the curriculum can be found at rcu.msstate.edu/curriculum/curriculumdownload.

Applied Academic Credit
The latest academic credit information can be found at mdek12.org/ese/approved-course-for-the-secondary-schools.

Teacher Licensure
The latest teacher licensure information can be found at

mdek12.org/oel/apply-for-an-educator-license.

Professional Learning
If you have specific questions about the content of any training sessions provided, please contact the RCU at 662.325.2510 or helpdesk@rcu.msstate.edu.

Course Outlines

Option 1— Four 1-Carnegie Unit Courses

This curriculum consists of four one-credit courses that should be completed in the following sequence:

1. **Introduction to Polymer Science I—Course Code: 994502**
2. **Introduction to Polymer Science II—Course Code: 994503**
3. **Advanced Topics in Polymer Science—Course Code: 994504**
4. **Careers in Polymer Science—Course Code: 994505**

Course Description: Introduction to Polymer Science I
This course orients the students to the polymer science program and lab. During this course, students learn computer applications relevant to polymer science. They are also introduced to chemistry concepts.

Course Description: Introduction to Polymer Science II
This course emphasizes polymer synthesis and selection, the manufacturing and processing techniques associated with polymers, and the methods and benefits of plastics recycling.

Course Description: Advanced Topics in Polymer Science
This course allows students to explore an industry problem through the scientific design process and investigate advanced polymer manufacturing processes.

Course Description: Careers in Polymer Science
This course focuses on metals, ceramics, surface coatings, and composite materials.

Introduction to Polymer Science I—Course Code: 994502

Unit	Unit Title	Hours
1	Orientation to Industrial Employability and Safety	40
2	Chemistry of Solids and Solutions	70
3	Foundational Organic Chemistry	30
Total		**140**

Introduction to Polymer Science II—Course Code: 994503

Unit	Unit Title	Hours
4	Polymers	80
5	Thermoplastic Polymer Processing	60
Total		**140**

Advanced Topics in Polymer Science—Course Code: 994504

Unit	Unit Title	Hours
6	Polymer Safety and Concepts Review	30
7	Industry Guided Work-Based Learning	60
8	Advanced Polymer Manufacturing	50
Total		**140**

Careers in Polymer Science—Course Code: 994505

Unit	Unit Title	Hours
9	Metals	30
10	Ceramics and Glass	30
11	Surface Coatings	30
12	Composite Materials, Manufacturing, and Applications	50
Total		**140**

Option 2—Two 2-Carnegie Unit Courses

This curriculum consists of two 2-credit courses that should be completed in the following sequence:

1. **Polymer Science I—Course Code: 994500**
2. **Polymer Science II—Course Code: 994501**

Course Description: Polymer Science I
This course encompasses the course and lab. During the course, students learn computer applications relevant to polymer science, and they are also introduced to chemistry concepts and the structures and properties of polymers. Students are also taught the processing techniques associated with thermoplastic polymers and the methods and benefits of plastics recycling.

Course Description: Polymer Science II
This course allows students to explore an industry problem through the scientific design process and investigate advanced polymer manufacturing processes. Instruction focuses on metals, ceramics, surface coatings, and composite materials.

Polymer Science I—Course Code: 994500

Unit	Unit Title	Hours
1	Orientation to Industrial Employability and Safety	40
2	Chemistry of Solids and Solutions	70
3	Foundational Organic Chemistry	30
4	Polymers	80
5	Thermoplastic Polymer Processing	60
Total		**280**

Polymer Science II—Course Code: 994501

Unit	Unit Title	Hours
6	Polymer Safety and Concepts Review	30
7	Industry Guided Work-Based Learning	60
8	Advanced Polymer Manufacturing	50
9	Metals	30
10	Ceramics and Glass	30
11	Surface Coatings	30
12	Composite Materials, Manufacturing, and Applications	50
Total		**280**

Career Pathway Outlook

Overview
The Polymer Science pathway will target careers at the professional and technical levels in polymer science. Students enrolled in these courses should be better prepared to pursue degrees at the community college and four-year college level.

Needs of the Future Workforce
Data for this synopsis were compiled from the Mississippi Department of Employment Security (2021). Employment opportunities for each of the occupations are listed below.

Table 1.1: Current and Projected Occupation Report

Description	Jobs, 2018	Projected Jobs, 2028	Change (Number)	Change (Percent)	Average Hourly Earnings, Year
Chemical Engineers	250	260	10	4%	$52.15, 2021
Chemical Technicians	490	490	0	0%	$25.13, 2021
Chemists	250	260	10	4%	$40.12, 2021
Materials Engineers	160	160	0	0%	$41.03, 2021

Source: Mississippi Department of Employment Security; mdes.ms.gov (2021).

Perkins V Requirements and Academic Infusion
The Polymer Science curriculum meets Perkins V requirements of introducing students to and preparing them for high-skill, high-wage occupations in polymer science fields. It also offers students a program of study, including secondary, postsecondary, and institutions of higher learning courses, that will further prepare them for polymer science careers. Additionally, this curriculum is integrated with academic college- and career-readiness standards. Lastly, it focuses on ongoing and meaningful professional development for teachers as well as relationships with industry.

Transition to Postsecondary Education
The latest articulation information for secondary to postsecondary can be found at the Mississippi Community College Board website, mccb.edu.

Best Practices
Innovative Instructional Technologies
Classrooms should be equipped with tools that will teach today's digital learners through applicable and modern practices. The Polymer Science educator's goal should be to include teaching strategies that incorporate current technology. To make use of the latest online communication tools—wikis, blogs, podcasts, and social media platforms, for example—the classroom teacher is encouraged to use a learning management system that introduces students to education in an online environment and places more of the responsibility of learning on the student.

Differentiated Instruction
Students learn in a variety of ways, and numerous factors—students' background, emotional health, and circumstances, for example—create unique learners. By providing various teaching and assessment strategies, students with various learning preferences can have more opportunity to succeed.

CTE Student Organizations
Teachers should investigate opportunities to sponsor a student organization. There are several here in Mississippi that will foster the types of learning expected from the Polymer Science curriculum. Technology Student Association (TSA) and Skills USA are examples of student organizations with many outlets for polymer science students. Student organizations provide participants and members with growth opportunities and competitive events. They also open the doors to the world of industry careers and scholarship opportunities. In addition, The University of Southern Mississippi (USM) has partnered with the secondary polymer science programs to host an annual student competition. For more information, please refer to the University of Southern Mississippi Polymer Science department, usm.edu/polymer.

Cooperative Learning
Cooperative learning can help students understand topics when independent learning cannot. Therefore, you will see several opportunities in the Polymer Science curriculum for group work. To function in today's workforce, students need to be able to work collaboratively with others and solve problems without excessive conflict. The Polymer Science curriculum provides opportunities for students to work together and help each other complete complex tasks. There are many field experiences within the Polymer Science curriculum that will allow and encourage collaboration with professionals currently in the polymer science field.

Work-Based Learning
Work-based learning (WBL) is an extension of understanding competencies taught in the Polymer Science classroom. This program may require students to obtain a minimum of 35 hours, which may include but are not limited to clinicals or worksite field experiences, entrepreneurships, internships, pre-apprenticeships, school-based enterprises, job placements, and simulated worksites. These real-world connections and applications provide a link to all types of students regarding knowledge, skills, and professional dispositions. Thus, supervised collaboration and immersion into the agricultural industry are keys to students' success, knowledge, and skills development. For more information on embedded WBL, visit the Mississippi Work-Based Learning Manual on the RCU website, rcu.msstate.edu.

Professional Organizations

American Chemical Society
acs.org

Society of Plastics Engineers
4spe.org

SPI: The Plastics Industry Trade Association
plasticsindustry.org

Using This Document

Competencies and Suggested Objectives
A competency represents a general concept or performance that students are expected to master as a requirement for satisfactorily completing a unit. Students will be expected to receive instruction on all competencies. The suggested objectives represent the enabling and supporting knowledge and performances that will indicate mastery of the competency at the course level.

Teacher Resources
All teachers should request to be added to the Canvas Resource Guide for their course. For questions or to be added to the guide, send a Help Desk ticket to the RCU by emailing helpdesk@rcu.msstate.edu.

Perkins V Quality Indicators and Enrichment Material
Some of the units may include an enrichment section at the end. This material will greatly enhance the learning experiences of students. If the Polymer Science program is using a national certification, work-based learning, or another measure of accountability that aligns with Perkins V as a quality indicator, this material could very well be assessed on that quality indicator. It is the responsibility of the teacher to ensure all competencies for the selected quality indicator are covered throughout the year.

Unit 1: Orientation to Industrial Employability and Safety

Competencies and Suggested Objectives
1. Evaluate the local program and explore how personality traits and learning styles can impact success in the classroom and workplace. DOK3 a. Examine the local student handbook and program, establishing rules and guidelines. b. Examine how understanding personality and learning styles can impact learning and workplace performance. • True Colors • Animal communications • Myers-Briggs • Learning style inventories • Multiple intelligence assessments c. Describe student organizations (including SkillsUSA and Technology Student Association) activities and participate in a polymer skills competition.
2. Explain and demonstrate employability skills over the course of the program. DOK4 a. Perform a self-evaluation and compare it to traits of a quality employee (e.g., integrity, loyalty, responsibility, etc.). b. Create an educational and/or career-track plan for a selected job in materials science. c. Prepare a résumé containing essential information for polymer specific careers. d. Complete a job application. e. Describe and demonstrate the procedures for a job interview. f. Explain personnel law, requirements of Title IX law, and employment procedures as related to plastics and polymer manufacturing.
3. Explain and demonstrate the roles human relations, teamwork, and leadership play in plastics and polymer manufacturing. DOK3, 4 a. Describe and practice the qualities of an effective leader (i.e., positive attitude, image, decisiveness, communication skills, and professional knowledge). b. Prepare a project-management methodology and use it consistently. c. Research and/or participate in personal-development seminars, leadership conferences, and national/international exchange programs, or research/participate in student organizations, competitions, and related activities.
4. Describe and demonstrate safe laboratory practices and environmental responsibility when working with laboratory equipment, chemicals, and processing equipment commonly encountered in polymer-related industries. DOK1, 2, 3 a. Apply safety rules/guidelines, colors, and symbols for the lab and workplace, and establish how to use safety equipment properly (e.g., Flinn safety test/contract). b. Investigate how industrial, governmental, and environmental organizations impact safe operations in polymer-related industries. • Occupational Safety and Health Administration (OSHA) • Environmental Protection Agency (EPA) • Chemical Safety Board (CSB) • American Chemical Society (ACS)

- American National Standards Institute (ANSI)
- Food and Drug Administration (FDA)

c. Identify basic laboratory equipment and functions while correctly and safely using selected pieces of equipment.
d. Detail safe practices related to the operation of equipment in laboratories and manufacturing facilities.
    - Lockout tags
    - Safety zones and floor markings
    - Emergency stop buttons
e. Evaluate the resources available for the safe handling and disposal of chemicals.
    - Department of Transportation (DOT) placards
    - National Fire Protection Agency (NFPA) safety diamond
    - Safety Data Sheets (SDS)

5. Demonstrate the ability to manage a computer operating system in relation to plastics and polymer applications. DOK1, 4
    a. Create files and transfer them between directories and subdirectories.
    b. Produce and utilize graphics in relation to research for plastics design and production.
    c. Produce quality word processing and multimedia documents related to polymer science topics.
    d. Create an e-portfolio to include all relevant materials.

Note: Safety is to be taught as an ongoing part of the program. Students are required to complete a written safety test with 100% accuracy before entering the workspace. Documentation should be kept on file.

Note: This unit will be ongoing throughout the year. Time allotted for this unit will be distributed over the entire year.

Unit 2: Chemistry of Solids and Solutions

Competencies and Suggested Objectives

1. Apply inquiry-based and problem-solving processes and skills to scientific investigations. DOK2, 3, 4
   a. Use current technologies to explore current research related to a specific topic.
      - Peer review
      - Web technology
      - Authentic vs. hearsay
      - Primary vs. secondary sources
   b. Clarify research questions and design laboratory investigations.
   c. Demonstrate the use of scientific inquiry and methods to formulate, conduct, and evaluate laboratory investigations.
      - Hypothesis
      - Experimental design
      - Observations
      - Data analyses
      - Interpretations
      - Theory development
   d. Organize data to construct graphs (e.g., plotting points, labeling the x- and y-axis, and creating appropriate titles and legends for circle, bar, and line graphs), draw conclusions, and make inferences.
   e. Evaluate the procedures, data, and conclusions to critique the scientific validity of research.
   f. Formulate and revise scientific explanations and models using logic and evidence (data analysis).
   g. Collect, analyze, and draw conclusions from data to create a formal presentation using available technology (e.g., computers, calculators, Smart Board, computer-based learning, lab interfaces, etc.).

2. Demonstrate an understanding of the atomic model of matter by explaining atomic structure. DOK2
   a. Describe and classify matter based on physical and chemical properties and the interactions between molecules of atoms (e.g., classifying properties such as boiling point, melting point, density, mass, volume, flammability, etc. as being physical or chemical; describing each state of matter in terms of internal energy, molecular motion, and the phase transitions within and between them).
   b. Classify matter as pure substances or mixtures, including homogeneous and heterogeneous mixtures and solution saturations, and investigate the conditions that impact mixture formation and stability (e.g., heat, agitation, solute-solvent compatibility, etc.).
   c. Develop a model of atomic and nuclear structure based on theory and knowledge of the fundamental particles including protons, neutrons, and electrons.

d. Describe the properties and interactions of the three fundamental particles of the atom and explain the laws of conservation of mass, constant composition, definite proportions, and multiple proportions. e. Use atomic numbers and mass numbers to calculate the number of protons, neutrons, and electrons in individual isotopes and ions.
3. Develop an understanding of the periodic table. DOK2 a. Analyze patterns and trends and make predictions regarding the organization of elements in the periodic table and compare their relationships to their positions in the table (e.g., atomic number, atomic mass, metal and non-metal character, electronegativity, and reactivity). b. Following the Aufbau principle, write electron configurations and Lewis diagrams of elements and ions.
4. Investigate the way the atomic structure and arrangement in matter impact bonding and chemical reaction. DOK2, 3 a. Use Lewis dot structures and periodic trends to predict and draw compound structures and formulas. b. Compare the properties of compounds according to their types of bonding, including metallic, ionic, and covalent bonding (e.g., non-polar and polar covalent bonds, single and multiple bonds [double and triple], and intermolecular forces, including hydrogen bonding and van der Waals forces). c. Classify reactions by type (synthesis, decomposition, single displacement, double displacement, combustion, and redox reactions), and identify reactants and the products involved in reaction, explaining how the electrons of reacting species interact to make these changes possible. d. Balance equations for chemical reactions, representing the connection between the microscopic (particles) and macroscopic (moles and bulk properties) levels of matter.

Enrichment
1. Research and explain the critical contributions and experiments of John Dalton, J. J. Thomson, Robert Millikan, Ernest Rutherford, Louis de Broglie, Erwin Schrödinger, and others to describe how each discovery contributed to the current model of atomic and nuclear structure.
2. Discuss the development of the periodic table and the contributions of Johannes Döbereiner, John Newlands, Dmitri Mendeleev, Henry Mosely, etc.
3. Use Lewis structures to predict molecular geometries (shapes and bond angles), polarities, hybridization, and intermolecular forces.
4. Using given reactants, predict possible reaction products.

Unit 3: Foundational Organic Chemistry

Competencies and Suggested Objectives
1. Identify common organic molecules and relate their structures to chemical and physical properties. DOK1 a. Construct models and illustrate structures for aliphatic, aromatic, and cyclic hydrocarbons, applying prior bonding knowledge. 2. Apply International Union of Pure and Applied Chemistry (IUPAC) nomenclature for simple organic structures and derivatives (i.e., functional groups such as alcohols, amines, aldehydes, ketones, carboxylic acids, esters, amides, ethers, etc.). DOK2, 3 a. Describe how functional groups affect properties of simple organic molecules.

Enrichment
1. Use Lewis structures to predict molecular geometries (shapes and bond angles), polarities, hybridization, and intermolecular forces. 2. Write and classify common reactions for aliphatic, aromatic, and cyclic hydrocarbons.

Unit 4: Polymers

Competencies and Suggested Objectives
1. Examine the history and development of the polymer and material science industries/professions, polymer and polymer architecture. DOK1 a. Trace the development of polymer and material science technologies/industries from beginning through present day (e.g., Materials Through the Ages timeline, polymer development timeline). b. Research and describe career opportunities, including educational requirements, earnings potential, etc. for polymer and materials-related fields.
2. Differentiate between polymer structure and architecture. DOK3 a. Structure • Chemical structure • Linear • Branched • Cross-linked • Tacticity b. Architecture • Phase diagram of block copolymers ○ Spherical domains ○ Continuous phase • Star • Comb • Brush • Ring • Dendrimer
3. Recognize and differentiate natural and synthetic polymers. DOK1, 2 a. Describe natural polymers. • Cellulose • DNA/RNA • Natural rubber • Starches • Proteins b. Describe synthetic polymers. • Thermoplastics • Thermosets • Fiber • Films • Elastomers • Adhesives c. Differentiate between the properties of natural and synthetic polymers, including polydispersity, degree of polymerization, and molecular weight.

4. Relate plastics recycling/conservation principles and their effects on the environment. DOK2
   a. Classify the different types of plastics and their recycling codes.
      - PETE—Polyethylene terephthalate
      - HDPE—High-density polyethylene
      - V—Polyvinyl chloride
      - LDPE—Low-density polyethylene
      - PP—Polypropylene
      - PS—Polystyrene
      - Other plastics
   b. Research and describe the various sorting and recycling methods (e.g., primary, secondary, and tertiary recycling, or the three Rs).
   c. Debate the cost of using recycled polymers versus virgin polymers in manufacturing.
   d. Examine the human issues related to recycling for the different types of plastics, including e-waste and ocean pollution.

5. Relate small molecule chemistry to the production of polymer compounds. DOK2, 3
   - Polyethylene
   - Polypropylene
   - Polystyrene
   - Polytetrafluoroethylene
   - Polyvinyl chloride
   - Polyvinyl alcohol
   - Polyvinyl acetate
   - Polymethyl methacrylate
   - Polybutadiene
   - Polyurethanes
   - Epoxies
   - Phenolics (e.g., Bakelite, etc.)
   - Melamine

   a. Using models, demonstrate the structure of monomers and their repeat units.
   b. Using models, demonstrate the structure and synthesis of homopolymers illustrating the following: linearity, various types of branching, and tacticity.
   c. Using models, demonstrate the structure and synthesis of various types of copolymers and terpolymers illustrating the following: random, alternating, block, and graft structures.

6. Explore how the chemistry of polymer preparation affects performance properties. DOK2
   a. Describe and demonstrate different types of polymer syntheses to include condensation and addition polymerization.
   b. Communicate the relationship that exists between polymerization type (step-growth and chain-growth) and graphical representations of growth rates.
   c. Explore the effects of molecular weight, molecular weight distribution, branching, tacticity, and cross-linking on polymer properties.

7. Explore physical properties and how they affect end-use performance. DOK3
   a. Thermal transitions, glass transition temperature, and crystalline melting point
   b. Mechanical properties
   c. Rheological properties (e.g., viscosity, melt flow, etc.)

Enrichment

1. Implement additive and subtractive techniques to repurpose or reuse recyclable materials.
2. Investigate recycling and repurposing strands within the maker, tinker, and/or fab movements.
3. Research the history of rheology and viscosity.

Unit 5: Thermoplastic Polymer Processing

Competencies and Suggested Objectives
1. Differentiate between polymer synthesis, manufacturing, and processing. DOK2
2. Explain how basic processing techniques are used to convert polymer feedstock into plastic products, and manufacture plastic parts using each processing technique. DOK4 a. Describe and demonstrate single-step polymer processing techniques. • Extrusion • Injection molding • Thermoforming/vacuum-forming • Rotational molding • Fiber formation • Blow molding (extrusion and injection) • Blown film extrusion • Dip coating
3. Identify acceptable and unacceptable products for each single-step processing technique. DOK1 a. Identify short-shots, flashing, and warped parts. b. Troubleshoot various processing techniques to create good parts.
4. Apply the principles of computer-aided design and drafting (CADD) to create designs and prototypes for plastic parts. DOK3 a. Interpret and apply basic CADD symbols to create, edit, and print parts and drawings in preparation for making plastic parts. b. Demonstrate the importance of wall thickness, draft angles, ribs, fillets, and rounds in part design. c. Design, create, edit, and produce a rapid prototyped part from 2D and 3D prints/plots according to specifications. d. Compare and contrast additive and subtractive 2D and 3D manufacturing techniques in making quality parts.

Enrichment
1. Demonstrate the ability to read and interpret a basic blueprint. a. Demonstrate the ability to read the various parts of a blueprint. b. Demonstrate the ability to interpret the different views of a blueprint.

Unit 6: Polymer Safety and Concepts Review

Competencies and Suggested Objectives
1. Re-evaluate the local program and explore how personality traits and learning styles can impact success in the classroom and workplace. DOK1 a. Re-examine the local student handbook and program, establishing rules and guidelines. b. Re-examine how understanding personality and learning styles can impact learning and workplace performance, such as True Colors, animal communications, Myers-Briggs, learning style inventories, multiple intelligence assessments, etc. c. Describe student organizations (including SkillsUSA and TSA) activities and participate in a polymer skills competition.
2. Describe and demonstrate safe laboratory practices and environmental responsibility when working with laboratory equipment, chemicals, and processing equipment commonly encountered in polymer-related industries. DOK2 a. Apply safety rules/guidelines, colors, and symbols for the lab and workplace and establish how to use safety equipment properly (e.g., Flinn safety test/contract). b. Investigate how industrial, governmental, and environmental organizations impact safe operations in polymer-related industries (e.g., OSHA, EPA, CSB, ACS, ANSI, FDA, etc.). c. Identify basic laboratory equipment and functions while correctly and safely using selected pieces of equipment. d. Detail safe practices related to the operation of equipment in polymer-related laboratories and manufacturing facilities (e.g., lockout tags, safety zones and floor markings, emergency stop buttons, etc.). e. Evaluate resources available for safe handling and disposal of chemicals (e.g., DOT placards, NFTA safety diamond, SDS documents).

Note: Safety is to be taught as an ongoing part of the program. Students are required to complete a written safety test with 100% accuracy before entering the workspace. Documentation should be kept on file.
Note: This unit will be ongoing throughout the year. Time allotted for this unit will be distributed over the entire year.

Unit 7: Industry Guided Work-Based Learning

Competencies and Suggested Scenarios
1. Identify a materials science related problem encountered in industry. DOK1
2. Reach out to the polymer science advisory committee members or industry professionals to get a list of possible problems that could produce a viable solution after the students work through the scientific design process. DOK3 a. Select one materials science related problem submitted by industry to be investigated using the scientific design process.
3. Develop a detailed plan for investigating the problem. DOK3 a. Research the problem. b. Brainstorm possible solutions. c. Consider or establish constraints and specifications. d. Select option for further analysis. e. Create procedures appropriate to investigate the problem.
4. Test or research the chosen solution (i.e., prototype, process, etc.), recording any data or observations. DOK4
5. Analyze all the accumulated data and organize the findings in a clear fashion for communication of the results (i.e., graphs, tables, charts, diagrams, literary reviews, etc.). DOK4
6. Independently prepare detailed documentation of the research experience (i.e., lab report, multimedia presentation, journal article, etc.). DOK4
7. Present documentation to industry representatives for evaluation. DOK4

Unit 8: Advanced Polymer Manufacturing

Competencies and Suggested Objectives
1. Explain how additives affect the properties of a polymeric material. DOK2 a. Explain how compounding and formulation change the properties and processing of polymers by using additives or modifiers.
2. Explain how advanced manufacturing techniques are used to create products. DOK3 a. Describe and demonstrate advanced manufacturing processes. • Casting • Open- and closed-cell foam processing • Expanded bead molding • Calendering • Compression molding
3. Differentiate between acceptable and unacceptable products for each advanced processing technique. DOK3 a. Troubleshoot the various processing techniques to create good parts.

Unit 9: Metals

Competencies and Suggested Objectives
1. Demonstrate a foundational understanding of the properties of metals and related materials. DOK3 a. Analyze the properties of metals as compared to other materials, including alloys, ceramics, and composites. b. Relate the macroscopic properties of metallic substances to crystalline metal microstructures.
2. Demonstrate a foundational understanding of the processing techniques for metals and related materials. DOK3 a. Assess the importance of, describe the processes used, and apply various methods of reduction to obtain metals from their ores as it pertains to industrial metals production. b. Perform conditioning processes to harden, temper, and anneal metal.

Enrichment
1. Use materials testing to analyze the macroscopic properties of metals and other materials that arise from processing and work hardening stresses.

Unit 10: Ceramics and Glass

Competencies and Suggested Objectives
1. Demonstrate a foundational understanding of the properties of ceramics and glass. DOK3 a. Analyze the relationship between the metallic ores, metals, and ceramic materials arising from the oxidation of metallic materials. b. Assess how chemical bonding and the observable properties of ceramic materials give rise to a wide variety of ceramic uses in our society. c. Analyze the amorphous structure and properties of glass (also known as the special ceramic).
2. Demonstrate a foundational understanding of the manufacturing techniques for ceramics and glass. DOK3 a. Examine and perform ceramic processing techniques, including Raku.

Enrichment
1. Examine and demonstrate glass batching and other glass processing techniques.

Unit 11: Surface Coatings

Competencies and Suggested Objectives
1. Describe the production of various types of surface coatings. DOK2 a. Differentiate between the types of coatings (e.g., Architectural [DIY], Original Equipment Manufacturer [OEM], and specialty purpose coatings, their properties, and their uses in industry). b. Research and communicate the development of coatings through the years, including binder type advancements (from drying oils through high solids coatings). c. Illustrate the synthesis of waterborne binders for surface coatings (i.e., emulsions). d. Identify legislation that influences the push for low to no volatile organic compounds (VOCs) coatings and discuss industry responses.
2. Demonstrate the properties of coatings. DOK3 a. Expand understanding of the use of additives with regards to coatings formulations to influence performance properties. b. Evaluate application suitability of surface coatings using various properties (e.g., impact, adhesion, hardness, flexibility, etc.).

Unit 12: Composite Materials, Manufacturing, and Applications

Competencies and Suggested Objectives
1. Examine composite materials and their configurations in final parts to determine how each affects the finished properties of a composite structure. DOK2 a. Evaluate possible matrix and reinforcement materials in terms of chemistries and forms (e.g., particulate, fiber-reinforced, laminar, etc.). b. Assess how composite performance is influenced by various structural configurations of reinforcements (e.g., stressed skin, oriented fibers, tubes vs. rods, etc.).
2. Investigate different composite manufacturing methods and composite applications. DOK3 a. Research and communicate how advanced needs and technologies have influenced the development of composites materials and processing (e.g., Portland cement, aerocrete, fiberoptic concrete, aerogels, plywood, glulam, particle board, fiberglass, carbon fiber, and graphene). b. Evaluate various composites manufacturing techniques (e.g., hand lay-up, spray lay-up, Vacuum Assisted Resin Transfer Molding [VARTM], vacuum bagging, autoclave prepreg, etc.) emphasizing their influences on finished products. c. Investigate the automation of manufacturing processes (e.g., Resin Transfer Molding [RTM], filament winding, pultrusion, automated tape lay-up [ATL], etc.).

Student Competency Profile

Student's Name: _____

This record is intended to serve as a method of noting student achievement of the competencies in each unit. It can be duplicated for each student, and it can serve as a cumulative record of competencies achieved in the course.

In the blank before each competency, place the date on which the student mastered the competency.

Unit 1: Orientation to Industrial Employability and Safety		
	1.	Evaluate the local program and explore how personality traits and learning styles can impact success in the classroom and workplace.
	2.	Explain and demonstrate employability skills over the course of the program.
	3.	Explain and demonstrate the roles human relations, teamwork, and leadership play in plastics and polymer manufacturing.
	4.	Describe and demonstrate safe laboratory practices and environmental responsibility when working with laboratory equipment, chemicals, and processing equipment commonly encountered in polymer-related industries.
	5.	Demonstrate the ability to manage a computer operating system in relation to plastics and polymer applications.
Unit 2: Chemistry of Solids and Solutions		
	1.	Apply inquiry-based and problem-solving processes and skills to scientific investigations.
	2.	Demonstrate an understanding of the atomic model of matter by explaining atomic structure.
	3.	Develop an understanding of the periodic table.
	4.	Investigate the way the atomic structure and arrangement in matter impact bonding and chemical reaction.
Unit 3: Foundational Organic Chemistry		
	1.	Identify common organic molecules and relate their structures to chemical and physical properties.
	2.	Apply International Union of Pure and Applied Chemistry (IUPAC) nomenclature for simple organic structures and derivatives (i.e., functional groups such as alcohols, amines, aldehydes, ketones, carboxylic acids, esters, amides, ethers, etc.).
Unit 4: Polymers		
	1.	Examine the history and development of the polymer and material science industries/professions, polymer and polymer architecture.
	2.	Differentiate between polymer structure and architecture.
	3.	Recognize and differentiate natural and synthetic polymers.

	4.	Relate plastics recycling/conservation principles and their effects on the environment.
	5.	Relate small molecule chemistry to the production of polymer compounds.
	6.	Explore how the chemistry of polymer preparation affects performance properties.
	7.	Explore physical properties and how they affect end-use performance.
Unit 5: Thermoplastic Polymer Processing		
	1.	Differentiate between polymer synthesis, manufacturing, and processing.
	2.	Explain how basic processing techniques are used to convert polymer feedstock into plastic products, and manufacture plastic parts using each processing technique.
	3.	Identify acceptable and unacceptable products for each single-step processing technique.
	4.	Apply the principles of computer-aided design and drafting (CADD) to create designs and prototypes for plastic parts.
Unit 6: Polymer Safety and Concepts Review		
	1.	Re-evaluate the local program and explore how personality traits and learning styles can impact success in the classroom and workplace.
	2.	Describe and demonstrate safe laboratory practices and environmental responsibility when working with laboratory equipment, chemicals, and processing equipment commonly encountered in polymer-related industries.
Unit 7: Industry Guided Work-Based Learning		
	1.	Identify a materials science related problem encountered in industry.
	2.	Reach out to the polymer science advisory committee members or industry professionals to get a list of possible problems that could produce a viable solution after the students work through the scientific design process.
	3.	Develop a detailed plan for investigating the problem.
	4.	Test or research the chosen solution (i.e., prototype, process, etc.), recording any data or observations.
	5.	Analyze all the accumulated data and organize the findings in a clear fashion for communication of the results (i.e., graphs, tables, charts, diagrams, literary reviews, etc.).
	6.	Independently prepare detailed documentation of the research experience (i.e., lab report, multimedia presentation, journal article, etc.).
	7.	Present documentation to industry representatives for evaluation.
Unit 8: Advanced Polymer Manufacturing		
	1.	Explain how additives affect the properties of a polymeric material.
	2.	Explain how advanced manufacturing techniques are used to create products.
	3.	Differentiate between acceptable and unacceptable products for each advanced processing technique.
Unit 9: Metals		

	1.	Demonstrate a foundational understanding of the properties of metals and related materials.
	2.	Demonstrate a foundational understanding of the processing techniques for metals and related materials.
Unit 10: Ceramics and Glass		
	1.	Demonstrate a foundational understanding of the properties of ceramics and glass.
	2.	Demonstrate a foundational understanding of the manufacturing techniques for ceramics and glass.
Unit 11: Surface Coatings		
	1.	Describe the production of various types of surface coatings.
	2.	Demonstrate the properties of coatings.
Unit 12: Composite Materials, Manufacturing, and Applications		
	1.	Examine composite materials and their configurations in final parts to determine how each affects the finished properties of a composite structure.
	2.	Investigate different composite manufacturing methods and composite applications.

Appendix A: National Standards

	Units	1	2	3	4	5	6	7	8	9	10	11	12
Standards													
HS-PS1-1			X										
HS-PS1-2			X	X									
HS-PS1-3			X					X					
HS-PS1-4			X	X	X			X			X	X	X
HS-PS1-5			X	X	X			X					
HS-PS1-6		X	X	X					X				
HS-PS1-7			X	X	X						X		
HS-PS1-8			X		X								
HS-PS2-1			X	X				X					
HS-PS2-2			X	X	X								
HS-PS2-3		X				X		X		X			
HS-PS2-4			X										
HS-PS2-5			X					X					
HS-PS3-1			X										
HS-PS3-2			X							X			
HS-PS3-3		X	X			X		X					
HS-PS3-4			X		X	X		X		X			
HS-PS3-5			X	X									
HS-PS4-1			X								X		
HS-PS4-2			X			X							
HS-PS4-3													
HS-PS4-4			X										
HS-PS4-5			X		X								X

NGSS - A Framework for K-12 Science Education

HS-PS1 Matter and Its Interactions

1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.
4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.
5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.
7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
8. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

HS-PS2 Motion and Stability: Forces and Interactions

1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
3. Apply science and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
4. Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
5. Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

HS-PS3 Energy

1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative position of particles (objects).
3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).
5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

HS-PS4 Waves and Their Applications in Technologies for Information Transfer

1. Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

2. Evaluate questions about the advantages of using digital transmission and storage of information.
3. Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.
4. Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Appendix B: College and Career Readiness Standards

	Units	1	2	3	4	5	6	7	8	9	10	11	12
Standards													
CHE.1.1		X	X			X		X					
CHE.1.2		X	X		X			X					
CHE.1.3		X	X		X	X		X	X			X	X
CHE.2.1			X		X								
CHE.2.2			X		X								
CHE.2.3		X	X				X	X					
CHE.2.4			X										
CHE.3.1			X		X					X	X		
CHE.3.2			X					X		X	X		
CHE.3.3			X					X		X	X		
CHE.4.1			X	X	X	X			X				
CHE.4.2			X	X	X	X							
CHE.4.3			X										
CHE.4.4			X	X	X				X		X		
CHE.4.5			X	X	X					X	X		X
CHE.4.6			X		X				X	X		X	X
CHE.4.7			X					X		X		X	X
CHE.4.8			X		X			X		X		X	X
CHE.5.1			X	X	X				X			X	
CHE.5.2			X					X	X			X	
CHE.5.3			X	X		X		X	X			X	
CHE.6.1			X	X	X	X						X	
CHE.6.2		X	X	X	X			X				X	X
CHE.6.3		X	X	X	X				X			X	
CHE.6.4			X					X		X	X		X
CHE.6.5			X					X					
CHE.6.6			X										
CHE.6.7			X					X				X	
CHE.7.1			X		X								
CHE.7.2		X	X			X		X					
CHE.7.3		X	X					X		X	X		
CHE.7.4			X		X					X			
CHE.7.5		X	X			X		X					X
CHE.7.6			X	X									
CHE.7.7			X					X					
CHE.7.8		X	X					X					
CHE.8.1		X	X			X		X		X	X		
CHE.8.2			X	X	X								
CHE.8.3			X		X	X				X		X	
CHE.8.4			X					X					

CHE.8.5		X	X			X		X					
CHE.8.6			X		X		X	X					
CHE.8.7			X	X				X					
CHE.8.8		X			X		X						
CHE.9.1			X	X				X		X	X		
CHE.9.2			X	X				X		X	X		
CHE.9.3			X					X					
CHE.9.4			X	X									
CHE.9.5			X	X									
CHE.9.6			X	X				X					
CHE.10.1			X	X	X								
CHE.10.2			X	X				X					
CHE.10.3			X	X	X			X			X		
CHE.10.4			X		X								X
CHE.11.1			X	X	X				X	X			
CHE.11.2			X	X				X					
CHE.11.3			X	X		X		X					
CHE.12.1			X	X							X	X	X
CHE.12.2			X	X	X						X		
CHE.12.3			X	X	X							X	

Chemistry: 2018 Mississippi College and Career Readiness Standards for Science -Applied Academic Credit Benchmarks

CHE.1 Mathematical and Computational Analysis Conceptual Understanding: Mathematical and computational analysis is a key component of scientific investigation and prediction of outcomes. These components create a more student-centered classroom.

CHE.1 Students will use mathematical and computational analysis to evaluate problems.

1. Use dimensional analysis (factor/label) and significant figures to convert units and solve problems.
2. Design and conduct experiments using appropriate measurements, significant figures, graphical analysis to analyze data.
3. Enrichment: Research information from multiple appropriate sources and assess the credibility, accuracy, possible bias, and conclusions of each publication.

CHE.2 Atomic Theory Conceptual Understanding: Atomic theory is the foundation of modern chemistry concepts. Students must be presented with a solid foundation of the atom and its components. These concepts lead to an understanding of the interactions of these components to explain macro-observations of the world.

CHE.2 Students will demonstrate an understanding of the atomic structure and the historical developments leading to modern atomic theory.

1. Investigate the historical progression leading to the modern atomic theory, including, but not limited to, work done by Dalton, Rutherford's gold foil experiment, Thomson's cathode ray experiment, Millikan's oil drop experiment, and Bohr's interpretation of bright line spectra.
2. Construct models (e.g., ball and stick, online simulations, mathematical computations) of atomic nuclei to explain the abundance weighted average (relative mass) of elements and isotopes on the published mass of elements.
3. Investigate absorption and emission spectra to interpret explanations of electrons at discrete energy levels using tools such as online simulations, spectrometers, prisms, flame tests, and discharge tubes. Explore both laboratory experiments and real-world examples.
4. Research appropriate sources to evaluate the way absorption and emission spectra are used to study astronomy and the formation of the universe.

CHE.3 Periodic Table Conceptual Understanding: Modern chemistry is based on the predictability of atomic behavior. Periodic patterns in elements led to the development of the periodic table. Electron configuration is a direct result of this periodic behavior. The predictable behavior of electrons has led to the discovery of new compounds, elements, and atomic interactions. Predictability of atom behavior is a key to understanding ionic and covalent bonding and production of compounds or molecules.

CHE.3 Students will demonstrate an understanding of the periodic table as a systematic representation to predict properties of elements.

1. Explore and communicate the organization of the periodic table, including history, groups, families, family names, metals, nonmetals, metalloids, and transition metals.
2. Analyze properties of atoms and ions (e.g., metal/nonmetal/metalloid behavior, electrical/heat conductivity, electronegativity and electron affinity, ionization energy, and atomic/ionic radii) using periodic trends of elements based on the periodic table.
3. Analyze the periodic table to identify quantum numbers (e.g., valence shell electrons, energy level, orbitals, sublevels, and oxidation numbers).

CHE.4 Bonding Conceptual Understanding: A firm understanding of bonding is necessary to further development of the basic chemical concepts of compounds and chemical interactions.

CHE.4 Students will demonstrate an understanding of the types of bonds and resulting atomic structures for the classification of chemical compounds.

1. Develop and use models (e.g., Lewis dot, 3-D ball-stick, 3-D printing, or simulation programs such as PhET) to predict the type of bonding between atoms and the shape of simple compounds.
2. Use models such as Lewis structures and ball and stick models to depict the valence electrons and their role in the formation of ionic and covalent bonds.
3. Predict the ionic or covalent nature of different atoms based on electronegativity trends and/or position on the periodic table.
4. Use models and oxidation numbers to predict the type of bond, shape of the compound, and the polarity of the compound.

5. Use models of simple hydrocarbons to exemplify structural isomerism.
6. Use mathematical and computational analysis to determine the empirical formula and the percent composition of compounds.
7. Use scientific investigation to determine the percentage of composition for a substance (e.g., sugar in gum, water and/or unpopped kernels in popcorn, percent water in a hydrate). Compare results to justify conclusions based on experimental evidence.
8. Plan and conduct controlled scientific investigations to produce mathematical evidence of the empirical composition of a compound.

CHE.5 Naming Compounds Conceptual Understanding: Polyatomic ions (radicals) and oxidation numbers are used to predict how metallic ions, nonmetals, and transition metals are used in naming compounds.

CHE.5 Students will investigate and understand the accepted nomenclature used to identify the name and chemical formulas of compounds.

1. Use the periodic table and a list of common polyatomic ions as a model to derive chemical compound formulas from compound names and compound names from chemical formulas.
2. Generate formulas of ionic and covalent compounds from compound names. Discuss compounds in everyday life and compile lists and uses of these chemicals.
3. Generate names of ionic and covalent compounds from their formulas. Name binary compounds, binary acids, stock compounds, ternary compounds, and ternary acids.

CHE.6 Chemical Reactions Conceptual Understanding: Understanding chemical reactions and predicting products of these reactions is essential to student success.

CHE.6 Students will demonstrate an understanding of the types, causes, and effects of chemical reactions.

1. Develop and use models to predict the products of chemical reactions (e.g., synthesis reactions; single replacement; double displacement; and decomposition, including exceptions such as decomposition of hydroxides, chlorates, carbonates, and acids). Discuss and/or compile lists of reactions used in everyday life.
2. Plan, conduct, and communicate the results of investigations to demonstrate different types of simple chemical reactions.
3. Use mathematics and computational analysis to represent the ratio of reactants and products in terms of masses, molecules, and moles (stoichiometry).
4. Use mathematics and computational analysis to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. Give real-world examples (e.g., burning wood).
5. Plan and conduct a controlled scientific investigation to produce mathematical evidence that mass is conserved. Use percent error to analyze the accuracy of results.
6. Use mathematics and computational analysis to support the concept of percent yield and limiting reagent.

7. Plan and conduct a controlled scientific investigation to produce mathematical evidence to predict and confirm the limiting reagent and percent yield in the reaction. Analyze quantitative data, draw conclusions, and communicate findings. Compare and analyze class data for validity.

CHE.7 Gas Laws Conceptual Understanding: The comparison and development of the molecular states of matter are an integral part of understanding matter. Pressure, volume, and temperature are imperative to understanding the states of matter.

CHE.7 Students will demonstrate an understanding of the structure and behavior of gases.

1. Analyze the behavior of ideal and real gases in terms of pressure, volume, temperature, and number of particles.
2. Enrichment: Use an engineering design process to develop models (e.g., online simulations or student interactive activities) to explain and predict the behavior of each state of matter using the movement of particles and intermolecular forces to explain the behavior of matter.
3. Analyze and interpret heating curve graphs to explain the energy relationship between states of matter (e.g., thermochemistry-water heating from -20oC to 120oC).
4. Use mathematical computations to describe the relationships comparing pressure, temperature, volume, and number of particles, including Boyle's law, Charles's law, Dalton's law, combined gas laws, and ideal gas laws.
5. Enrichment: Use an engineering design process and online simulations or lab investigations to design and model the results of controlled scientific investigations to produce mathematical evidence that confirms the gas-laws relationships.
6. Use the ideal gas law to support the prediction of volume, mass, and number of particles produced in chemical reactions (i.e., gas stoichiometry).
7. Plan and conduct controlled scientific investigations to produce mathematical evidence that confirms that reactions involving gases conform to the law of conservation of mass.
8. Enrichment: Using gas stoichiometry, calculate the volume of carbon dioxide needed to inflate a balloon to occupy a specific volume. Use an engineering design process to design, construct, evaluate, and improve a simulated air bag.

CHE.8 Solutions Conceptual Understanding: Solutions exist as solids, liquids, or gases. Solution concentration is expressed by specifying relative amounts of solute to solvent.

CHE.8 Students will demonstrate an understanding of the nature of properties of various types of chemical solutions.

1. Use mathematical and computational analysis to quantitatively express the concentration of solutions using the concepts such as molarity, percent by mass, and dilution.
2. Develop and use models (e.g., online simulations, games, or video representations) to explain the dissolving process in solvents on the molecular level.

3. Analyze and interpret data to predict the effect of temperature and pressure on solids and gases dissolved in water.
4. Design, conduct, and communicate the results of experiments to test the conductivity of common ionic and covalent compounds in solution.
5. Use mathematical and computational analysis to analyze molarity, molality, dilution, and percentage dilution problems.
6. Design, conduct, and communicate the results of experiments to produce a specified volume of a solution of a specific molarity and dilute a solution of a known molarity.
7. Use mathematical and computational analysis to predict the results of reactions using the concentration of solutions (i.e., solution stoichiometry).
8. Enrichment: Investigate parts per million and/or parts per billion as it applies to environmental concerns in your geographic region, and reference laws that govern these factors.

CHE.9 Acids and Bases (Enrichment)

CHE.9 Enrichment: Students will understand the nature and properties of acids, bases, and salt solutions.

1. Enrichment: Analyze and interpret data to describe the properties of acids, bases, and salts.
2. Enrichment: Analyze and interpret data to identify differences between strong and weak acids and bases (i.e., dissociation).
3. Enrichment: Plan and conduct investigations using the pH scale to classify acid and base solutions.
4. Enrichment: Analyze and evaluate the Arrhenius, Bronsted-Lowry, and Lewis acid-base definitions.
5. Enrichment: Use mathematical and computational thinking to calculate pH from the hydrogen ion concentration.
6. Enrichment: Obtain, evaluate, and communicate information about how buffers stabilize pH in acid-base reactions.

CHE.10 Thermochemistry (Enrichment)

CHE.10 Enrichment: Students will understand that energy is exchanged or transformed in all chemical reactions.

1. Enrichment: Construct explanations to explain how temperature and heat flow in terms of the motion of molecules (or atoms).
2. Enrichment: Classify chemical reactions and phase changes as exothermic or endothermic based on enthalpy values. Use a graphical representation to illustrate the energy changes involved.
3. Enrichment: Analyze and interpret data from energy diagrams and investigations to support claims that the amount of energy released or absorbed during a chemical reaction depends on changes in total bond energy.
4. Enrichment: Use mathematical and computational thinking to solve problems involving heat flow and temperature changes, using known values of specific heat and latent heat of phase change.

CHE.11 Equilibrium (Enrichment)

CHE.11 Enrichment: Students will understand that chemical equilibrium is a dynamic process at the molecular level.

1. Enrichment: Construct explanations to explain how to use Le Chatelier's principle to predict the effect of changes in concentration, temperature, and pressure.
2. Enrichment: Predict when equilibrium is established in a chemical reaction.
3. Enrichment: Use mathematical and computational thinking to calculate an equilibrium constant expression for a reaction.

CHE.12 Organic Nomenclature (Enrichment)

CHE.12 Enrichment: Students will understand that the bonding characteristics of carbon allow the formation of many different organic molecules with various sizes, shapes, and chemical properties.

1. Enrichment: Construct explanations to explain the bonding characteristics of carbon that result in the formation of basic organic molecules.
2. Enrichment: Obtain information to communicate the system used for naming the basic linear hydrocarbons and isomers that contain single bonds, simple hydrocarbons with double and triple bonds, and simple molecules that contain a benzene ring.
3. Enrichment: Develop and use models to identify the functional groups that form the basis of alcohols, ketones, ethers, amines, esters, aldehydes, and organic acids.