ACS Chemistry for Life®

ACS Guidelines and Recommendations for Teaching Middle and High School Chemistry

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ABOUT THIS DOCUMENT

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INTRODUCTION

One of the goals of the American Chemical Society (ACS) is to "Foster accessible science education and continuous learning to enable all people to make informed decisions and address global challenges."[1] In the spirit of this commitment, this document is the updated and expanded version of the 2018 "ACS Guidelines and Recommendations for Teaching Middle and High School Chemistry."

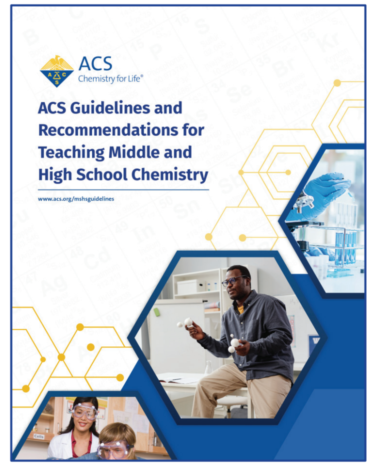
To broaden their reach and relevance, these guidelines also consider the needs of middle school instruction, where chemistry is usually connected to and taught as physical science. Although many of the topics included at the middle school level are not addressed in as much detail as at the high school level, building a chemistry foundation and integrating it with other branches of science serves 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 a 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 presented as 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. While most of the recommendations here apply specifically to the teaching of chemistry, they also build on more fundamental strategies and practices that apply to other subjects.

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.

Ensuring the Safety of Chemistry Students and Teachers in Your Middle and High Schools



If you are a school system administrator, you know how challenging it is to ensure your schools can deliver chemistry instruction in a way that is safe for students, teachers, and staff.

The American Chemical Society (ACS) is a professional organization dedicated to supporting professionals throughout the chemical enterprise, including those who teach chemistry. ACS has developed a free, comprehensive guide for chemistry teachers and school administrators titled, *ACS Guidelines and Recommendations for Teaching Middle and High School Chemistry*.

Of special interest to school system administrators, the *Guidelines* contain recommendations on such topics as:

- **Physical space for chemistry instruction —** For maximum safety for students and teachers, the National Science Teaching Association recommends a maximum of 24 students per classroom, based on 60 square feet per student. (see pp. 25–29 of the *ACS Guidelines*)
- **Areas for storage of chemicals —** Designated, locked areas designed for chemical storage. Safety features for chemical storage must follow local and state guidelines and recommendations, including restricted-use chemicals. (see pp. 32–33)
- **Environmental considerations —** Various steps teachers can take to make chemistry as “green” as possible when designing or choosing a laboratory activity. (see pp. 32–33)
- **Safety Data Sheets (SDS) —** Documents (available for free from Flinn Scientific) describing the safe handling of any potentially hazardous materials stored in designated areas. (see pp. 33–34)
- **Professional development resources —** School systems need to ensure their teachers know how to safely handle and dispose of chemicals used in their classroom and laboratories. Note that school system personnel designated as chemical hygiene officers (CHOs) require extra education and training to help your teachers stay safe. (see pp. 37 –38)

In addition, the *Guidelines* contain recommendations for teaching and assessment strategies, teaching students with different abilities, and the use of technology in the chemistry classroom. The *Guidelines* are available at www.acs.org/mshsguidelines.

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TEACHING & ASSESSMENT

INTRODUCTION

Teaching high school and middle school students requires a mix of structure, flexibility, and understanding of the unique needs and capabilities of this age group. For those who are teaching chemistry to this population, there are additional considerations. In the pages that follow, we highlight several strategies and issues that may have special relevance to those teaching chemistry.

EXPECTED STUDENT OUTCOMES

In an effective and comprehensive 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 curriculum elements 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 for students to learn about chemistry 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 viewing and representing chemical phenomena is known as Johnstone's Triangle.[2]

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 about what takes place on the particulate level and represent those events 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 also 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 events 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. These tables have been generated with the guidance of the Next Generation Science Standards (NGSS) **disciplinary core ideas (DCIs)** in the physical sciences. The task force identified the concepts that fall into each DCI within the core ideas.

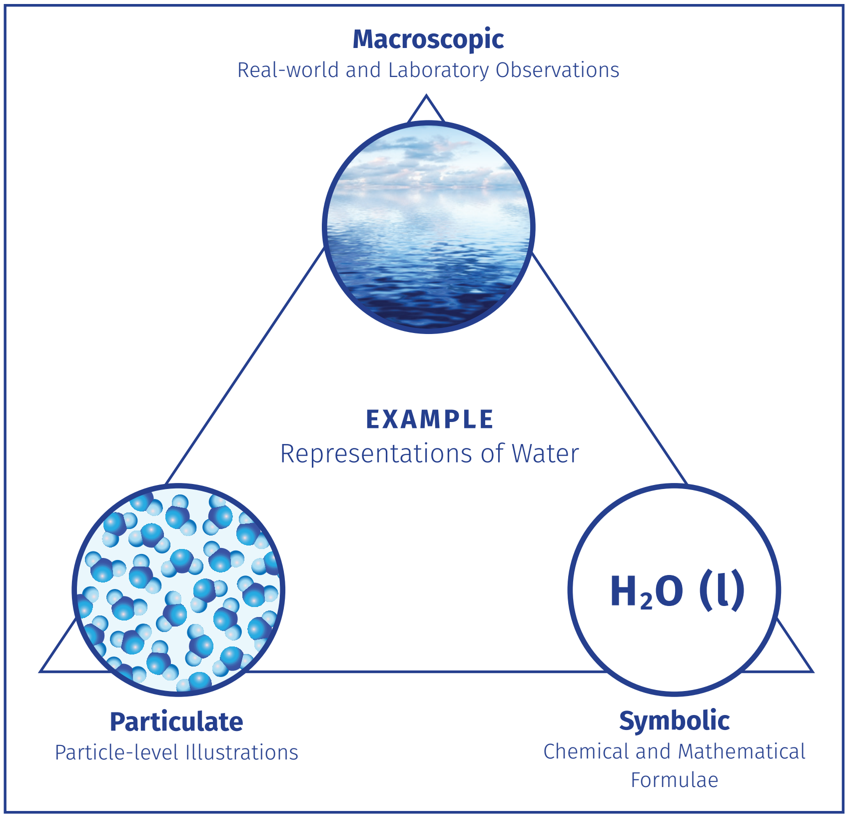
To appropriately address the essential chemical concepts detailed in NGSS, the concepts should be taught using the three dimensions: science and engineering practices (SEPs), crosscutting concepts (CCCs), and DCIs. Keep in mind that the concepts are not isolated from each other; for example, reaction types can't be taught without incorporating the concepts of atoms, ions, bonding, and chemical equations. **Appendices H and K of NGSS** provide information about the nature of science and curriculum building.

The content does not need to be learned or shared in the order presented in the table below, 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 either a physical science or chemistry curriculum, or both.)

Teachers may have additional standards that they need to incorporate into their teaching practice (such as the Common Core State Standards in English Language Arts & Mathematics). Teachers also may need to consult state and local standards to ensure that all of the essential elements and assessment boundaries of their curriculum are included.

"Table 1A" and **"Table 1B"** on the following pages outline the core ideas in chemistry that should be addressed in any comprehensive middle or high school curriculum.

JOHNSTONE'S TRIANGLE



Each core idea is further broken down, first into chemical principles, and then into suggested concepts to teach within those ideas. The task force identified the concepts that fall into each DCI within the core ideas of the physical sciences.

At both the middle and high school levels, students should be made aware of how chemistry relates to 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 their appreciation of it. 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.

Teachers may also try to incorporate inquiry activities and encourage students to pursue learning and topics that interest them. It can be helpful to give students opportunities to ask, and try to answer, their own questions using the scientific method. In addition, it can be highly effective to give students opportunities to assess their own understanding through informal self-reflection, formative assessments, and other activities.

TABLE 1A
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
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)

TABLE 1B

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's involvement 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	• Wave properties • Electromagnetic radiation • Information technologies and instrumentation All topics identified in this section may align more closely with physical science course content.	In a physical science course, teachers could address topics related to sound waves, light waves, and the interactions between energy and matter.

Examining, explaining, and understanding matter and its transformations at the various levels is 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, open-ended 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 Experience section of this document.

Success in chemistry involves imagination, organization, and reasoning with chemical ideas on the part of both 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 meaningful connections between their prior knowledge and their new understanding.

EFFECTIVE STRATEGIES FOR TEACHING CHEMISTRY

Teachers of chemistry in middle and high school are faced with a multifaceted pedagogical challenge. The subject matter is complicated, and the students come with a variety of needs, capabilities, and limitations. In the pages that follow, we offer several recommendations for practices and strategies that have been proven to optimize the teacher's ability to reach—and teach—all their students.

Lesson Formats

Advanced planning is crucial for active student engagement. As guided by local and/or state standards, teachers should decide on 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) facilitates the incorporation of three-dimensional (3D) learning and encourages student participation and understanding. Making the material relevant to students' lives will also promote their engagement in learning.

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. Designed to foster participation and inclusion, this pedagogical approach is outlined in "A Framework for K-12 Science Education" and detailed in the NGSS. Several lesson formats such as guided inquiry, modeling, and investigating problems promote deeper understanding by students. In the 5E Instructional Model, teachers engage students with a short activity that connects the curriculum topic to their prior knowledge, then students explore the topic 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. Another lesson model is Process Oriented Guided Inquiry Learning (POGIL), an instructional strategy designed to optimize student learning and engagement. Differentiated instruction is always appropriate.

Cognitive science discourages "teaching as telling."[3] Therefore, careful planning is necessary to avoid having science assessments become rote presentation, or learning become mere 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 students' understanding.[4]

Last but not least, teachers need to be prepared to interact with students in a variety of modes. Whether one is teaching in-person, online, or in a hybrid setting, either synchronously or asynchronously, it's helpful to develop strategies to engage with students and check for understanding, both formatively and summatively.

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 have learned.

Approaches to providing *engaging questions* include:

- Having students create diagrams and drawings that allow them to develop an initial conceptual model of their current understanding.
- Presenting students with a provocative question related to their lives or providing them with a puzzling discrepant event to challenge prior conceptions. Often these questions uncover incomplete ideas or misconceptions about the process that will be addressed later in the lesson.
- Beginning 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 students to explain phenomena they have observed can be an effective way for students to evaluate their progress in understanding the concept. For example, 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 laboratory procedure or explaining the answer to them without allowing them to struggle with the concept—leads to a much deeper understanding of the concept.

Students must learn to explore problems and understand that taking a “wrong” step is often just as valuable as following the “correct” path.

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 either have only one answer, or can be answered with a simple 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 any possible misconceptions that may have been generated but not yet resolved. The instructor can use the responses to the closing questions to prepare appropriate engaging questions for the next lesson.

Problem Solving

Chemistry students must become good problem solvers. This is an active, sometimes confusing process, which is often frustrating but frequently rewarding. A classic illustration of this idea is the observation that Thomas Edison didn’t invent the light bulb by following a recipe. Instead, he developed more than 1,000 faulty light bulbs before he finally figured out how to make one that worked. 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 the desired solution. Recommendations include:

- 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 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. At the same time, fluency in communicating quantitative reasoning (showing one’s work with units) is an essential part of learning chemistry.
- 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. Such activities may not appear in a textbook topic, but they do require students to apply textbook knowledge to real-life scenarios.

Modeling

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 different types 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 used at the high school level to justify observations.

Scientific Terminology

Students can sometimes use vocabulary to mask their misconceptions. For instance, students may be able to define density as the ratio of mass to volume and perform a density calculation on paper, but they might still not understand the relevance of the ratio or be able to predict whether a given object will float or sink in water. Vocabulary should be introduced near the end of the lesson to give names to the concepts the students have come to comprehend more thoroughly.[5] Effective modeling and three-dimensional assessments can help teachers understand what their students know.

Multilingual Learners

Science often uses words for which there are different meanings in everyday English, such as believe, claim, consider, and model. In chemistry, there are even more terms with multiple meanings, such as mole, concentration, and solution. Teachers should think ahead about potentially confusing terms for multilingual learners (just as they would for any student learning chemistry for the first time).

Fortunately, some vocabulary in chemistry has Latin origins, so students who speak Spanish or other Latin-based languages may easily relate to these terms. Multilingual learners may also struggle with prepositions, idiomatic expressions, and words having multiple meanings (e.g., set, model, or right). Students or teachers may produce visual representations of important words to ensure all students have the same definition of the word.

Whenever possible, teachers should refer to each student's specific multilingual learning accommodations. Different levels of progression in English language proficiency are supported with different types of scaffolding. One popular evidence-based framework is the [WIDA framework](),[6] which is centered on equity and fosters the assets, contributions and potential of multilingual learners. There are also science-specific frameworks for making assessments of multilingual learners more accessible, including the [Science Assessment for Emergent Bilingual Learners (SAEBL)]()[7] checklist and scaffolded written assessments.[8]

Breaking down words may be a helpful way to make

vocabulary more meaningful to all students, not just multilingual learners. For example, when learning chemical symbols, students can be challenged to determine which country was named for silver (Argentina, from the Latin argentum). Another useful approach is to break down a term into its root words:

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 multilingual learners, 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.

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..."
- Have students write a letter to a relative or a friend explaining in nontechnical terms what was learned in chemistry that week.
- Assign students to keep a journal or search for real-world examples (such as local ecosystems, geological features, etc.) as evidence of what they have 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

The Impact of Student Choice

Many students can demonstrate achievement of learning objectives when they're allowed to choose how to express their understanding through alternative modes. Examples of these alternative approaches include delivering an oral presentation, creating a portfolio, or completing a creative project. Some students require a structured environment, so when presenting such options to students, 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, and can also benefit students with various cognitive conditions and disabilities. Providing options gives an opportunity for students to lean more into their strengths to communicate their comprehension. Student motivation is improved when students are actively involved in learning and allowed to share their perspectives.

For these reasons, teachers should consider developing their content in a way that allows students to make meaningful choices about how they interact with the curriculum. For example, teachers can allow students to choose between several different options for demonstrating their understanding of chemistry concepts, including writing a research paper, reading articles for an assignment, and other options. It can also be effective to give students options for working in teams and collaborating with fellow students.

Connecting Students with Chemistry in Their Communities

Another core idea for helping students grasp critical concepts in chemistry is to incorporate examples to which students can relate. This is a central strategy in culturally responsive teaching, which emphasizes framing instruction "within the lived experiences and frames of reference for students."[9] Using this strategy, educators can show how chemistry principles apply and are used throughout students' lives.

Some popular sources of inspiration and ideas include:

- Science Coaches. An educational outreach program that pairs chemists (coaches) with AACT teacher members in elementary, middle, and high school to work together on a variety of projects
- Careers & the Chemical Sciences. A section on the ACS website that lets visitors explore careers in

industry, academia, government, and the non-profit sector

- ACS Strategic Initiative on Fostering a Skilled Technical Workforce. A program focused on recruiting and engaging a diverse group of potential employers and students who have not earned bachelor's degrees
- ACS local sections. An easy way for teachers to make connections and network with local working chemists
- **Connecting to local phenomena.** Check with regional news media for reports on developments that can spur discussion and inquiry about chemistry, including contaminated water supplies, wildfires, flooding, agricultural runoff, industrial accidents, train derailments, etc.
- **Promoting a feeling of belonging in chemistry education.** Help all students understand the importance of diversity by incorporating the contributions of chemists from multiple races, ethnicities, cultures, and countries of origin
- **Exploring the synergies between chemistry and medical discoveries.** For example, CRISPR technology's potential to help people with African ancestry, who are more likely to contract sickle cell anemia
- *ChemMatters* magazine. A resource presenting multiple ways to engage students with real-world applications of scientific concepts (published four times a year)

Additional sources of insight that may be helpful include professional organizations that focus on specific groups within the broader chemical enterprise, including:

- American Indian Science and Engineering Society (AISES)
- National Organization for the Professional Advancement of Black Chemists and Chemical Engineers (NOBCChE)
- Society for Advancement of Chicanos/Hispanics & Native Americans in Science (SACNAS)

These organizations produce a variety of public-facing events that provide networking opportunities for all, and in particular, for people from groups historically excluded from STEM. As a result, they can be very effective venues for making connections and expanding one's network.

Helping 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, Equity, Inclusion, and Respect that speaks to the value of being an inclusive and diverse community, and the organization also offers a variety of resources 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. One approach is to ask students themselves to identify people who do chemistry with whom they identify. In addition to the ACS diversity statement, other resources that teachers can rely on to support and promote diversity include:

- ACS chemistry landmarks
- ACS webinars about nontraditional career options
- ACS Proud to Be a Chemist campaign

This list is by no means exhaustive, but these resources may be good starting points that instructors can reference.

Chemistry for All Students

The American Chemical Society's official mission is: "Advance scientific knowledge, Empower a global community, Champion scientific integrity." In pursuit of that mission, the organization adheres to four core values:

- Passion for Science
- Lifelong Learning
- Inclusion and Belonging
- Sustainability

Teachers play a vital role in furthering this mission by helping all of their students recognize the role of chemistry in their lives and by encouraging them to explore the connections between course content and their lived experiences. In this way, teachers can help students understand and build on the cultural resources (knowledge, interests, and experiences) that they bring to the practice of scientific argumentation. This can increase student engagement and inclusion, especially for those from racial and ethnic groups historically excluded from STEM. Selecting culturally relevant phenomena helps engage all learners. This is often easier said than done, however, and the teacher might need to ask their students for their thoughts on what is culturally relevant to them personally.

One effective method is for teachers to engage with students to understand their connections to chemistry. This engagement can be in the form of class discussions about students' hobbies, having students fill out questionnaires about their interests (technology, cosmetics, etc.), or other means. It's also important to be observant about how students' attitudes and engagement change over time, as they learn more about chemistry and its relationship to their lives.

A number of strategies to engage students from a wide variety of backgrounds are included throughout this Effective Strategies for Teaching Chemistry section. More ideas can be found in the book, *Educating Everybody's Children: Diverse Teaching Strategies for Diverse Learners.*[10]

Differentiating Teaching Styles to Reach Every Student

Teachers should have high expectations for every student, at every level, from physical science to Advanced Placement (AP) Chemistry. To meet the needs of all students, chemistry teachers should present information in multiple ways, using alternatives to engage everyone, including multilingual learners and those with varying cognitive abilities.

A teacher's primary resource for understanding what supports are needed by students with disabilities are each student's Individualized Education Plan or other documentation of the student's accommodations.

Students who use sign language may have idioms that can make a concept more memorable, and students with limited mobility may need a more accessible way of conducting a laboratory procedure. Blind students may conduct experiments with a directed assistant, who performs operations as directed by the student and reports the results of each step.

To provide learning opportunities using multiple means, teachers can share information visually and verbally, 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 the 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. A case in point is the 2023 train crash in Palestine, Ohio, and the immediate and long-term effects of chemical hazards in nearby areas. Teachers can use relevant news stories to emphasize how chemistry affects communities in real life and examine how chemistry impacts communities in a variety of ways.

Many students will seek opportunities beyond a first-year

Teaching Students with Disabilities: Key Resources for Teachers

Teaching students with disabilities can present challenges to some teachers. But with some preparation and planning, it can become an integral part of a teacher's regular approach to teaching. Reevaluating procedures with accessibility in mind might also reveal safer techniques that all students can potentially benefit from. It starts with understanding the laws around the subject, including section **504 of the Rehabilitation Act of 1973**, the **Individuals with Disabilities Education Act (IDEA)**, and the **Americans with Disabilities Act of 1990**.

ACS's Committee on Chemists with Disabilities (CWD) has prepared a free downloadable eBook on this topic, **Teaching Chemistry to Students with Disabilities**, which goes into greater detail than is possible in this document. In essence, the guide provides resources and context to help teachers enable full participation by all their students in the classroom and the laboratory. The manual includes recommendations for teachers from pre-semester planning, to teaching during the semester itself, through testing and evaluation. It also includes resources about assistive technology and accessible computing, universal design, and other topics.

chemistry course while in high school. To meet the needs of these students, science departments should consider offering AP or International Baccalaureate (IB) chemistry courses. Third-party organizations like the College Board and IB offer extensive syllabi for advanced high school chemistry, and also provide opportunities for professional development for teachers (see the [Professional Development](#) section of this document).

Teachers can help students pursue their chemistry interests 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 Activities](#) section of this document.) Above all, teachers of chemistry should offer students of all abilities and interests an avenue to expand their knowledge, experience, and appreciation of chemistry.

Above all, teachers of chemistry should offer students of all abilities and interests an avenue to expand their knowledge, experience, and appreciation of chemistry.

Last but not least, it is worth noting that each of the strategies listed above can help all students learn chemistry, but they can be especially helpful for multilingual students, students who have disabilities, and students who are neurodivergent.

Chemistry and Science Literacy

Another aspect of teaching chemistry is to help students develop chemistry and science literacy.

This type of insight is more than just knowledge of specific chemistry and science facts. As explained in user-friendly terms by the National Institutes of Health, science literacy comprises three core aspects: "content knowledge, understanding of scientific practices, and understanding of science as a social process."[11] Although it does include content knowledge, science literacy also incorporates understanding science as a way of knowing. For that reason, it emphasizes the core practices of doing science (such as designing experiments to test hypotheses, the peer review process, evidence-based reasoning, etc.).

Science literacy is a broader understanding that helps us analyze and understand our world as objectively as possible and allows people to take part in creating new scientific knowledge, as well as using existing information in new ways. It encompasses an understanding of scientific processes and practices, as well as of the ways in which science and scientists work. It also involves understanding science as a social endeavor: science does not exist in a vacuum, and the results and applications of scientific research can have important societal implications, both positive and negative. Last but not least, the concept of science literacy includes developing the ability to assess and evaluate scientific findings and to take part in civic discussions about the value of science.

To help students acquire this understanding, teachers should incorporate activities that require students to read, write, and engage in discussions regarding books and articles about science, scientists, and contemporary issues in science and society.

Possible sources include articles in *ChemMatters*, nonfiction science-themed books like *Disappearing Spoon*, articles of the week, etc. Some teachers of accelerated science classes have also had success introducing science fiction novels and short stories as part of their curriculum. Such readings give the teacher and students an opportunity to discuss and explore not only the truths contained in the books, but often societal inequities and other problems as well. Even in the earlier grades, teachers can assign books to read that incorporate more literacy functionality, with a science perspective, into the classroom. Chemistry Close Read is an activity, [available on the AACT website](#), that offers a way for students to engage actively with the science texts referenced above.

These readings not only help students practice reading/writing skills but also learn about real-world applications of science. At the same time, reading these types of materials can be used to increase student interest and engagement with science more broadly. In addition, in districts where reading scores are low, rather than reduce time spent on science in order to focus on reading, science teachers can strive to incorporate select readings to supplement the traditional reading curriculum.

In nurturing students' science literacy, teachers can be guided by one of the NGSS Science & Engineering Practices, "Obtaining, Evaluating, and Communicating Information," which discusses various components of literacy. Activities should be designed to help students learn how to identify and evaluate information sources for reliability (including print, web, video, etc.). Another possible avenue is for a teacher to work with their school's librarian to help students incorporate readings into research projects, evaluate sources, etc., and to communicate what they know about science in written and oral presentations.

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.[12] As a result, student understanding should be monitored throughout a unit using informal assessments or evaluations. This informs the instructor of where students are in terms of their understanding of the content and provides feedback about what content needs reinforcement or adjustment.

Students often draw upon a diverse set of prior understanding and experiences when attempting to explain phenomena. Formative assessment allows teachers to better understand students' alternative conceptions and plan for instruction that moves students toward more expert-like conceptions. Of course, lessons and follow-up activities should be planned ahead of time, and then 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 assessments are 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. Asking open-ended assessment questions allows a teacher to see where students are in their understanding, allowing the teacher to refocus their efforts where they are most needed. 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.
- Summative assessments are performed at periodic intervals to assess a collection of knowledge at particular points in time. Summative assessments may take the form of traditional assessments, including quizzes, exams, laboratory reports, and term papers, but may also include projects, posters, presentations, etc.
- Student self-assessments can be in the form of a metacognitive 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, although there are other types of 3D assessment as well. In general, these assessments require students to demonstrate content knowledge (DCIs), the ability to make connections (CCCs), and knowing how to develop solutions to solve a problem (SEPs).

- Model-based assessments allow students to demonstrate content knowledge. The creative diagramming aspect of the model means that students, especially multilingual learners, 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.

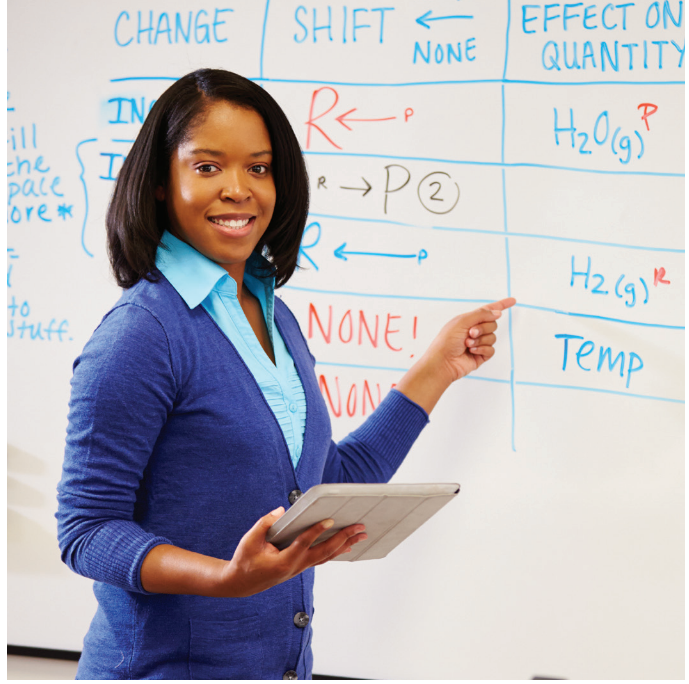
Effective assessment tools should be used for any assessment, whether formal or informal. The assessment should be valid and reliable. Assessment questions should be clear and unambiguous, and assessments should be based on learning objectives. To help determine whether one is using an effective tool, teachers should consider the following questions:

- Is the assessment type appropriate?
- Are the questions on level?
- Does the assessment have flexibility for student accommodations?
- Is the delivery method of the assessment effective?
- What should/does the scoring method look like?[13]

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 used to enhance student learning by improving the program accordingly.

THE IMPORTANCE OF THE LABORATORY EXPERIENCE

Chemistry is a laboratory science and can be most effectively taught by including robust hands-on laboratory experiences for students at both the middle and high school levels. This perspective reflects one of the core



principles of the Next Generation Science Standards: the idea that students can learn content by engaging in scientific practices.

The identification, manipulation, and general use of laboratory equipment are integral parts of the subject. Where resources allow, the school laboratory should have equipment to conduct meaningful demonstrations and experiments (see a full list of recommended equipment in the Lab and Safety Equipment section of this document). 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 disabilities can participate in the laboratory experience.

Instruction that is student-centered, hands-on, and emphasizes the role of laboratory demonstrations and experiments is the best method to ensure that students develop the essential skills of science. Laboratory investigations should come in three phases: the pre-lab, the laboratory 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 laboratory and introduce any new laboratory equipment they will use.
- The **laboratory** 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 laboratory investigations may

enhance how students collect and manipulate data (see the [Technology in the Laboratory](#) section of this document).

- 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 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.

Optimizing the Laboratory Experience

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 that students can understand a new concept.

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 merely 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 laboratory stations. Simple household materials and safe kitchen chemicals can be used to foster inquiry, gather data, interpret results, and explore phenomena. The site **www.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 laboratory and demonstration materials available for purchase; ACS publishes a variety of **books and magazines** for chemistry students of all ages; and the **National Science Teaching Association (NSTA)** offers many resources about laboratory investigations in the chemistry classroom.

Teachers can help students continue to expand on chemistry concepts outside the classroom. One core strategy is to encourage interested students to participate in afterschool programs that will give them opportunities to demonstrate and deepen their understanding of chemistry. Other examples include starting an extracurricular club or apply-

Same Reaction, Multiple Lessons

Some laboratory experiences can be used in a variety of teaching contexts. For example, 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

It can be helpful to repeat this reaction multiple times throughout the year to show students that the reaction always has the same outcome and shows evidence of many types of chemical phenomena.

ing for internships with local companies, universities, etc. For more ideas about engaging students in chemistry outside the classroom, see the Chemistry Resources and Extracurricular Activities section of this document.

TECHNOLOGY IN THE CLASSROOM

Technology has transformed education and our society. Cell phones, projectors, artificial intelligence (AI), wireless Internet access, interactive whiteboards, graphing calculators, laptop computers, tablets, and other evolving technologies are among the devices and technologies available to use in a chemistry classroom and to enable remote instruction. 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. It's important to emphasize to students that there are vast amounts of "junk science" on the Internet, and that being able to assess sources and references is a learned skill. Teachers should also promote the use of primary literature and other practical ways to determine whether a website is a good source of information.

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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 CAST (formerly 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 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.
- ACS offer a variety of video resources. One is the ACS YouTube channel, which includes a variety of science videos with a special focus on chemistry. Another is the Reactions section of the ACS website, which features chemistry science videos and infographics.
- Other social media sites and platforms can also be helpful, although teachers should always review any shared sites for accuracy and safety. Teachers can also 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.

The Role of Artificial Intelligence

Few topics in chemistry education have generated more uncertainty, hope, and anxiety among teachers than that of artificial intelligence (AI). Whatever one's personal feelings about the topic, it seems likely teachers will have to deal with AI for the foreseeable future.

As this guide is being updated in winter 2025, AI is still in its infancy. What role it will eventually play in classrooms in general—and in chemistry teaching in particular—has not yet come into focus. At the very least, some teachers have begun successfully using AI to handle some of the more routine parts of teaching, such as creating practice questions for students. But AI also has the potential for much more, and educators will need to monitor its growing use as a tool for teaching and learning. At the same time, some chemistry teachers have found that AI is not 100% accurate all the time, such as its ability to solve certain chemistry math problems. Indeed, some teachers have already had to spend time undoing the damage AI did in terms of inaccurate student understanding.

Another aspect of AI is its potential for use by chemistry students—including both as a legitimate tool for learning, but also as a tool for cheating. Students can use AI platforms to generate practice test questions, reword explanations of advanced chemistry concepts to more appropriate reading levels, and others. If students do use AI to create products, they should be instructed to cite it as they would any other resource.
At the time this Guide is being updated, the most comprehensive resource for teachers interested in this topic is the website, www.teachAI.org. The website is the product of TeachAI, a collaborative effort involving more than 60 education and government agencies. According to its website, "The TeachAI initiative is committed to providing thought leadership to guide governments and educational leaders in aligning education with the needs of an increasingly AI-driven world and connecting teaching with AI to teaching about AI, including computer science."

The bottom line is that AI is neither a magic bullet that will solve all one's challenges as a teacher, nor the end of teaching as we know it. It is highly likely that it will continue to evolve and improve, and that more and more educators will find effective ways to use it—and to control its misuse. At the end of the day, chemistry teachers are still the experts in their classrooms and labs and will remain the arbiters of what their students are learning.

Staying Current

To ensure that effective technology is available for use in 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. Many schools have policies about the various platforms available, safe Internet usage, Internet speed, and digital citizenship, so teachers should be informed of their school's guidelines 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 **U.S. Government's Office of Educational Technology**, to ensure that the tools they are using to engage and inspire their students are up-to-date and appropriate. In addition, teachers can review the **Teacher Professional Responsibilities and Training** section of this document.

Technology in the Laboratory

Laboratory activities may be performed with data-collection instruments that interface directly with cell phones, computers, tablets, or calculators. Data collection devices, such as those developed by Vernier and Pasco, are examples of available technology appropriate for middle and high school 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. Data collection devices and other adaptive technology will also make it possible for students with disabilities to carry out the experimental work.

At the high school chemistry level, advanced data analysis can take place with the help of technology. From digitally collected data, students can generate lines of best fit or trend lines to allow for interpolation, extrapolation, and drawing 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 also be used on a smaller scale, resulting in less waste and greater safety (see the **Solutions and Strategies for Rural and Low-Resourced Classrooms** section of this document).

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.

Videos of laboratory apparatus or advanced laboratory techniques can be created to assist students with a new experiment or method. Alternatively, if a student is absent from class on the day of an experiment or demonstration, a video can provide them with the visual experience that other students had in laboratory, ensuring that they don't miss out on crucial learning experiences. Videos also allow an instructor to show experiments using techniques or chemicals that might not be safe in a real-life demonstration. ACS offers a safety rubric to help teachers determine if a video is pedagogically sound for replacing teacher demonstrations or hands-on investigations.

Shared documents are powerful tools that not only foster collaboration in the classroom but also enhance student engagement. They allow for the collection of class sets, enhancing the accuracy of data analysis. For instance, when conducting a titration, a class set of data can be generated and shared. This collaborative approach enables students to collectively consider and analyze erroneous data points within a large data set, rather than being limited to the two or three trials they conducted individually.

In short, although technology is helpful in providing students with a modern education, students need to understand and articulate the underlying chemistry principles. Additionally, learning can still take place, even when a school or its laboratory lacks the latest technology.

When to Substitute a Hands-On Lab

For an experiment that is too hazardous or impractical to conduct as a hands-on investigation, a teacher-led demonstration may be a suitable substitute, but only if appropriate safety equipment is present. Other experiments that may be too costly or require hard-to-find

resources 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. (The same safety rubric mentioned above can be helpful here as well).

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.

2

CLASSROOM & LABORATORY FACILITIES

INTRODUCTION

The physical facilities provided for learning any science must be planned, built, arranged, and maintained so as to ensure that students learn in a secure and safe environment. 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 a 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.

CLASSROOM DESIGN

The 21st-century chemistry classroom should provide a safe learning environment that is student-centered and curriculum-driven. Flexibility in the arrangement of space is recommended, and 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
- problem solving

Universal design for learning (UDL) allows students with disabilities to participate and have access to all necessary facilities and equipment. UDL is a framework for educators that helps them design learning experiences to address the needs of all learners. By employing UDL strategies, teachers can transition from a one-size-fits-all approach to one that adapts to accommodate variabilities among learners. UDL is built around the idea that we should have clear goals for students, and use flexible means to attain those goals. The end result is a more equitable and engaging classroom.

In addition to the classroom facilities that would be found in any classroom (desk, chair, computer, etc.), chemistry classrooms require additional equipment if chemical demonstrations are done in the classroom space. These include a demonstration table with a sink, natural gas connection (if permitted), and a safety shield. To further ensure student safety, the school should provide, near the classroom's sink:

- a hands-free, plumbed-in eyewash station,
- a safety shower,
- a fire extinguisher,
- a first-aid kit, and
- a goggle UV-sanitizer cabinet for the class set of chemical splash goggles.[14]

If these safety features are not available in the classroom, then the class should move to the laboratory space for the demonstration to ensure access to proper safety equipment. See the **Lab and Safety Equipment tables** for a complete list of recommended safety equipment.

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.

CONSIDERATIONS ABOUT LABORATORY LAYOUT

The laboratory should be arranged so that instruction and laboratory skills can be practiced safely and effectively.

Science classrooms with scientific equipment and supplies should not be used for non-science courses or activities unless the science materials can be stored in a secured area. Laboratory activities should only be conducted in a science classroom/laboratory that is outfitted with proper laboratory and safety equipment. The chemistry classroom often contains laboratory facilities. Shared classrooms where chemicals are used must not be used for meals as a substitute for a cafeteria, and laboratory tables must never be used for food activities. Even with cleaning, the risk of chemical transfer is too great. Teachers must have adequate preparation time for demonstrations and experiments and a classroom/laboratory should be vacant one period per day to allow for preparation and maintenance.

If the laboratory is not in the same space as the classroom, it should contain a fully equipped teacher station suitable for demonstrations and general work with chemicals as described for the high school setting.

Student work 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 a school has movable stations, the teacher may consider upgrading to fixed stations.

To ensure student safety with adequate supervision, NSTA has produced a **position statement** on the liability of science educators for laboratory safety in middle and high school settings. Chemistry educators, as well as school administrators, may wish to consult this document which,

Solutions and Strategies for Rural and Low-Resourced Classrooms

For schools that lack adequate laboratory equipment and resources, there are several strategies that can help deliver meaningful laboratory experiences for students.

- Seek out organizations or exchange programs that offer gently used laboratory equipment at no cost.
- Look for "kitchen chemistry" type experiments and activities that use readily available, inexpensive materials that don't require special disposal considerations.
- Use microscale reactions that require smaller amounts of chemicals. This approach also allows students to complete more trials, and also makes cleanup easier and generates less waste.
- Avoid experiments that require a certified chemical fume hood if one is not available or tested annually.
- Wherever possible, use one reaction to show different chemistry concepts. (See, for example, the description of how carrying out **the simple reaction** between $CuSO_4$ and Al can be used to demonstrate a variety of essential concepts.
- When scientific equipment is in short supply, consider collecting data sets that the entire class can access.
- Apply for **grants** for materials, equipment, and professional development opportunities.
- Partner with a local university for expertise, supplies, hazardous waste removal, etc.
- Partner with a chemist mentor, such as are available through the ACS/AACT **Science Coaches Program**.

LAB EQUIPMENT
HIGH SCHOOL CHEMISTRY

REQUIRED EQUIPMENT	DETAILS
Bunsen burners	Enough for each laboratory group to have access to one
Buret clamps	
Chromatography paper	
Deionized/distilled water	
Dropper bottles	Either store-bought or made in the lab, in clearly labeled bottles
Drying oven	For dispensing chemicals in labs
Electronic balances	1 centigram (0.01 g) accuracy; small, low-cost balances from are available on the Internet
Filter paper	
Funnels	
Glassware	Various sizes of beakers, Erlenmeyer flasks, volumetric flasks, graduated cylinders, test tubes, and burets
Heat-resistent gloves	For handling hot glassware
Hot plates with magnetic stirring capabilities	To label glassware
Label tape, permanent marker, or grease pencils	
Metal spatulas (microspatulas and scoopulas)	
Microscale equipment	All can be labeled, stored, and reused, including microtip pipets, straight-stem pipets, and combination plates
Molecular modeling kits	
pH paper	
Ring stands (with iron rings)	
Stir bars	
Stirring rods	
Storage bottles	Plastic
Test tube clamps and holders	
Test tube racks	
Thermometers	Alcohol (not mercury) and/or digital
Tongs	
Watch glass	
Weighing dishes	Small and medium
Wooden splints	

LAB EQUIPMENT
HIGH SCHOOL CHEMISTRY

NICE TO HAVE EQUIPMENT	DETAILS
Beaker tongs	
Calculators	Inexpensive class set
Crucibles (with wire gauze, clay triangles, crucible tongs)	
Desiccator	
Digital probes	Temperature, pressure, colorimeter with cuvettes, pH, conductivity
Evaporating dishes	
Laminated periodic tables	
Mortar and pestle	
Pipet bulbs or other pipetting devices	
Power supply and spectral tubes	
Ring clamps	
Rubber stoppers	
Rulers	
Striker (to light Bunsen burner)	
Volumetric pipets	

among other guidelines, recommends a maximum of 24 students per classroom, based on 60 square feet per student.[15] The square footage per student must meet state regulations, which can differ from one state to another. Space requirements may also be based on building and fire safety codes, appropriate supervision, and the special needs of students in the class.

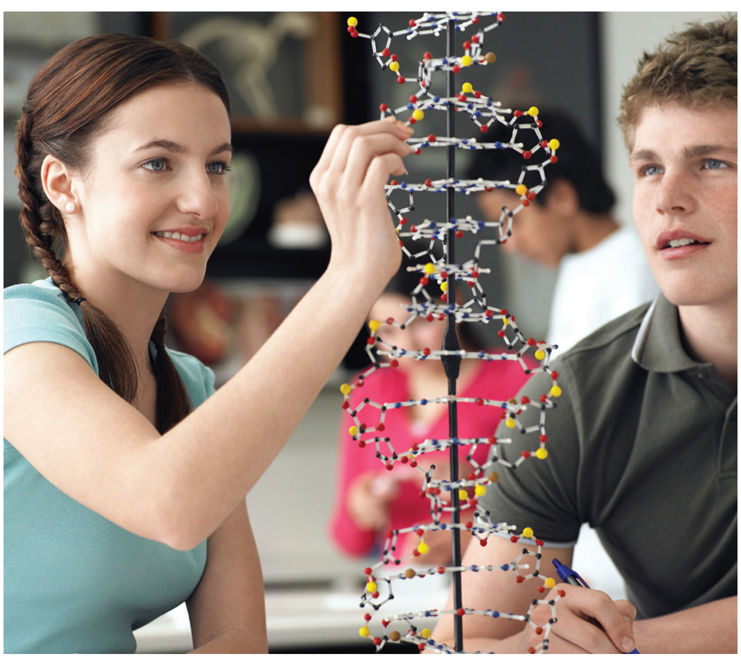
Additional areas should include a safety station and a station for students with disabilities, with a lower bench height and space underneath to allow a student in a wheelchair to pull up to the bench and access all facilities. Care must be taken to ensure that students who must perform the experiment from a seated position are protected with additional PPE such as aprons. The arrangement of furniture must allow for adequate flexibility and supervision. For safety reasons, stools and other impediments should not be in the walkways during laboratory investigations. Workstations should have access to natural gas (if permitted), 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.

SAFETY EQUIPMENT
Broken-glass disposal bin
Chemical splash goggles (one pair per student)
Eyewash station (with plumbing connection)
Fire blanket (optional; instruction on the stop, drop, and roll technique can replace)
Fire extinguisher of an appropriate type
First-aid kit
Fume hood (nice to have for middle school)
GFCI electric outlets
Lab aprons (one per student; nondisposable/plastic)
Nonlatex gloves
Paper towels/soap at each sink
Portable safety shield (nice to have for middle school)
Safety posters
Safety shower
Sinks, including several with hot/cold water connections
Spill control materials (pillows, clay-based cat litter, vermiculite, or other absorbent materials)
UV-sterilizing goggle cabinet

LAB EQUIPMENT
MIDDLE SCHOOL CHEMISTRY

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

Separate disposal containers should be clearly labeled for both hazardous and non-hazardous chemical waste, as well as 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 laboratory 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, that is locked when not in use. Chemical storage and disposal containers should not be in the classroom or laboratory. Containers and shelving must be compatible with the chemicals being stored within them. Access must be limited to science teachers and authorized personnel only, and must be clearly designated and labeled using the Globally Harmonized System (GHS). (See Safety Data Sheets and GHS Guidance on Chemical Classification and Safety.)



Laboratories 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 on the previous page. Gas connections and safety shields may not be necessary at the middle school level.

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 may be purchased at the store, in the laboratory they should only be handled and used under teacher supervision (e.g., wafting to smell). All food that is used in a laboratory setting should be labeled, "NOT FOR HUMAN CONSUMPTION."

For students to carry out investigations in a safe environment, the safety equipment listed in the table on the previous page must be in each laboratory space. These items must also be in the classroom in cases where the classroom is a separate room from the laboratory and where chemical demonstrations will take place. If the chemical storage area is separate from the laboratory area, these safety features must also be provided in the chemical storage area. Certain experiments require fume hoods and portable safety shields, and should not be done if this equipment is not present. All safety equipment must be properly maintained and tested on a regular basis.

3

SAFETY & 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 not meant to be an exhaustive source of information on laboratory safety. Rather, the goal here is to provide teachers, administrators, and school personnel with a "big picture" overview of the potential risks involved, and current best practices and resources.

For information on recommendations regarding specific kinds of safety equipment, see the **Lab and Safety Equipment section** in this document; see also the resources available about training in Safety and Sustainability below.

THE "RAMP" PRINCIPLES FOR SAFETY

In 2016, ACS released updated safety guidelines for schools, which are based on RAMP safety procedures.[16]

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

- **R**ecognize the hazards
- **A**ssess the risks of the hazards
- **M**inimize the risks of the hazards
- **P**repare for emergencies

RAMP represents a comprehensive risk management framework utilized in laboratories where chemicals are used to systematically identify hazards, assess and minimize risks from these hazards, and prepare for potential emergencies.

The updated safety guidelines document mentioned above 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. Teachers should use the guidelines to perform complete risk assessments for experiments and demonstrations. The ACS website also includes additional resources helpful in communicating the RAMP principles, on its **"What is RAMP?"** and **Safety Videos & Webinars pages**.

IMPORTANT! Special Safety Update on "Rainbow" Demonstrations Available

Many instructors have carried out the classic "rainbow demonstration" (essentially a macro-scale flame test for cations) in unsafe ways in recent years, often resulting in serious injuries. ACS has released a safety alert that advises how to conduct the investigation in a safe way.

QUICK LINKS TO SAFETY TRAINING RESOURCES

- Through the ACS Center for Lab Safety, ACS offers two free e-learning courses: one for chemical storage and one for chemical safety.
- Flinn Scientific offers extensive safety training, including courses for both middle and high school teachers, as well as student courses
- AACT provides safety resources, including teacher reference material, student activities, safety videos, and more, as well as general information and good practices in its periodical and through webinars

For more information on safety training resources, see the Opportunities for Professional Development in Chemical Safety section of this document.

ENVIRONMENTAL CONSIDERATIONS

Teachers should consider a variety of factors to make chemistry as "green" as possible when designing or choosing a laboratory activity. A number of green chemistry resources are available to help teachers choose experiments that are appropriate for the learning objectives, but have minimal environmental impact. The ACS Green Chemistry Institute and Beyond Benign provide some resources that support green chemistry practices. Teachers should also familiarize themselves with ACS recommendations regarding the handling of restricted-use chemicals (see the Chemical Storage and Hazardous Waste and Disposal Considerations sections).

In short, with a little planning, teachers can introduce greener practices for their laboratories that also happen to provide educational benefit to students.

CHEMICAL STORAGE

Chemicals should be methodically stored and organized in a specially designated area. The storage area should be securely locked when not in use, and students should not have access to it. Safety features for chemical storage must follow local and state guidelines and recommendations. At a 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.
- Cabinets to store equipment that are separate from cabinets used to store 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.).

Teachers should account for hazardous chemicals and chemical incompatibility when organizing their storerooms. If volatile materials are stored in an area which is susceptible to high temperatures, particularly when school is not in session, it may be necessary to store them in a

Safety Instructions

If practical and allowable under the teacher's school district's policies, safety instructions and labels on laboratory safety equipment should be available in the language of students whose first language is not English. These instructions should be prominently displayed and printed copies should be provided to the students. NOTE: There can be different policies on this matter from one district or school systems to the next, so teachers should be aware of their own district's policies.

refrigerator rated for storage of flammable materials, not a household refrigerator.

Teachers will often have **hazardous** chemicals in their laboratories. These chemicals may be needed for a specialized experiment or left behind from a previous teacher. Some schools and/or districts specify certain chemicals that are absolutely not allowed in their schools.

If a school or system does not limit what chemicals can be in a classroom setting, teachers can consult the ACS Restricted-Use Chemicals list on pages 3–9 of 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 rather to ensure that teachers are aware of specific hazards and can take the appropriate safety precautions to prevent exposure. In addition, Flinn Scientific offers helpful resources regarding chemical prep and setup, including its FlinnPrep for AP Chemistry online offering.

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 guide, which accounts for storage of incompatible chemicals. Note that there are limits as 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.

Going Small to Go Green

One effective way for teachers to "go greener" is to reconsider the scale of quantities used, the amount and category of waste generated, and the proper in-class disposal methods for chemical waste.

Microscale investigations, which require smaller amounts of chemicals, can be a winning strategy. They help reduce the amounts of reactants used and products created and waste generated, making cleanup quicker and easier. In addition, the smaller scale involved can often allow time and resources for more trials, giving students and teachers larger and more robust datasets.

SAFETY DATA SHEETS AND GHS GUIDANCE ON CHEMICAL CLASSIFICATION AND SAFETY

It is important to know how to read and interpret safety labels and the new Safety Data Sheets (SDSs), which updated and replaced Material Safety Data Sheets beginning in 2016. Chemical labels and SDSs are now required to use the Globally Harmonized System of Classification and Labelling of Chemicals (GHS), which is an international system designed to provide a consistent method of communicating chemical hazards. Most household chemicals are not sold with an SDS, but the information is available online and should be downloaded and consulted when the items are not used for their intended use. The short ACS video, "Safety Information: Globally Harmonized System of Classification and Labelling of Chemicals," describes the fundamentals of the system.

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 (provided by the company for purchased chemicals and available for free from Flinn for inherited or gifted chemicals) and organize them in a binder to store in the chemical storage room (or, in some jurisdictions, outside 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 by pouring them down the sink. Teachers should verify the following guidelines with their local codes, as restrictions may vary. Guidance on best practices for managing hazardous waste are provided in the AACT web document, "Managing Chemical Wastes in the High School Lab." Additional information is available on managing hazardous waste in the free ACS Institute eLearning course, "Foundations for

Storing, Organizing and Disposing of Chemicals in Educational Settings."

If the teacher is disposing of approved chemicals in the trash, they should 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 indicate whether or not a certain chemical can go into the trash, teachers can refer to the chemical provider for further guidance.

Chemical Disposal Guidelines: a Quick Reference*

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

- Non-radioactive
- 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 this guidance is not indicated on an SDS, teachers 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 general guidelines for sink disposal are as follows:

- Chemicals that meet criteria for trash disposal
- Dilute acids and bases with a pH between 5.5 and 10.5
- Compounds that are a soluble combination of the cations and anions listed to the right.

Other disposal tips

- Use laboratory sinks only, and never a storm drain that goes directly to a water source without treatment
- If the compound is not a pairing of a cation AND an anion on this list, it is not safe for drain disposal and needs to be disposed of by hazmat pickup. For example, $AlBr_3$ can be disposed of down the drain. However, $CuBr_2$ or AlF_3 should be disposed of by hazmat.
- Double-check with local hazmat authorities or a reputable source such as the Flinn catalog before flushing the chemicals down the drain.

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 as such, 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 such 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.

Cations			
Al^{3+}	NH_4^+	Ca^{2+}	Cs^+
H^+	Li^+	Mg^{2+}	K^+
Na^+	Sr^{2+}	Sn^{2+}	Zr^{2+}
Fe^{2+}/Fe^{3+}		Ti^{3+}/Ti^{4+}	

Anions			
HCO_3^-	HSO_3^-	BrO_3^-	Br^-
CO_3^{2-}	ClO_3^-	Cl^-	OH^-
IO_3^-	I^-	NO_3^-	NO_2^-
O^{2-}	PO_4^{3-}	SO_4^{2-}	SO_3^{2-}
BO_3^{3-}	$B_4O_7^{2-}$	OCN^-	SCN^-

** Access free chemical disposable guidelines (PDF) that a teacher can post in their laboratory. Note: this quick-reference guide is not exhaustive, but is helpful for day-to-day chemical disposal.*

4

TEACHER PROFESSIONAL RESPONSIBILITIES & TRAINING

INTRODUCTION

Many people who become scientists and chemists as adults credit the influence and encouragement they received from a favorite science teacher as a key reason they decided to pursue careers in science. In fact, it's no exaggeration to observe that the entire chemistry enterprise benefits from enthusiastic, knowledgeable, and well-trained teachers in K-12 classrooms.

As a result, teachers in middle and high school chemistry have a variety of professional responsibilities in educating and guiding students, providing an encouraging and rigorous learning environment, and staying current with best practices. It's equally important for chemistry teachers to keep up with relevant professional learning to ensure the safety of students in their laboratories. In this section, we discuss some of teachers' most important professional responsibilities.

OPENING DOORS TO CHEMISTRY

Of special relevance to educators, ACS has created several statements that explain the organization's beliefs and values, including its **Strategic Plan** and **Statement on Diversity, Equity, Inclusion, and Respect**. Many chemists rely on ACS to make the discipline more welcoming and accessible to everyone, and teachers of chemistry are expected to practice this perspective within the classroom setting.

The mantra of "Science for All" is a cornerstone of ACS's 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 mantra of "Science for All" is a cornerstone of ACS's vision for high school chemistry.

The implications of this position extend beyond the needs of a single classroom. Schools, school districts, and their states 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:

- Be aware of research on best practices aimed at reaching and teaching all students
- Transform and adapt instructional practices to promote student learning
- Serve as role models in the classroom and to the community at large
- Incorporate more diverse historical or current scientists into the curriculum
- Recognize and teach to students' strengths
- Provide a learning environment focused on trust and fairness
- Connect with the cultures 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 also model environmentally responsible actions for their students.

Teachers should consider how they and their class consume energy, water, 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 the [Safety and Sustainability]() and [Environmental Considerations]() sections of this guide for more ideas and information.

PROFESSIONAL DEVELOPMENT

> School districts and administrations must support teachers' efforts by providing time, opportunity, and funding to support 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 regarding requirements that chemistry teachers must meet in order 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.

ACS expects the full support of each teacher's school and district to assist in educators' growth 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.[17] To this end, schools and districts must highly value such professional development and be willing and able to provide and/or support it. In keeping with educational practices, teachers should consider the authority and reliability of the professional development resource.
Specific examples of effective professional development offerings for chemistry teachers include:

- active learning opportunities, derived from both research and practice
- opportunities to further develop both content skills and knowledge
- opportunities to reflect on the practice and effectiveness of their teaching and share these reflections
- accessible alerts regarding accidents that occur when common laboratory activities and/or demonstrations are carried out, with access to recommended modifications
- opportunities 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. In smaller schools, there may be only one or two science teachers, so it is important for them to make efforts to expand their peer group. Professional networking can be accomplished in meetings and workshops or via online communications. For example, some opportunities include:

- [AACT membership,]() which includes two to four webinars per month during the school year (these are free for everyone, while an archive of previous webinars is available to members only); AACT members also receive discounts on some science teacher meetings and workshops

- Chemistry Teacher Day at ACS meetings (check specific meeting program for details)
- Biennial Conference on Chemical Education (BCCE) (occurs in the summers of even years)
- ChemEd (occurs in the summers of odd years)
- ChemEdXchange and ChemEdX conferences
- Regional and local ACS meetings (throughout the year)
- High school teacher groups in local ACS sections
- NSTA conferences and webinars
- The AACT/ACS Science Coaches program (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 readily available to teachers.

OPPORTUNITIES FOR PROFESSIONAL DEVELOPMENT IN CHEMICAL SAFETY

Recommendations and chemical knowledge about chemical safety frequently change, and it can be a challenge to stay abreast of the latest best practices. Developing competencies in chemical safety best practices requires both education and training. Teachers must attend regular professional development activities in safety to remain current. A teacher assigned as the school chemical hygiene officer (CHO) is required to have extra education and training. 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.

Through the ACS Center for Lab Safety, ACS offers two free e-learning courses, one for chemical storage and one for chemical safety. Flinn Scientific offers extensive training, including a certificate for both middle and high school teachers. AACT also provides safety resources, including student activities and others in its Resource Library, as well as general information and good practices in its periodical, on its blog, and through webinars.

EVALUATING TEACHER PERFORMANCE

Each school district makes its own decisions regarding the evaluation of teacher performance. That said, one of the most widely used criteria is whether and how a teacher is using the latest teaching and assessment methods in their classroom. This speaks to the need for district-wide policies that recognize the importance of such methods, as well as effective communication between administrators and 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.[18] The organizations listed below 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 effective ways to stay current in the profession.

In addition to ACS, listed below are some select professional organizations, committees, and programs 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 Committee on Chemists with Disabilities (CWD)
- 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)
- American Modeling Teachers Association (AMTA)
- 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 Teaching Association (NSTA)

The ACS also has local sections across the country, which may support associated teacher groups. There may also be 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 useful networking opportunities.

CHEMISTRY RESOURCES AND EXTRACURRICULAR ACTIVITIES

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 opportunities 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 multiple articles that extract chemistry concepts from the real world.

Specifically for chemistry teachers, AACT makes available many resources for the classroom. In addition, the ACS/AACT Science Coaches program provides opportunities for teachers to partner with professional chemist, which can include collaboration on content and practice.

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.

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 groups historically excluded from STEM who are interested in studying chemistry.

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

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SOCED Task Force on the Guidelines and Recommendations for Teaching Middle and High School Chemistry 2024

Michael Adams, Xavier University of Louisiana, SOCED Chair

Tracy Halmi, Penn State University, SOCED Supporting Excellence in Education (SEE) Subcommittee Chair

Tyler Kinner, Georgia Institute of Technology, SOCED SEE K–12 Subgroup and Task Force Chair

Ranie Abia, Oak Ridge High School

Roxie Allen, St. John's School

Jesse Bernstein, Miami Country Day School (retired)

Russ Carley, New Castle Jr/Sr High School and Butler County Community College

Anjana Iyer, Hillsborough High School

Pamela M. Leggett-Robinson, Founder & Executive Director, PLR Consulting, Inc.

Pradip Chandra Misra, Bagdad Unified School District #20

Amiee Modic, Duchesne Academy of the Sacred Heart – Houston

J. Antoine Shade, Gwinnett County Public Schools

ACS Staff Liaisons

Jodi Wesemann

Terri Chambers

Monica Wixon

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