ACS Guidelines and Recommendations

FOR TEACHING MIDDLE AND HIGH SCHOOL CHEMISTRY




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Introduction

One of the goals of the American Chemical Society (ACS) is to support excellence in education by fostering the development of innovative, relevant, and effective chemistry and chemistry-related education. In the spirit of this commitment, this document is the updated and expanded version of the 2012 “ACS Guidelines and Recommendations for Teaching High School Chemistry.” To broaden their reach and relevance, these guidelines also consider the needs of middle school instruction, where chemistry is usually connected to and taught as physical science. Although many of the topics included at the middle school level are not addressed in as much detail as at the high school level, building a chemistry foundation and integrating it with other branches of science serve students well as they progress to high school chemistry and other science courses.

The purpose of this document is to provide guidance to the middle and high school physical science and chemistry education community, with focus on the nature of instruction, the core ideas to teach, the physical instructional environment, safety, sustainability, and the professional responsibilities of teachers. Although this document is not intended to be a prescribed course outline or “how to” list, it is intended to emphasize the essential components of a successful and safe learning environment for the teaching of chemistry.

The primary audiences for this document are middle and high school physical science and chemistry teachers, curriculum developers, principals, and other school administrators who support teachers in those roles. These guidelines should also serve as a resource for pre- and in-service teacher preparation programs. This document describes the broad requirements necessary to teach chemistry to all students, with an emphasis on student-centered learning. These guidelines recognize the professional integrity of teachers who may want to share information with their school or district administrators about ways they can be supported, best practices for teaching chemistry, and the physical environment, which includes the tools of educational technology and laboratory facilities. These guidelines are presented to support the work of classroom chemistry teachers and provide research-based information to administrators who support those teachers.


CHANGE
SHIFT
NONE
NONE!
Temp

Pathways to Learning: Core Ideas for Students and Best Practices for Teachers to Use

EXPECTED STUDENT OUTCOMES

In an outstanding curriculum, students will learn how to communicate scientific ideas. Students will be exposed to and engage in activities that involve problem solving and reasoning with chemical concepts to help them develop their scientific literacy skills. Students will investigate and verify scientific concepts and principles by analyzing data, whether they are collected through their own experiments or gathered from other reliable sources. Students should understand the interactions of matter at the macroscopic and particulate levels, as well as symbolically. These essential elements of a curriculum will help students make informed decisions about relevant scientific issues in their daily lives. In addition, the curriculum will instill a desire to further investigate the wonder, excitement, and dynamic nature of science.

JOHNSTONE'S TRIANGLE–REPRESENTATIONS OF CHEMISTRY

One of the most important ideas about chemistry for students to learn is that what is perceived at the macroscopic level is a result of interactions at the particulate level—at the level of atoms, ions, and molecules—which can be represented symbolically. This way of explaining chemical phenomena is known as Johnstone's triangle.[i] This approach to perceiving and modeling chemical processes has tremendous utility and can help students understand some seemingly perplexing ideas. Chemists explain and predict the behavior of matter by observing how it interacts on the macroscopic level. They draw conclusions of what takes place on the particulate level and represent those happenings symbolically. Effective instruction requires teachers to help students understand how phenomena relate at the particulate, symbolic, and macroscopic levels.

For example, a fire—a macroscopic event—produces heat and light, and causes typically invisible air to be noticed. A chemist, at the particulate level, knows that oxygen molecules and carbon-rich molecules collide at high velocities to produce carbon dioxide, water, and other products. At the middle school level, students' learning should focus on the conceptual and qualitative happenings on the macroscopic and particulate levels, and the chemistry content can be integrated into other scientific disciplines through developmentally and culturally appropriate explanations. At the high school level, extensions into symbolic and mathematical understandings of the chemistry content should be explored.

CORE CONCEPTS IN CHEMISTRY

The tables below and on the following pages outline the core ideas in chemistry that should be addressed in any comprehensive middle or high school curriculum. Each core idea is further broken into chemical principles, and suggested concepts to teach within those ideas are listed. These tables have been generated with the guidance of the Next Generation Science Standards [ii] (NGSS) disciplinary core ideas (DCIs) in the physical sciences. The task force identified the concepts that fall into each DCI within the core ideas.

The content does not need to be learned or shared in the order presented, and this is not an all-inclusive list. For example, there are DCIs within the Earth & Space Sciences (ESS) as well as the Engineering, Technology & Applications of Science (ETS) standards that could be learned by students within a physical science or chemistry course. (For example, Global Climate Change is a DCI within ESS and could easily be addressed in a physical science or chemistry curriculum.) Teachers may have additional standards (such as the Common Core State Standards in English Language Arts & Mathematics) that they need to incorporate into their teaching practice. Teachers also may need to consult state and local standards to ensure all of the essential elements and assessment boundaries of their curriculum are included.

FOR HIGH SCHOOL

CORE IDEAS	CHEMICAL PRINCIPLES (DCIS)	CHEMISTRY CONCEPTS
Matter and its interactions	Structure and properties of matter Chemical reactions Nuclear processes	States of matter Solutions Periodicity Bonding and intermolecular forces Physical changes Chemical changes Reaction types Stoichiometry Kinetics Equilibrium Nuclear chemistry
Motion and stability: forces and interactions	Structure and properties of matter Forces and motion Types of interactions Definitions of energy	Periodicity and atomic structure Bonding and intermolecular forces Ionic bonding Covalent bonding Molecular structure Types of chemical reactions Kinetics Electrochemistry Materials: properties explained by molecular structure Chemical engineering
Energy	Definitions of energy Conservation of energy and energy transfer Relationship between energy and forces Energy in chemical processes	Thermochemistry Thermodynamics Equilibrium Bonding and intermolecular forces Electrochemistry Nuclear chemistry Nature of science Chemical engineering Thermodynamics
Waves and electromagnetic radiation	Energy in chemical processes Wave properties Electromagnetic radiation Information technologies and instrumentation	Atomic structure Quantum chemistry Electromagnetic radiation spectrum Quantitative analysis (e.g., Beer's law)

FOR MIDDLE SCHOOL

CORE IDEAS	CHEMICAL PRINCIPLES (DCIS)	CHEMISTRY CONCEPTS
Matter and its interactions	Structure and properties of matter Chemical reactions Definitions of energy	Chemical and physical properties States of matter Phase changes Chemical equations Evidence of a chemical change Law of conservation of matter Energy is involved in chemical changes
Motion and stability: forces and interactions	Forces and motion Types of interactions	Attractions and repulsions Types of chemical bonding: ionic and covalent
Energy	Definitions of energy Conservation of energy and energy transfer Relationship between energy and forces	Temperature and energy Convection, conduction, and radiation Energy and chemical reactions Chemical engineering
Waves and their applications in technologies for information transfer	*All topics identified in this section may align more closely with physics course content.* Wave properties Electromagnetic radiation Information technologies and instrumentation	In a physical science course, teachers could address topics related to sound waves, light waves, and the interactions between energy and matter

These concepts are not isolated from each other. For example, reaction types can't be taught without incorporating the concepts of atoms, ions, bonding, and chemical equations. To appropriately address the chemical principles (DCIs), as outlined in "A Framework for K-12 Science Education"[iii] and detailed in NGSS, the concepts should be taught using the three dimensions: science and engineering practices (SEPs), crosscutting concepts (CCCs), and DCIs. Appendices H and K of NGSS provide information about the nature of science and curriculum building.

At both the middle and high school levels, students should be made aware of how chemistry relates to many other science fields. Also, informing students that chemistry is present in other subjects outside of science, such as history, math, and language arts, benefits students' understanding of chemistry and may extend their appreciation for chemistry. Likewise, the chemistry curriculum should not be limited to addressing only chemical principles. Rather, students should be exposed to the nature of science in general and how chemistry relates to other sciences and other subjects. And of course, the core ideas of chemistry are not solely the domain of chemistry teachers. Teachers of other sciences should incorporate some of these topics, as should teachers of subjects outside of science to a lesser extent.

Examining, explaining, and understanding matter and its transformations at the various levels are accomplished best by allowing students to investigate. Investigation should be prominent in any science curriculum both at the middle and high school levels. Simple concepts that are widely accepted today, such as the percentage of oxygen in the air, were the result of many years of observations, questions, investigations, and experimentation. Participating in the classroom means that students, too, will learn the practices of science and engineering, as suggested by NGSS. Experiments should be performed at both the middle and high school levels to generate data that will provide evidence and discourse for solving scientific questions and engineering problems. See more about investigations in the Laboratory section of this document.

Success in chemistry involves imagination, organization, and reasoning with chemical ideas on the part of teachers and students. Middle school teachers should be prepared to introduce and support concepts of metric measurement, bar and line graphs, making detailed observations, using technology (such as photos and slow motion video) to enhance observations, modeling, discourse, and conclusion writing. High school chemistry teachers should be prepared to teach and reinforce additional science and mathematical skills, as well as critical reading and writing skills, to ensure all students' needs are met. This is best done by helping students make connections between their prior knowledge and their new understanding.

EFFECTIVE STRATEGIES FOR TEACHING CHEMISTRY

Lesson Formats

Advanced planning is crucial for active student engagement. As guided by local and/or state standards, teachers should decide on the conceptual learning goals, with focus on chemical principles and concepts within the core ideas in chemistry. Spiraling the curriculum (building on and making connections to what students have already learned) encourages student participation and understanding. Making the material relevant to students' lives will also promote engagement in their learning.[iv] Teachers should highlight guiding questions at the beginning of each lesson to focus the attention of both teachers and students on the key learning objectives for the lesson. This pedagogical approach fosters participation and inclusion of learning via the three dimensions.

Several lesson formats such as guided inquiry, modeling, and investigating a problem promote deeper understanding by students. In the 5E Instructional Model, teachers engage students, allow them to explore through experimentation, explain or summarize their new learning, elaborate through application, and finally evaluate their claims. The expanded 7E model adds an elicit step at the beginning and an extension step before students evaluate their claims.

Other effective lesson formats appropriate for some topics in chemistry include role playing, manipulation of concepts via simulations, and modeling. Process Oriented Guided Inquiry Learning (POGIL) is also an instructional strategy designed to optimize student learning and engagement. Differentiated instruction is always appropriate. Cognitive science discourages "teaching as telling." [v] Therefore, careful planning is necessary to avoid having science lessons become rote presentation or memorization of facts. If the most effective way to teach a concept is by lecturing, allow students to preview the information and provide them in advance with organizers to maximize participation and promote student understanding. [vi]

Assess Student Understanding by Questioning

Regardless of the lesson format that is chosen, teachers must prepare appropriate questions to assess student understanding during each phase of the lesson. These questions include an *engaging question* at the beginning of a lesson to determine what students already know, *probing questions* during the lesson to guide student learning, and *closing questions* at the end of the lesson to gauge what students learned.

The *engaging questions* should be answered by students with the understanding that students don't have to have the "right" answer; the purpose of these questions is to generate initial ideas.

- Diagrams and drawings allow for students to develop an initial conceptual model for their current understanding.
- A lesson about intermolecular forces could begin with a question about how water pollutants dissolve in water. Often these questions uncover naive ideas or misconceptions that will be addressed later in the lesson.
- Students could be presented with a provocative question related to their lives or provided with a puzzling discrepant event to challenge prior conceptions.

- Many chemistry teachers begin a lesson with a demonstration or video clip that makes students think about the topic in a different way. Sometimes a simple demonstration paired with a good question is sufficient to spark student learning.

> Asking, "What are the bubbles made of?" while pouring water from a pitcher into a beaker will encourage students to think more deeply about everyday experiences. This can be followed by heating the beaker of water on a hot plate and discussing the difference between the small bubbles viewed initially and the large bubbles produced when the water boils. Asking students how they can test their ideas about the composition of the bubbles—rather than providing them with a step-by-step lab procedure or explaining the answer to them without allowing them to struggle with the concept—leads to a much deeper understanding of the concept.

During a lesson, effective *probing questions* help students develop their ability to solve problems. The questions should help students make connections to other learning. To determine what students truly understand, open-ended questions are more effective than questions that have only one answer or questions that can be answered with yes or no.

At the conclusion of the lesson, it's a good idea to ask a *closing question*, which allows students to consider what was discussed during the lesson and provides feedback to the instructor about possible misconceptions that were generated. Using the responses to the closing questions can allow the instructor to prepare appropriate engaging questions for the following lesson.

Problem Solving

Chemistry students must become good problem solvers. This is an active, sometimes confusing process, which is often frustrating but frequently rewarding. Thomas Edison didn't invent the light bulb by following a recipe; he developed more than 1,000 faulty light bulbs before figuring out how to make one work. Students must learn to explore problems and understand that taking a "wrong" step is often just as valuable as following the correct path. Students should be observant and self-critical during the problem-solving process to evaluate whether they are getting closer to or farther from the desired solution.

- Teachers should model their own thinking to help students understand how experts work through a problem: Start with the given information, put the pieces together, and evaluate whether students arrive at a solution that seems reasonable. Students must evaluate whether their answer is reasonable; learning to estimate mathematical answers is crucial to problem solving.
- Cooperative learning strategies could be used to help students solve meaningful real-life problems.
- To avoid cries of, "Why do we have to know this?" from students, teachers should develop a context for learning. For example, students could work in teams to investigate local air quality, learn the nutritional value of their favorite foods, or discover the effects of fertilizer on water quality. This is not a textbook topic, but it requires students to apply textbook knowledge to real-life scenarios.

Modeling

Much of chemistry involves questioning macroscopic phenomena that cannot be physically observed at the particulate level. By developing and modifying models, students can refine their understanding and eventually develop a model through the process of consensus. Deliberately teaching that all models have limitations allows new types of models to be introduced that enable students to further explore the depth of the concepts and to recognize limitations in facets of understanding. Then, to help students understand these abstract concepts, carefully prepared analogies and models can be used.

Visualizations of phenomena with computer-based models are great tools to describe how chemical processes relate to changing particle motion and organization. Simulations to demonstrate these microscopic properties can be found at middleschoolchemistry.com, PhET, the American Association of Chemistry Teachers (AACT), and other platforms.

> Modeling molecular motion and particle arrangement is common at the middle school level. But at the high school level, chemical phenomena are described using Lewis structures and molecular models. In addition, mathematical equations such as gas laws are also used at the high school level to justify observations.

Scientific terminology

Students can use vocabulary to hide their misconceptions. For instance, students may be able to define density mathematically, as well as state that an object will float in water if its density is less than that of water. But when asked why, students may be unable to explain floating in terms of particle organization. Vocabulary should be introduced near the end of the lesson to give names to the concepts the students have come to comprehend more thoroughly. [vii] Effective modeling and three-dimensional assessments can help teachers know what their students know.

Choice

Many students can demonstrate achievement of learning objectives when they have the option to choose how to express their understanding through alternative modes such as by delivering an oral presentation, creating a portfolio, or completing a creative project. Some students require a structured environment, so chemistry teachers should provide explicit instructions and rubrics for assignments in advance. Giving students a choice in the chemistry classroom enriches their understanding of the content. Student motivation is improved when students are actively involved in learning and allowed to share their perspectives.

Promoting student reflection

Providing students time to reflect on their new knowledge helps ensure their understanding endures past the closing bell.

- Ask students to complete exit cards with prompts, such as "Today I Learned ...," "I would still like to know more about ...," or "I still don't understand...".
- Students can write a letter to a relative or a friend explaining in nontechnical terms what was learned in chemistry that week.
- Students can keep a journal or search for real-world examples as evidence of topics learned in class.
- Add new rules or evidence to a student-generated or classroom-public model to build understanding.

Teachers can capitalize on the importance of chemistry in everyday life to engage their students. Teachers should follow through with opportunities for students to actively explore and struggle with new concepts in a way that allows them to embrace three-dimensional learning. To motivate students and deepen their understanding of chemistry, instructors need to plan thoughtful lessons in advance and establish clear learning goals. Allowing students to reflect on their knowledge complemented by effective questioning from the instructor helps them solidify concepts.

USING ASSESSMENT TO IMPROVE INSTRUCTION

An assessment is not just a test at the end of a unit. Assessments should be designed so students do science themselves, not just learn about how other people have done it or memorize facts. [viii] As a result, student understanding should be monitored throughout a unit using informal assessments or evaluations. This informs the instructor of where students are with their understanding of the content and provides feedback about what content needs reinforcement or adjustment. Student misconceptions of scientific concepts are common and should be dispelled as soon as possible. Of course, lessons and follow-up activities should be planned ahead of time but should be modified according to the feedback gathered from assessments. The evaluation of student learning should use a combination of different assessment tools, such as the following:

Formative assessment is accomplished during the learning process (as knowledge is "formed") and can include observing students during classroom and laboratory activities, posing questions during a lesson, taking polls, collecting exit slips, or conducting informal conversations with students. This gives teachers the opportunity to adjust lessons to ensure proper student understanding and dispel apparent misconceptions. Various technologies can be used for this form of assessment, including those suggested by Common Sense Education.

A **summative assessment** is performed at periodic intervals to assess a collection of knowledge at a particular point in time. Summative assessments may take the form of traditional assessments, including quizzes, exams, lab reports, and term papers but may also include projects, posters, presentations, etc.

Student self-assessment could be in the form of a journal that is used to encourage students to reflect and assess their progress. This allows for students to "think about their thinking" and understanding of the content. Another form of self-assessment is allowing students to score their own work using a rubric or scoring key.

Performance-based assessments have proven to be effective in assessing three-dimensional learning. This requires students to demonstrate content knowledge (DCIs), the ability to make connections (CCCs), and developing solutions to solve a problem (SEPs).

Model-based assessment allows students to demonstrate content knowledge. The creative diagramming aspect of the model means that students, especially English language learners (ELLs), can demonstrate content understanding without being bogged down by vocabulary; they can show their comprehension is deeper than vocabulary.

Third-party assessment tools have the advantage of being unbiased and statistically valid. Local, district, and state assessments may be examples of third-party assessments, including end-of-course exams. Some tools, such as those from the ACS Exams Institute, can provide objective national or regional performance rankings.

Effective assessment tools should be used for any assessment, whether formal or informal. The assessment should be valid and reliable. Assessment questions should be clear and unambiguous, and assessments should be based on learning objectives. To help determine whether you're using an effective tool, consider the following: Is the assessment type appropriate, are the questions on level, is the delivery method of the assessment effective, and what should/does the scoring method look like.[ix]

Regardless of the assessment method, the results of these assessments should be reviewed thoroughly by teachers so they can improve their delivery of content. These assessment tools provide teachers with feedback about how students are mastering (or not mastering) the concepts of chemistry. A credible assessment of an overall chemistry program should be based on information from a variety of assessment tools over a span of several years. The gathered information should be carefully examined and must be used to enhance student learning by improving the program from the collected results.

TEACHING STUDENTS OF DIFFERENT ABILITIES—DIFFERENTIATION

All students should learn the core ideas and concepts in chemistry. That way, they will develop an understanding of the material world around them while learning to question what's happening in their surroundings. Teachers should have high expectations for every student, at every level, from physical science to Advanced Placement Chemistry. To meet the needs of *all* students, chemistry teachers should present information in multiple ways, using alternatives to engage everyone including those with varying physical and cognitive abilities as well as limited English language proficiency. Students should be given options for demonstrating their understanding; Universal Design for Learning (UDL) can be a resource for possible approaches. Teachers may also benefit from consulting the publication *Teaching Chemistry to Students with Disabilities.* Technology can also be a tool to assist with varying lessons, as demonstrated by the Center for Applied Special Technology.

Students who use sign language may have idioms that can make a concept more memorable, and students with limited mobility may need a more efficient way of conducting a lab procedure.

To provide learning opportunities using multiple means, teachers can share information visually and orally, or use symbols and words. Chemistry teachers have a distinct advantage because of the demonstrable nature of the subject; if a student doesn't buy into a phenomenon, a demonstration or investigation can satisfy the student's curiosity. All students benefit when teachers simultaneously display and name the apparatus to use, the chemical being discussed, the safety practice to follow, or a problem-solving strategy to implement. Chemistry teachers can make chemistry personally and culturally relevant to a diverse student population by using regional or international examples. For example, the water crisis in Flint, Michigan, was featured on national news starting in 2014. Teachers can use that news story to emphasize how chemistry affects communities in real life and examine how chemistry impacted that community.

Many students will seek opportunities beyond a first-year chemistry course while in high school. To meet the needs of these students, science departments should consider offering Advanced Placement (AP) or International Baccalaureate (IB) chemistry courses. These third-party organizations (the College Board and IB) offer extensive syllabi for advanced high school chemistry, and they also provide opportunities for professional development for teachers (see the Professional Development section for other opportunities).

Teachers can help students pursue their chemistry interest by connecting them with summer research opportunities, which are offered by many universities and government research labs. ACS ChemClubs is another program that can enrich learners. (See other options in the Extracurricular section.) Above all, teachers of chemistry should offer students of all abilities and interests an avenue to expand their knowledge, experience, and appreciation of chemistry.

English Language Learners (ELLs)

Common English words such as believe, claim, or consider can be problematic for nonnative speakers. However, some vocabulary in chemistry has Latin origins, so students who speak Spanish or other Latin-based languages may easily relate to these terms. ELLs may also struggle with prepositions, idiomatic expressions, and words having multiple meanings (e.g., mole, set, model, or right). Students or teachers may produce visual representations of important words to ensure all students properly comprehend the concept. Breaking down words may be a helpful way to make vocabulary more meaningful to all students, not just ELLs.

When learning chemical symbols, students can be challenged to determine which country was named for silver (Argentina, from the Latin argentum).

Breaking down words is a useful tool: Exothermic – diagram the word showing exo = out, therm = heat

Model-based assessment frequently provides equal access to demonstrating content knowledge. The creative diagramming aspect of the model means that ELL students, and others, can demonstrate their understanding without worrying about vocabulary, and it simultaneously allows students to demonstrate a true conceptual understanding, not just memorization of vocabulary.

Chemistry for All Students

Teachers need to understand and build on the cultural resources (knowledge, interests, and experiences) that students bring to the practice of scientific argumentation.

This can increase their engagement and inclusion, especially for students from nondominant communities. Selecting culturally relevant phenomena helps engage all learners. To support the diverse cultural and economic backgrounds of students, culturally strong lessons are instrumental in the classroom. Consider adopting the 12 key elements[x] in effective teaching for ethnic and language minority students.

Help Students See Themselves in Science

Chemists and chemistry professionals are as diverse as the elements on the periodic table. ACS has a statement on diversity that speaks to how accepting a diverse community is beneficial, and it includes resources ACS offers to promote and support a diverse community. In the classroom, teaching that the chemistry field is open to all people might include showcasing leaders and highlighting biographies of individuals who contributed to and are currently pioneering the field of chemistry. In addition to the ones mentioned in the ACS diversity statement, other resources that teachers can rely on to support and promote diversity include:

- AACT videos
- ACS chemistry landmarks
- ACS webinars about nontraditional career options
- a statement by AAAS CEO
- the Chemical Heritage Foundation's Beckman Center for the History of Chemistry

By no means is this an exhaustive list, but these resources may be good starting points that instructors can reference.

THE LABORATORY EXPERIENCE

Chemistry is a laboratory science and cannot be effectively taught without a robust laboratory experience for students at both the middle and high school levels. The identification, manipulation, and general use of laboratory equipment are integral parts of the subject. A school laboratory should have equipment to conduct meaningful demonstrations and experiments (see a full list of recommended equipment in the Classroom Setting section). The laboratory environment must be accessible to all students and maintained with safety in mind. Teachers should use safety measures to protect students and themselves during any investigation. With appropriate accommodations, students with limited strength or mobility can participate in the laboratory experience.

Instruction that is student-centered and emphasizes the role of laboratory demonstrations and experiments is the best method to ensure students develop the essential skills of science. Laboratory investigations should come in three phases: the pre-lab, the lab experience, and the post-lab.

- In the pre-lab, students should consider the concept or principle to be investigated. This gives them the opportunity to make predictions and hypotheses. Effective pre-lab questions can prompt students to review and recall previously learned concepts that are pertinent to the investigation. This is also an opportunity to discuss safety protocols for the lab and introduce any new lab equipment they will use.
- The lab experience allows students to learn how to plan their actions and to identify and control variables. During the investigation, they will observe, measure, classify, and record data. They must conduct all labs following safety guidelines. Incorporating technology into lab investigations may enhance how students collect and manipulate data (see the Technology in the Lab section).
- The post-lab provides an opportunity for students to analyze and interpret data, evaluate the effectiveness of the procedure, formulate models, and communicate their findings in written and oral formats. Students can also relate or compare results and concepts with classmates and to previously learned phenomena. It's important to emphasize during this part that collecting the same data does not mean final reports will be the same; there's a difference between collaborating and copying. Each student will grapple with the data a little differently and express their findings using their own voice. The post-lab is also a time for students to evaluate the safety guidelines that were presented in the pre-lab.

The laboratory experience is an opportunity for students to test scientific hypotheses and not simply verify predicted outcomes. In this vein, do not hesitate to repeat experiments. Focus on different aspects of the reaction through a different lens so students can realize a new concept.

Carrying out the simple reaction between $CuSO_4$ and Al illustrates many concepts of chemistry.

- Chemical change
- Single replacement reaction
- Redox chemistry
- Activity series
- Solubility
- Concentration
- Conservation of mass

There's nothing wrong with repeating this reaction multiple times throughout the year to show that the reaction always has the same outcome and shows evidence of many types of chemical phenomena.

It is often appropriate to begin a unit with an investigation (especially discovery-style activities). This creates a concrete and unified example that students can relate to as they study concepts throughout a unit. Laboratory work should be an integral part of the curriculum and appropriately fit into the lesson structure—labs should not be done for the sake of doing them; students should be able to draw a conclusion from the investigation that relates to the concepts in the unit.

Middle school chemistry classrooms can function very much like those in high school, even without dedicated lab stations. Simple household materials and safe kitchen chemicals can be used to foster inquiry, gather data, interpret results, and explore phenomena. Middleschoolchemistry.com provides a comprehensive curriculum with videos, simulations, demonstrations, and labs that are age appropriate.

Many resources are available for planning student-centered laboratory instruction. The Chemical Education Xchange regularly publishes blog posts by teachers about activities they are doing with their students; AACT has a library of resources to pull from as well as a quarterly periodical written by chemistry teachers about what they practice in their classrooms; most science supply companies, including Flinn Scientific, Carolina Biological, Sargent Welch, and others, have many lab and demonstration materials available for purchase; ACS publishes a variety of chemical demonstration books; and the National Science Teachers Association (NSTA) offers many resources about lab investigations in the chemistry classroom.

APPLYING TECHNOLOGY IN THE CHEMISTRY CLASSROOM

Technology has transformed education and our society. Cell phones, projectors, wireless Internet access, interactive whiteboards, graphing calculators, laptop computers, tablets, and other evolving technologies are among the devices available to use in a chemistry classroom. If used appropriately, these tools can enhance student-centered instruction. Furthermore, with the advancement of social media, chemistry classrooms can easily access new findings and information that can deepen conversation and put chemistry into action. Students should be introduced to the concept of information literacy when using the Internet to research pre-lab assignments or experimental results. The use of primary literature and determining a "good" website should be promoted.

Benefits of Technology

Various forms of computerized assessments allow students and teachers to obtain immediate feedback of student understanding.

- Many assistive technologies, such as those from the Center for Applied Special Technology, are available to enhance the learning experience for students with disabilities.
- Educational technology has the power to enhance communication. Students and teachers can access research and resources beyond the walls of their school and share paperless reports that are rich in content.
- Teachers can access professional development via webinars, communicate with students and parents over email and social media, and interact online with colleagues throughout the world in real time from their classroom desks.
- Sites like Twitter and Facebook are helpful; teachers can join professional learning networks to gain ideas, get feedback, and discuss practices and policies. Furthermore, using educational blogs and chemistry-related YouTube channels can help teachers share current events with students and gain new ideas to incorporate into their own curriculum.

Staying Current

To ensure that effective use of technology is available for student learning, chemistry teachers should consult with their school's technology department, department chair, or appropriate personnel to identify what may work best for them and their students, and within the constraints of their school. With many schools being aware of the platforms available, safe Internet usage, Internet speed, and digital citizenship, teachers should be informed of their school's policies and adhere to them.

Teachers should stay current on the ever-evolving tools of educational technology and choose those that are most useful in terms of the value they might add to the chemistry curriculum. Since new technologies are constantly emerging, teachers should check different websites, such as the Office of Educational Technology, to ensure that the tools they are using to engage and inspire their students are up-to-date and appropriate.

Technology in the Lab

Laboratory activities may be performed with data collection instruments that interface directly with computers or calculators. Data collection devices, such as those developed by Vernier and Pasco, are examples of available technology appropriate at these grade levels. For example, digital sensors and wireless interfaces can be used for pH testing and water quality analysis. Once collected, these data are displayed on clearly labeled graphs, and students can easily interpret data.

At the high school chemistry level, advanced data analysis can take place with the help of technology. From digitally collected data, students can generate regression equations and lines of best fit to allow for interpolation and extrapolation to draw conclusions. The *Journal of Chemical Education*, *The Science Teacher,* and *Mathematics Teacher* journals are sources of investigations that use these devices, many of which may be used on a smaller scale—resulting in less waste and greater safety (see the Environmental Considerations section).

Videos of lab apparatus or advanced lab techniques can be created to assist students with a new experiment or method. Or if a student is absent from class the day of an experiment or demonstration, a video can provide him or her with the visual experience that other students had in the laboratory.

With access to shared documents, class data sets can be collected for more accurate data analysis. For example, when conducting a titration, a class set of data can be generated and shared. This provides students an opportunity to consider erroneous data points within a large set of data, rather than the limited two or three trials they conducted.

Although the use of technology is crucial to provide students with a modern education, it is important for students to understand the underlying chemistry principles and be able to articulate them.

When To Substitute a Hands-On Lab

Some experiments are too hazardous or impractical to be a hands-on investigation, in which case a teacher-led demonstration may be a suitable substitute. Other experiments may be too costly or require obscure resources. Those can be viewed on video. Thermite reactions, for instance, could be witnessed on a screen, eliminating the associated danger and required safety equipment. In a middle school classroom, many videos of hazardous chemical demonstrations are a great tool to engage budding young chemists.

Some concepts are difficult to investigate on a macroscale using chemicals. Computer animations and simulations are available for students on both the Internet and as applications on a computer or tablet. For example, the University of Colorado, Boulder, offers a number of age-appropriate chemistry simulations on its PhET website, and the Concord Consortium is another good source of simulations. These simulations typically investigate what happens on the particulate level via computer-generated models of molecular motion and interactions.

It is important to emphasize that hands-on laboratory experiences are critical to a quality chemistry curriculum. ACS recommends that technology should not be considered a replacement for the laboratory experience but rather an enhancement to it.

The Chemistry Setting: Classroom and Laboratory Facilities

INTRODUCTION

The physical facilities provided for learning any science must be planned, built, arranged, and maintained to optimize student learning securely and safely. This is especially true for the teaching and learning of chemistry, where equipment and supplies not only offer the opportunity for basic and advanced learning but also present unique and serious hazards. Whether designing and building new space or updating an existing one, the planning team must carefully consider every detail that may impact teacher effectiveness as well as student learning and safety.

THE CLASSROOM

The 21st-century chemistry classroom provides a learning environment that is student-centered and curriculum-driven. The floor plan should be designed for conversation, collaboration, and discovery. The classroom should contain enough space and storage to permit long-term multidisciplinary projects, individual and small-group learning, inquiry lessons, project-based learning, and problem solving. Flexibility in the arrangement of space is recommended. Universal design allows students with disabilities to participate and have access to all necessary facilities and equipment.

Teacher accommodations in the classroom should include a desk, chair, computer, and a demonstration table that includes a sink, natural gas connection, and a safety shield. Near the demonstration area should be the following safety equipment: a hands-free, plumbed-in eyewash station; a fire extinguisher; a first-aid kit; and a goggle UV-sanitizer with a class set of goggles.[xi] A system of secure communications with school administration and emergency response personnel is critical. A wireless network allows computers, printers, electronic display boards, and video projection systems to be connected.

The aforementioned equipment—especially safety equipment—should also be present in laboratory spaces that are separate from the classroom.

If students don't have individual devices, a portable cart with a class set of tablets or computers (one or two students per device) should be available, but they can be shared with other classrooms. This technology will connect students with each other, classrooms around the world, reference materials, and data collection systems. Computers also allow for enhanced access for students with disabilities.

A lockable file cabinet should be available for teacher use. Bookcases, storage cabinets that are master-keyed, and shelves are needed for classroom supplies. Wall space should be provided for electronic communications boards and displays.

For the Middle School Setting

Middle school classrooms may double as laboratory space and should also include access to the accommodations and essential safety equipment referenced above. Gas connections and safety shields may not be necessary at the middle school level.

THE LABORATORY

Lab work is an integral part of the chemistry experience. It allows students to explore chemical concepts, view changes in matter, and acquire scientific skills in an atmosphere that mimics a professional scientific environment. The laboratory should be arranged so that instruction and lab skills can be practiced safely and effectively. All laboratories must be equipped with the essential safety equipment. Science classrooms with scientific equipment and supplies should not be used for non-science courses or activities. The chemistry classroom often contains laboratory facilities. The classroom/laboratory should be vacant one period per day for safe lab preparation and maintenance. Teachers must have adequate preparation time. Lab activities should only be conducted in a science classroom/lab that is outfitted with proper lab and safety equipment. Special effort must be made to ensure that laboratory tables are never used for food activities.

> If the lab is not in the same space as the classroom, it should contain a fully equipped teacher station suitable for demonstrations and lab work.

Student lab stations should be arranged throughout the remaining work area; fixed stations are preferred. Arrangement of furniture must allow for adequate flexibility and teacher visibility of all students for supervision. If you have movable stations, consider upgrading to fixed stations.

To ensure student safety with adequate supervision the NSTA recommends a maximum of 24 students per classroom based on 60 square feet per student.[xii] NSTA has produced a position statement for middle and high school settings on the liability of science educators for laboratory safety that chemistry educators may wish to consult. The square footage per student must meet state regulations. Different state mandates may require additional square footage. Space requirements may also be based on building and fire safety codes, appropriate supervision, and the special needs of students in the class.

Additional areas should include a safety station and a station for students with disabilities. The arrangement of furniture must allow for adequate flexibility and supervision. For safety reasons, stools should not be in the walkways during laboratory investigations. Workstations should have access to natural gas, water, and electricity. Electrical outlets built into the frame of the workstation and equipped with a ground-fault circuit interrupter (GFCI) must be away from water and gas outlets and should be available to appropriately accommodate computers and technology equipment.

Separate disposal containers should be clearly labeled for chemical waste and broken glassware. Cabinetry within the workstations, or placed around the perimeter of the room, should be used to store supplies and serve as storage for additional lab equipment. Cabinets used for storing laboratory equipment should be selected to accommodate long or heavy equipment. There should be a secured chemical storage area, either attached to the room or elsewhere, locked when not in use. Chemical storage should not be in the classroom or lab. Access must be limited to science teachers and authorized personnel only.

For the Middle School Setting

A middle school laboratory may be a classroom with laboratory tables and sinks available. The space should be set up in a way that facilitates classroom activities and laboratory work. Many of the substances used at the middle school level are often common household items; however, once the chemicals are moved to the teaching environment they should be treated as laboratory chemicals. Students need to know that chemicals used in the science laboratory should never be tasted or consumed. Even though the chemicals are purchased at the store, in the lab they should only be smelled by wafting and under teacher instruction. All household items that are used in a laboratory setting should be labeled, “NOT FOR HUMAN CONSUMPTION.”

LAB & SAFETY EQUIPMENT

FOR A HIGH SCHOOL LAB	
Distilled water	Distilled water bottles, clearly labeled Ability to make distilled water, or distilled water source
Electronic balances	Centigram (0.01 g)
Weighing dishes	Small and medium size
Bunsen burners	Enough for each lab group to have access to one
Label tape, permanent marker, or grease pencils	To label glassware
Metal spatulas (microspatulas and scoopulas)	
Tongs	
Test tube clamps and holders	
Hot plates with magnetic stirring capabilities	
Stir bars	
Watch glass	
Microscale equipment	All can be labeled, stored, and reused, Microtip pipets, Straight-stem pipets, Combination plates
Thermometers	Alcohol (not mercury) and/or digital
Drying oven	
Wooden splints	
pH paper	
Glassware	Various sizes, Beakers, Erlenmeyer flasks, Volumetric flasks Graduated cylinders, Test tubes, Burets
Stirring rods	
Buret clamps	
Test tube racks	
Storage bottles	Plastic
Dropper bottles	For dispensing chemicals in labs
Chromatography paper	
Funnels	
Filter paper	
Ring stands	Iron rings
Molecular modeling kits	

NICE TO HAVE IN A HIGH SCHOOL LAB	
Laminated periodic tables	
Desiccator	
Beaker tongs	
Striker (to light Bunsen burner)	
Power supply and spectral tubes	
Volumetric pipets	
Pipet bulbs	
Ring clamps	
Mortar and pestle	
Rubber stoppers	
Evaporating dishes	
Crucibles	Wire gauze, Clay triangles, Crucible tongs
Rulers	
Calculators	Inexpensive, class set
Digital probes	Temperature, Pressure, Colorimeter with cuvettes, pH, Conductivity

FOR A MIDDLE SCHOOL LAB
Balance (0.1 g)
Weighing boats
Spatulas/scoopulas
Tongs
Hot plates
Beakers, various sizes
Erlenmeyer flasks, various sizes
Alcohol and/or digital thermometer
Graduated cylinders
Labeling tape, permanent marker, or grease pencil
Molecular modeling kits
Test tubes
Test tube racks
Funnels
Filter paper
Petri dishes

For students to carry out investigations in a safe environment, the following safety equipment must be in each lab space. These items must also be in the classroom if it's a separate room from the lab where chemical demonstrations will take place. If the chemical storage area is separate from the lab area, these safety features must also be outfitted in the chemical storage area. Fume hoods and portable safety shields are optional at the middle school level. All safety equipment must be properly maintained and tested on a regular basis.

SAFETY EQUIPMENT
Chemical splash goggles (one pair per student)
UV-sterilizing goggle cabinet
Lab aprons (one per student; nondisposable/plastic)
Nonlatex gloves
Broken-glass disposal bin
Eyewash station (plumbed in)
Fire blanket (optional; stop, drop, and roll can replace)
Fire extinguisher
First-aid kit
Fume hood (nice to have for middle school)
GFCI electric outlets
Paper towels/soap at each sink
Portable safety shield (nice to have for middle school)
Safety posters
Safety shower
Sinks – several with hot/cold water

In the Lab: Safety and Sustainability

INTRODUCTION

Teachers should be knowledgeable about the potential hazards (both chemical and physical) that are present in a teaching chemistry laboratory. It is important that teachers model best practices for their students, incorporate chemical safety principles into lessons, and enforce safety expectations with a conscious and consistent effort. The aim of this section is to provide teachers, administrators, and school personnel with an overview of current best practices and resources where further safety information may be located. This section is not meant to be an exhaustive source of information on laboratory safety. In 2016, ACS released updated safety guidelines for schools, which are based on RAMP safety procedures.[xiii]

THE "RAMP" PRINCIPLES FOR SAFETY

RAMP is an acronym designed to help teachers and students keep laboratory safety prominent, simple, and familiar.

Recognize the hazards

Assess the risks of the hazards

Minimize the risks of the hazards

Prepare for emergencies

The RAMP approach does not encompass specific procedures but principles that lead to identifying methods to minimize risks of hazards. The document includes hazards and risks in the laboratory, a list of appropriate laboratory safety equipment, safety rules and procedures, and emergency responses for middle and high school.

OPPORTUNITIES FOR SAFETY TRAINING

Teachers must receive and update safety training regularly. Recommendations and chemical knowledge frequently change, and it can be a challenge to stay abreast of the latest good practices. Those teachers assigned to be the school chemical hygiene officer (CHO) require extra education and training. Because of the changing nature of the field, professional development should be encouraged and supported by school administrators. Large school districts may provide this training, but if not, reputable online training courses are available. Flinn Scientific offers extensive training, including a certificate for both middle and high school teachers. AACT also provides safety resources, including student activities in its resource library as well as general information and good practices in its periodical, on its blog, and through webinars.

CHEMICAL STORAGE

Chemicals should be methodically stored and organized. Teachers should account for hazardous chemicals and chemical incompatibility when organizing their storerooms. The chemical storage area should be securely locked when not in use.

Teachers will have chemicals that are considered *hazardous* in their laboratories. These chemicals may be needed for a specialized lab or left behind from a previous teacher. Some schools and/or districts specify chemicals that are absolutely not allowed in schools. If a school or system does not limit what chemicals can be in a classroom setting, you can consult the ACS Restricted-Use Chemicals list (pages 3–9) in the document "Reducing Risks to Students and Educators from Hazardous Chemicals in a Secondary School Chemical Inventory." This list indicates whether a chemical is explosive, toxic, an irritant, carcinogenic, corrosive, an oxidizer, poisonous, an allergen, flammable, or capable of creating violent reactions. It is an extensive but not all-inclusive list; its intent is not to prohibit the use of these chemicals but to ensure that teachers are aware of specific hazards and can take the appropriate safety precautions to prevent exposure.

Another important aspect of storage is making sure that **incompatible chemicals** are physically separated when stored. Chemicals should never be stored alphabetically; this can allow incompatible chemicals to be near each other and react inside storage cabinets. Flinn Scientific offers help for teachers to organize their chemical storage area with this quick reference, which accounts for storage of incompatible chemicals. Note that there are limits to how long and in what quantities chemicals identified as waste can be stored. When setting aside chemicals for hazmat pickup, keep this in mind.

CHEMICAL STORAGE AREA

All chemicals should be stored in designated, locked areas designed for chemical storage. Safety features for chemical storage must follow local and state guidelines and recommendations. At the bare minimum the area should contain the following:

- Shelving for chemicals, organized to account for hazards and incompatibility.
- Separate, designated, enclosed cabinets for acids, bases, oxidizers, organics, and other flammables.
- Equipment should be stored in separate cabinets from chemicals.
- If chemical storage is near a classroom with emergency equipment and no physical barrier, then no additional safety equipment is needed in the chemical storage area. If the chemical area is detached from the classroom, it should be outfitted with safety equipment. If the chemical storage room is located remotely, consideration for safe transport must be made (carts, secondary containers, transport time, etc.).

SAFETY DATA SHEETS (SDSs)

It is important to know how to read and interpret safety labels and the new SDSs (updated from Material Safety Data Sheets (MSDS) in 2016). SDSs use the Globally Harmonized System (GHS), a universal system designed to provide a consistent method of communicating chemical hazards.

The Occupational Safety and Health Administration (OSHA) requires a full list of SDSs to be present in the laboratory, so it's recommended to print SDSs (available for free from Flinn) and organize them in a binder to store in the chemical storage room. Many fire department and emergency personnel require printed copies of all SDSs to be available to them in case of accident. These sheets can also be helpful when taking inventory of chemicals and for disposal. Teachers should consult the SDS for each chemical that will be used in an experiment or demonstration to review handling, disposal, and storage information. This also assists with the required RAMP hazard and risk assessment for the activity.

HAZARDOUS WASTE AND DISPOSAL CONSIDERATIONS

Waste is generated in the laboratory on a regular basis; however, not all waste is hazardous. Some chemicals can safely go in the trash or can be disposed of down the sink. Verify the following guidelines with your local codes, as restrictions may vary.

If you're disposing of approved chemicals in the trash, make sure they are in a tightly sealed container. Always alert maintenance staff when chemicals are in the trash to avoid any accidents. If an SDS doesn't communicate whether a chemical can go into the trash, you can refer to the chemical provider for further guidance. But the following guidelines may also be helpful:

To be safely disposed of in regular trash, a chemical must be:

- nonradioactive
- not a biological hazard
- not flammable, reactive, corrosive, toxic, or listed as hazardous per the Environmental Protection Agency (EPA)
- not a substance that may adversely affect human or environmental health
- not a carcinogen

Some chemicals are suitable for drain disposal. Again, if it's not indicated on an SDS, you can refer to the chemical provider for guidance. Only small amounts of approved chemicals should be disposed of down the drain (typically no more than a few hundred grams or milliliters per day).

The following general guidelines for sink disposal are as follows:

- chemicals that meet criteria for trash disposal
- 1-molar solutions of weak acids and bases with a pH between 5.5 and 10.5
- compounds that are a soluble combination of the cations and anions listed below

You should double-check with local hazmat authorities or a reputable source such as the Flinn catalog before flushing down the drain.

AACT created a quick-reference disposal chart to post in your laboratory that summarizes these best practices. It is not exhaustive but is helpful for day-to-day chemical disposal.

Teachers should keep a log of the contents of all hazardous waste disposal containers to avoid extra costs associated with hazmat pickup. If technicians know exactly what is in hazardous waste disposal containers, they will not have to perform expensive additional identification testing, which could be billed back to the school. All hazardous waste material should be clearly labeled with those words and the names of the contents should be spelled out with percentages.

Hazardous materials provide a unique problem for chemistry teachers because most do not have a quick and safe way to store or dispose of them. District officials should know the next scheduled hazmat pickup and whether teachers should store hazmat materials or deliver them to a central location. A nearby college or university can also be a resource, as those institutions have more frequent pickups and could help local schools with safe disposal. Additionally, fire departments can be a resource for local chemical disposal guidelines and hazmat pickup, especially for flammables.

ENVIRONMENTAL CONSIDERATIONS

Teachers should consider a variety of factors to make chemistry as "green" as possible when designing or choosing a laboratory activity. This includes considering the scale of quantities used, the amount and category of waste generated, and the proper in-class disposal methods for chemical waste. Microscale investigations can be effective in reducing the amounts of reactants used and products generated while providing cost-effective approaches for hands-on experiences for students.

A number of green chemistry resources are available to help teachers choose experiments appropriate for the learning objectives, with minimal environmental impact. The ACS Green Chemistry Institute and Beyond Benign provide some resources that follow green chemistry practices.

Professional Responsibilities: Teacher Expectations and Training

EQUITY

ACS has produced several statements that explain the organization's beliefs and values with respect to equity. One such statement is the ACS Statement on Diversity and Inclusion. Many chemists rely on ACS to promote inclusion and diversity within the discipline, and teachers of chemistry are expected to practice equity within the classroom setting. "Science for All," a phrase used by many—most notably the American Association for the Advancement of Science (AAAS)—is the cornerstone of the vision for high school chemistry. ACS fully supports the goal of a scientifically literate society and maintains that one way to achieve this goal is by providing equal opportunities for all students to learn chemistry. The implications of this position extend beyond the needs of a single classroom. Schools and the states that support them are responsible for supplying the resources needed for the development and enactment of a chemistry program. These programs should be inquiry-based, student-centered, and accessible to all learners so they can succeed.

Schools are charged with the responsibility of hiring professionals with values that align with the Science for All philosophy, who possess the pedagogical content knowledge required to enact a rigorous chemistry curriculum, and who view themselves as lifelong learners. Some of the research-based strategies that teachers should be aware of to achieve this vision of equity include the following:

- Be aware of research on best practices aimed at teaching and reaching all students
- Transform and adapt instructional practices to promote student learning
- Serve as equity role models in the classroom and to the community at large
- Recognize and teach to students' strengths
- Provide a learning environment focused on trust and fairness
- Connect with the culture of students, students' families, and the community

It is expected that teachers from the school and/or district will be provided with the support needed to meet these requirements.

ETHICS

Chemistry teachers work as both professional educators and as science professionals. In addition to adopting an ethical practice as science professionals, chemistry teachers are responsible for adhering to ethical conduct within the scope of their practice in the classroom. Ethical teachers present course content without distortion, bias, or personal prejudice. They model and promote ethical experimental design, honestly report and interpret data, reference sources of information, and credit the work of others. They refrain from misrepresentation of self and others and do not engage in fabrication, falsification, or plagiarism of ideas, images, or information.

Teachers must maintain confidentiality when evaluating student performance and exhibit ethical, professional, and respectful interactions within the education and scientific communities.

Chemistry teachers should make conscious decisions to promote safety and limit negative environmental impact by the design and enactment of their curriculum; they should model environmentally responsible actions for their students.

Teachers should consider how they and their class consume energy and other natural resources. Similarly, in the laboratory, an environmentally responsible curriculum includes, but is not limited to, the appropriate selection, storage, use, and disposal of chemical reagents, as well as the use of microscale procedures when suitable.

See Laboratory Safety and Environmental Considerations sections for more ideas and information.

PROFESSIONAL DEVELOPMENT

ACS recognizes that teaching is a complex and intellectually challenging profession. Successful chemistry teachers will adopt the stance of lifelong learning and be willing to collaborate and share their expertise with other science education professionals. Further, there should be continuity among states for certification purposes requiring chemistry teachers to hold a certification in chemistry. The requirements for certification should include training on good safety practices for setting up and conducting hands-on laboratory activities and demonstrations. School districts and administrations must support teachers' efforts by providing time, opportunity, and funding to support professional development, including updates on safety procedures when inspired by laboratory accidents with specific techniques that are frequently used by chemistry teachers.

> Many instructors have carried out the classic rainbow demonstration in unsafe ways in recent years. ACS released a safety alert that advises how to conduct the investigation in a safe way.

ACS expects the full support of each teacher's school and district to assist educators to grow as professionals. Support includes providing a school environment that encourages teachers' inquiry into their own practice, providing the resources to promote teacher leadership in professional learning communities, enabling opportunities for teachers to regularly network with other educational and scientific professionals, and recognizing and supporting teachers' participation in professional organizations.

Research finds that the most effective professional development is sustained throughout a teacher's practice, is teacher-led and collective in nature, is content-based, and focuses on improved student learning.[xiv] To this end, schools and districts must highly value and be willing and able to provide and/or support such professional development. In keeping with educational practices, teachers should consider the authority and reliability of the professional development resource.

Specific characteristics of effective professional development for chemistry teachers include:

- active learning opportunities for teachers derived from both research and practice
- opportunities for teachers to further develop both content skills and knowledge
- opportunities for teachers to reflect on the practice and effectiveness of their teaching and share these reflections
- accessible alerts to chemistry teachers of accidents that occur when common laboratory activities and/or demonstrations are carried out, with access to recommended modifications
- opportunities for teachers to learn in collaborative settings, such as professional learning communities within schools and districts
- support for teachers in leadership roles

Effective professional development opportunities also involve collaboration with members of the greater educational and scientific communities. Professional networking can be accomplished in meetings and workshops or via online communications. For example, some opportunities include:

- AACT membership, which includes webinars (two to four per month during the school year; free for general public, archive available to members only) and discounts to some science teacher meetings and workshops
- Chemistry Teacher day at ACS national meetings (twice a year, spring and fall) and ACS regional meetings (check regional meeting program for details)
- Biennial Conference on Chemical Education (BCCE) (summer in even years)
- ChemEd (summer in odd years)
- ChemEdXchange and ChemEdX conferences
- Regional ACS meetings (throughout the year)
- NSTA conferences (five per year; three regional, one national, one STEM-focused) and web seminars
- AACT/ACS Science Coaches (a partnership between a teacher and a professional chemist)

Teachers can be overwhelmed with day-to-day activities and find themselves unable to take advantage of additional opportunities, no matter how worthy or needed. Therefore, school administrators and districts should provide teachers with release time during their workday or with stipends for opportunities to make professional development activities truly available to teachers.

PROFESSIONAL ORGANIZATIONS AND RESOURCES

Membership and active participation in professional organizations can provide chemistry teachers with a host of opportunities to network with other education professionals on multiple levels.[xv] These organizations provide continued learning, classroom resources, workshops, articles, grant announcements, and online courses. They provide teachers with ideas and activities for their classes as well as ways to improve their own pedagogy and content knowledge. Being an active member, using online resources, and attending local, state, or national conferences associated with such professional organizations are great ways to stay current in the profession.

Specifically for chemistry teachers, AACT makes available a number of resources for the classroom, and the ACS/AACT Science Coaches program provides partnership with a chemist, which can include content and practice.

In addition to ACS, here are some select national associations and professional development organizations, that provide a variety of support materials and opportunities for chemistry teachers at all levels:

- American Association of Chemistry Teachers (AACT)
- ACS Committee on Chemical Safety (CCS)
- ACS Division of Chemical Education (DivCHED)
- ACS Division of Chemical Health and Safety (DCHAS)
- ACS Green Chemistry Institute (GCI)
- ACS-Hach Programs
- Association for Science Teacher Education (ASTE)
- Beyond Benign (green chemistry education)
- American Association for the Advancement of Science (AAAS)
- Association for Supervision and Curriculum Development (ASCD)
- National Academy of Sciences (NAS)
- National Association for Research in Science Teaching (NARST)
- National Science Foundation (NSF)
- National Science Teachers Association (NSTA)

ACS has local sections, which may have an associated teacher group. There are also regional science or chemistry education groups that teachers can find in their area. NSTA has some local sections that sponsor chemistry teacher organizations, and some areas have independent organizations. Often, areas with a local college or university may offer on-campus science education presentations and workshops for teachers, which may provide networking opportunities.

CHEMISTRY RESOURCES AND EXTRACURRICULAR ACTIVITIES FOR STUDENTS

Teachers should seek out opportunities for their students to connect classroom learning to the world around them. By extending the focus of chemistry beyond the classroom, teachers can provide students with enriching activities designed to ignite students' interest and imagination.

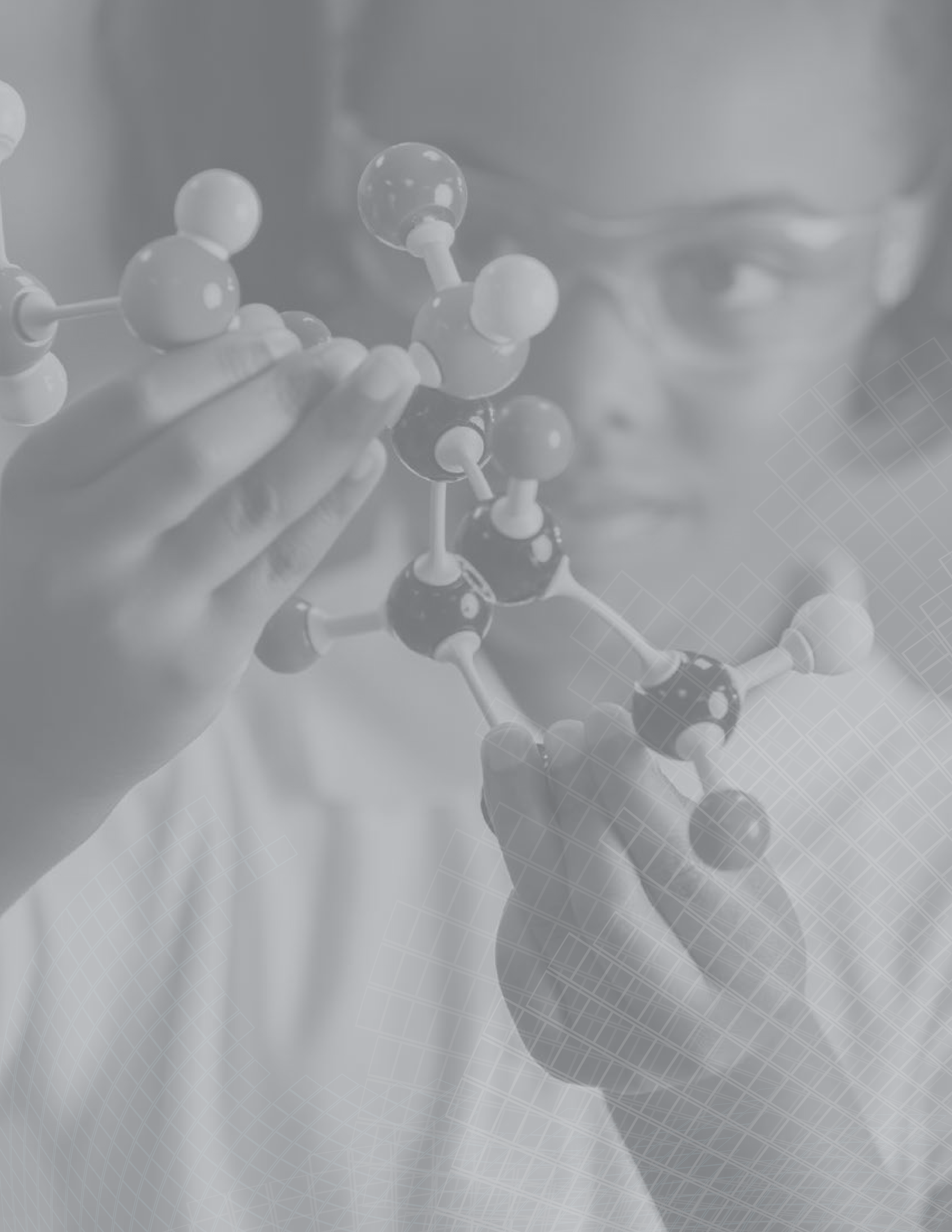
The ACS ChemClubs program provides fun, authentic, and hands-on opportunities for high school students to experience chemistry beyond the classroom. The Chemistry Olympiad competition brings together the world's most talented high school students to test their knowledge and skills in chemistry, resulting in an international Chemistry Olympics. National Chemistry Week (NCW) and Chemists Celebrate Earth Week (CCEW) offer an opportunity for students to join the broader chemistry community in connecting with and promoting the value of chemistry in everyday life. *ChemMatters* subscriptions for classrooms are available, and each issue of the magazine provides five articles that extract chemistry from the real world.

Teachers may also consider encouraging students to apply to one of the many summer research programs that provide students with academic enrichment and real-world experience, where they work alongside scientists in a laboratory. Project SEED is a summer research program sponsored by ACS for economically disadvantaged students. Other research opportunities are offered through local colleges or universities, in addition to government research facilities, such as the National Institutes of Health. Consider investigating the following organizations for opportunities for your students:

- Research Science Institute (RSI) at the Massachusetts Institute of Technology (MIT)
- Science & Engineering Apprenticeship Program (SEAP)
- American Society for Engineering Education (ASEE)
- Summer Internship Program in Biomedical Research (SIP)

Students who are interested in pursuing chemistry at the college level can look for chemistry-related scholarships. ACS offers the ACS Scholars Program, which provides up to $5,000 to students from underrepresented minority groups who are interested in studying chemistry.

AACT is under the umbrella of ACS and has resources and support for everything mentioned in these guidelines.



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