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ACS Guidelines and Recommendations for the Teaching of High School Chemistry

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Introduction

In the fall of 2009, the American Chemical Society (ACS) Education Division, under the auspices of the Society Committee on Education (SOCED), established and charged a task force to update a guidance document, titled "ACS High School Chemistry Guidelines and Recommendations," which was last revised in 1984. The purpose of this document is to provide guidance to the high school chemistry education community focusing on the nature of the instruction, including the physical and instructional environment, the big ideas in chemistry, and the professional responsibilities of chemistry teachers.

This document is not a course outline or syllabus, a detailed description of instructional methodologies and best practices, or a program outline for teacher preparation and professional development. The intent is to capture the importance and value of teaching chemistry at the high school level and to emphasize the essential components of the high school chemistry learning environment.

The primary audience for this document is high school chemistry teachers, their supervisors and principals, and school administrators. This document should also serve as a resource for pre- and in-service teacher preparation programs. The focus of this document is to describe the broad requirements necessary to teach chemistry to all high school students from diverse populations. These guidelines recognize the professional integrity of high school chemistry teachers who may want to share with their school or district administrators information about best practices and the physical environment, including the tools of educational technology and laboratory facilities. These guidelines are presented in order to support the work of classroom chemistry teachers.

Pathways to Learning

Expected Student Outcomes in a High School Chemistry Course

Since at least 2001, states have been developing and validating specific science standards to be learned. In nearly every case, these state science standards were influenced by two national-level publications, the National Research Council's (NRC) National Science Education Standards (NSES) (NRC, 1996) and the American Association for the Advancement of Science's Benchmarks for Scientific Literacy (AAAS, 1993).

The NSES defines scientific literacy as the ability to:

1. Ask, find, or determine answers to questions derived from curiosity about everyday experiences;
2. Describe, explain, and predict natural phenomena;
3. Read and understand articles in the popular press and engage in social conversation about the validity of the conclusions;
4. Identify scientific issues underlying national and local decisions and express ideas that are scientifically and technically informed;
5. Evaluate the quality of scientific information on the basis of its sources and methods; and
6. Pose and evaluate arguments based on evidence and apply conclusions appropriately (NRC, 1996).

The NRC defines scientific literacy as an approach to scientific understanding, or an ability to evaluate physical phenomena. Teachers of high school chemistry should strive to model and emphasize the inquiry, scrutiny, and information-sharing that is fundamental to the practice of science. Anyone can find the numerical value for the specific heat of water. However, scientifically literate chemistry students should be able to describe the concept of specific heat, and how the value could be investigated, verified, or applied. Students should also be able to carry out such an investigation.

To promote scientific literacy, an outstanding high school chemistry curriculum will expose and engage students in activities that involve problem solving and critical thinking. Students should acquire an appreciation for the interactions of matter at the macroscopic level, the atomic level. When we witness a fire—a macroscopic event—we sense heat, light, and the motion of air surrounding the fire. In the mind's eye of a chemist, at the atomic level, he or she sees oxygen molecules and carbon-rich molecules colliding at high velocity to produce carbon dioxide and water, among other things.

Students should develop an ability to investigate and verify scientific information. They must be required to communicate scientific ideas as part of their academic experience. These essential elements of a high school chemistry curriculum will help students make informed decisions about relevant scientific issues. The curriculum will also instill a desire to further investigate the wonders of science.

The Big Ideas That Must Be Explored in High School Chemistry

One of the most important ideas in chemistry is that what we see and perceive in the macroscopic world is a result of interactions at the atomic level. This concept has tremendous explanatory power, which can help us understand some of the most important issues of our time. These issues include the need for clean water, how climate changes, how chemical energy in fossil fuels or solar power is converted into useable mechanical and electrical forms for our cars and homes; and how chemical fertilizers are manufactured to boost food production for a growing human population. The knowledge gained through chemistry allows us to make informed decisions about our future. A strong chemistry curriculum should provide the opportunity for students to solve real-world problems and convey this information to others.

Investigation should be prominent in any science curriculum. Most of the big ideas in chemistry and other sciences were developed over many years of investigation. Simple concepts that are widely accepted today, such as the percentage of oxygen in the air, were the result of many years of observations, questions, investigations, and experiments. Experiments should be performed in the high school chemistry classroom to generate data that will help answer scientific questions.

Chemistry is the science of matter and its transformations. Matter, from the chemical point of view, consists of the substances we encounter in our daily lives, such as solids, liquids, and gases, as well as the atoms and molecules of which these substances are composed. Within this sweeping concept are several big ideas which the science of chemistry routinely encompasses. Chemists move among these ideas to come up with explanations of how matter behaves.

The following table outlines the big ideas in chemistry that should be addressed in any good curriculum. Within each of these big ideas, important additional topics are suggested. These big ideas need not be covered in the order presented, nor is this an all-inclusive list. See also the NRC, College Board, and others for a list of essential topics in chemistry. Teachers may wish to consult a variety of sources when considering all of the essential elements of their curriculum.

The Big Ideas in Chemistry	Important Topics within These Ideas
Conservation of matter and energy	• Atoms are not destroyed in chemical reactions; they are rearranged • Forms of energy; energy changes in chemical reactions • Stoichiometry and balancing chemical reactions
Behavior and properties of matter	• The periodic table of elements as the master organizer of chemistry • Gas laws • Distinguishing among elements, compounds, and mixtures • Chemical bonding • Intermolecular forces
Particulate nature of matter	• Kinetic Molecular Theory • Structure of atoms, ions, and molecules
Equilibrium and driving forces	• Le Chatelier's Principle • Reaction rates • Thermodynamics (entropy and enthalpy) • Acid-base reactions • Redox reactions • Combustion

It is understood that these topics are not isolated from each other. For example, one cannot discuss acid-base reactions without incorporating the concepts of atoms, ions, bonding, and chemical equations.

The big ideas in chemistry are not solely the domain of chemistry teachers. Teachers of other sciences will touch on these topics as will teachers of subjects outside of science. The chemistry curriculum should not be limited to addressing chemical principles. Rather, students should be exposed to the wonderful nature of science, in general, and how chemistry relates to other sciences and other subjects in the high school curriculum.

Effective Strategies for Teaching Chemistry

Advance planning is crucial for active student engagement in learning. Chemistry teachers should first decide on the conceptual learning goals for their students, focusing on broad concepts within the big ideas in chemistry. Spiraling the curriculum, building on and making connections to what students already know, will encourage student participation and understanding. Identifying the essential or guiding question at the beginning of each lesson focuses the attention of teachers and students on key learning objectives.

Several lesson formats, such as guided inquiry and investigations in the laboratory, promote a deeper understanding. In the 5E Learning Cycle Model (Bybee, 1997), teachers engage students, then allow them to explore through experimentation, explain or summarize their new learning, elaborate through application, and finally evaluate their claims. Other effective lesson formats appropriate for some topics in chemistry include role playing, simulations, and direct instruction. For more than 20 years, cognitive science has discouraged "teaching as telling" (Bransford et al, 2000). Therefore, careful planning is needed to avoid this pitfall. When lectures are used, previewing the information and providing advance organizers (Ausubel, 2000) helps maximize student participation and promote understanding.

Regardless of the lesson format that is chosen, teachers must prepare appropriate questions in advance 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 end with closing questions to gauge what students learned at the end of the lesson.

The opening questions should be answered by students with the understanding that the purpose of answering the questions is to confront students' initial ideas, not for students to have the "right" answer. For example, a lesson about intermolecular forces could begin with a question about how pollutants (and other substances) dissolve in water. Often these questions uncover naive ideas or misconceptions which will be addressed later in the lesson. During the lesson, effective questioning techniques help students develop their critical thinking skills, as well as 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 much more effective than questions that have only one answer.

Student engagement may begin with a provocative question related to students' lives, or a puzzling discrepant event to challenge prior conceptions. Many chemistry teachers enjoy beginning a lesson with a demonstration or video clip that makes students think about the topic in a different way. Sometimes even a simple demonstration paired with a good question is sufficient to spark student learning.

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 lead to a much deeper understanding than providing them with a step-by-step lab procedure, or telling them the answer.

Chemistry students must be good problem solvers. Solving problems is an active, messy process, which is often frustrating, but the process can be rewarding. Thomas Edison didn't invent the light bulb by following a recipe. He developed more than 1,000 faulty light bulbs during the process. Students must learn to explore problems and understand that taking a "wrong" step is often as valuable as following the correct path. Students should be observant during the problem-solving process to evaluate whether they are getting closer to, or farther from, the desired solution.

When modeling problem solving, teachers should model their own thinking to help students see how experts think through a problem, starting with the given information and ending by determining if the answer is reasonable. Cooperative learning strategies could be employed 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.

Much of chemistry deals with atomic and molecular phenomena that cannot be observed in the high school classroom. To help students understand these abstract concepts, carefully prepared analogies and models should be used. Lewis dot structures and molecular models are commonly used in chemistry, as are mathematical equations such as the gas laws. All models have limitations, so teachers should plan classroom discussions with good questions to prevent student misconceptions later on.

Vocabulary can be problematic in the chemistry classroom. Students often use vocabulary to hide their misconceptions. For instance, students may be able to define density mathematically, as well as state that an object will float in water if its density is less than 1 g/cm^3, but when asked to think more deeply about buoyancy, students may be unable to explain floating in terms of particles. As a general rule, vocabulary should be introduced near the end of the lesson to give names to the concepts the students have come to comprehend more thoroughly (Le Tellier, 2007.)

Finally, providing students with time to reflect on their new learning through journaling or searching for real-world examples will help ensure their understanding endures past the closing bell. One popular strategy is to 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. . . ." Another idea for student reflection is to ask them to write a letter to a relative or a friend explaining in nontechnical terms what they learned in chemistry that week.

In chemistry, well-planned lessons include effective questions, student interaction with new ideas, and student reflection—all focused on the conceptual learning goal. Chemistry teachers should capitalize on the importance of chemistry in everyday life to engage their students, and then follow through with opportunities for them to actively explore newly introduced concepts. Advance planning will reap big payoffs in student motivation and deepen their understanding of topics in chemistry.

Teaching Students of Diverse Backgrounds and Various Levels of Academic Ability

All high school students should learn the concepts, principles, and big ideas in chemistry to develop an understanding of the material world around them while learning to think critically. Teachers should have high expectations for every student, at every level of chemistry classes, from introductory to Advanced Placement (AP). To meet the needs of *all* students, chemistry teachers should provide multiple options when presenting information, using alternatives that will engage students with different learning styles, varying physical and cognitive abilities, and limited English-language proficiency. Students also need to be given multiple options for demonstrating their understanding; Universal Design for Learning (UDL) can be a resource for possible approaches. Teachers may also benefit from consulting the publication, titled *Teaching Chemistry to Students with Disabilities* (ACS, 2001).

Many chemistry teachers employ multiple means of presenting information, such as visually and orally, or using symbols and words. Chemistry teachers have a distinct advantage because the tangible nature of the subject encourages modeling of procedures and equipment. All students benefit when teachers simultaneously display and name the apparatus to use, the chemical being discussed, or the safety practice to follow. Chemistry teachers may make chemistry culturally relevant to a diverse student population by using regional or international examples. Students from the icy north bring experience with phase changes. Students who use sign language may have idioms that can make a concept more memorable. Students with limited mobility may find a more efficient way of doing a laboratory procedure.

When learning chemical symbols, for example, students could be challenged to determine which country was named for silver (Argentina, from the Latin *argentum*). Many other vocabulary words in chemistry have Latin roots, so students who speak Spanish or other languages derived from Latin may relate well to these terms. More problematic for English-language learners are common English words such as believe, claim, or consider. Most problematic are prepositions, idiomatic expressions, and words having multiple meanings (for example, “mole,” “set,” or “right”). Students or teachers may produce visual representations of important words to promote comprehension for everyone.

Many students can best demonstrate achievement of course goals when they have the option to choose how to express their understanding through oral presentations, portfolios, or creative projects. Some students require a structured environment, so chemistry teachers should provide explicit instructions and rubrics for assignments in advance. Diversity in the chemistry classroom enriches the content and improves student motivation when students are actively involved in learning and sharing their perspectives.

Success in chemistry involves imagination, organization, and critical thinking on the part of teachers and students. High school chemistry teachers should be prepared to teach and reinforce basic science and mathematical skills, as well as critical reading and writing skills, to ensure they are meeting the needs of all of their students. This is best done by helping students make connections between their prior knowledge and their new understanding.

Many students will seek to pursue advanced learning in chemistry while in high school. To meet the needs of these students, chemistry teachers should consider contacting organizations, such as the College Board AP course program and the International Baccalaureate (IB) diploma program. These organizations offer extensive syllabi for advanced high school chemistry, along with professional development opportunities for teachers.

The Laboratory Experience in High School Chemistry

The chemistry laboratory represents a wonderful opportunity for making the connection between the unseen microscopic world and the observable macroscopic world in which we live. Laboratory experiences provide opportunities for team building, inquiry-based learning, hands-on activities, and exposure to standard laboratory equipment and technology. Though an excellent laboratory experience will certainly require hours of behind-the-scenes work on the part of the teacher, a laboratory need not have the latest technology to be effective. Many, if not most, of the concepts and principles common in high school chemistry courses can be demonstrated or discovered through experiments performed with simple apparatus. Of course, all experiments should be evaluated carefully for scientific accuracy, and appropriate safety guidelines and warnings, prior to use in the classroom.

Within any given chemistry curriculum, teachers should develop instruction that is student-centered and emphasizes concrete examples of the concepts and principles to be learned. Student-centered lessons place emphasis on the students' learning rather than on the teachers' activities and teaching.

Chemistry is a laboratory science and cannot be effectively learned without robust laboratory experiences. Indeed, the identification, manipulation, and general use of laboratory equipment are integral parts of the subject of chemistry. A high school laboratory should have the equipment necessary to conduct meaningful demonstrations and experiments. The physical laboratory environment must be accessible to *all* students. Teachers must understand that students with limited strength or mobility can have a full laboratory experience with appropriate accommodation, such as a lab assistant.

Instruction that is student-centered and emphasizes the role of laboratory demonstrations and experiments is the best method to ensure that students develop these essential skills in science. Laboratory exercises should come in three phases: the pre-lab, the lab procedure, and the post-lab. In the pre-lab, students consider the concept or principle to be investigated. They predict and hypothesize. Effective pre-lab questions can prompt students to review and recall previously learned material that is pertinent to the lab. In the lab experience, students learn to plan their actions, and to identify and control variables; they observe, measure, classify, and record. The post-lab challenges students to analyze and interpret data, evaluate the effectiveness of the procedure, formulate models, and communicate their findings in written and oral formats. In the post-lab, students can also relate or compare the results and concepts to known phenomena.

When conducting a laboratory exercise, it is important that the students not know the outcome beforehand. For this reason, it is often appropriate to carry out a laboratory activity before the related concept is presented. Laboratory experiences, whether demonstrations or true experiments, must emphasize and model the investigative nature of science. Students should experience science as it is and not as a simple verification of concepts and principles already taught or assessed. Laboratory exercises should not be in the form of a "magic show," which is not specifically linked to particular concepts and principles of chemistry.

Teachers should consider a variety of factors to make the chemistry as "green" as possible when they are designing or choosing a laboratory activity. This would include consideration of the scale of quantities used, the amount and category of waste generated, and the proper in-class disposal methods for chemical wastes. A number of green chemistry resources are available to help teachers choose experiments most appropriate for the learning objectives, with minimal environmental impact (ACS Green Chemistry Institute (GCI), 2011).

Many resources are available for planning student-centered laboratory instruction. The ACS publishes a variety of chemical demonstration books and the *Journal of Chemical Education* (JCE) regularly publishes new and exciting experiments and video demonstrations in their “Chemistry Comes Alive” collection (JCE, 2011). Flinn Scientific (Flinn Scientific, 2011) is another resource for demonstration materials. In many cases, simple Internet searches can locate specific demonstrations for a chemical concept or principle.

Applying Technology in High School Chemistry

Information technology (IT) has transformed education and our society. Cell phones, liquid-crystal displays and projectors, wireless Internet access, interactive white boards, graphing calculators, laptop computers, and other evolving technologies are among the devices available in the chemistry classroom. These tools greatly enhance student-centered instruction.

Laboratory activities, for instance, may be performed with data collection instruments that interface directly with computers or calculators. Once collected, these data may be easily manipulated and displayed on clearly labeled graphs, highlighted to emphasize important features. Regression equations and lines of best fit are readily generated, which allow both interpolation and extrapolation, and a means of making predictions from data.

The *Journal of Chemical Education*, *The Science Teacher* and *Mathematics Teacher* journals are excellent sources of experiments that can be conducted using these devices, many of which may be used on a smaller scale—resulting in less waste and greater safety. Many automated processes, such as graphing and linear regression, have an important mathematical or theoretical basis. Students must thoroughly understand these underlying principles to analyze data and prepare laboratory reports.

Some experiments are too dangerous or impractical to be included in the hands-on laboratory curriculum. Such experiments and demonstrations may be viewed in classrooms capable of displaying video. Thermite reactions, for instance, could be witnessed on a screen, eliminating the associated danger and required safety equipment. It is important to emphasize that hands-on laboratory experiences are critical to a quality high school chemistry program and that technology should not be seen as a replacement for the laboratory, but rather as an enhancement.

Various forms of computerized formative assessment allow students and teachers to obtain immediate feedback on the progression of students' conceptual understanding of chemistry. These technologies allow teachers to make appropriate changes to the curriculum, as needed. Some technologies can be used in class to provide opportunity for real-time adjustments to a lesson, while others alert students to errors in their thinking. Many assistive technologies are available to enhance the learning experience for students with disabilities. More information about assistive technologies may be found at the Center for Applied Special Technology (CAST) web site.

Educational technology has the power to enhance communication. With a laptop computer and an Internet connection, students and teachers may access research and resources beyond the walls of their school and share paperless reports that are rich in content and appearance. Teachers can respond to students at any time from any location via e-mail and social networks. Teachers can, if desired, interact online with colleagues throughout the world, in real time, from their classroom desks, engage in professional development and conference calls, complete with audio and video components. High school teachers are strongly encouraged to take advantage of such opportunities, as appropriate. Finally, teachers must 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.

Using Assessments to Improve Instruction

An assessment is not a "test"; however, a test is one form of an assessment. An assessment incorporates a wide variety of tools for informing and improving instruction, for helping teachers and students improve their understanding of content, and for evaluating student performance and establishing grades. Teachers have a responsibility to not rely on only one or two major assessment tools in their chemistry course. Some students excel in writing, some in math; while others may be strong speakers or artists. Some students are pressured by written exams, and some are not. The evaluation of student learning must use a combination of different assessment tools along with the corresponding planning and follow-up activities.

Teachers must first answer a very important question: "Do you want to know how well your students are learning?"

Teachers who really want to know what their students know and understand will assess and reflect *every day*. Teachers should welcome evaluations of all types. Proper assessment will be used to continually adjust the classroom environment to improve learning. Teachers must recognize that even excellent programs can be improved.

An assessment of a chemistry lesson can be measured using a quiz, lab practical exam, written exam, or student satisfaction survey (formal); or can be evaluated through observations or conversation.

A formative assessment is accomplished during the learning process (as knowledge is “formed”), which includes observing classroom and laboratory activities, posing questions during a lesson, taking a poll, or having an informal conversation. A summative assessment is performed at periodic intervals to assess a collection of knowledge at a particular point in time. A summative assessment includes quizzes, exams, lab reports, and term papers. Personal journals may be used to encourage periodic self-reflection to help students assess their progress.

Local assessment tools are often very good for measuring locally identified student outcomes. Local tools are often designed by the teacher or a colleague and can be formatted any way that is desired. They do not compare students beyond the local boundary and can require much time and effort to develop.

Third-party assessment tools have the advantage of being unbiased and statistically valid. It is usually easy to administer and requires little preparation time. Some tools, such as those from the ACS Exams Institute, can provide objective national or regional ranking of performance. Many schools track the performance of their students who take subsequent chemistry courses at a postsecondary institution. This can provide an unbiased comparison of local students with a general population of college chemistry students. A third-party assessment can be expensive. It may provide only one aggregate score and may not be ideal for measuring local outcomes.

A complete assessment involves four essential components: planning, gathering, analyzing, and action. A credible assessment of a chemistry program will be based on information from a wide variety of assessment tools over a span of several years. The gathered information must be carefully examined and must be *used* to enhance student learning and to improve the program.

Physical Plant

The Classroom

The 21st century high school chemistry classroom provides a dynamic learning environment that is student-centered and curriculum-driven. The floor plan is designed for conversation, collaboration, and discovery. The classroom should contain multiple spaces that provide for long-term multidisciplinary projects, individual and small group learning, inquiry lessons, project-based learning, and problem solving. Flexibility in the arrangement of space, which includes movable workstations, is highly recommended. Universal design allows students with disabilities to fully participate and have access to all facilities, technology, and safety equipment.

Teacher accommodations should include a desk, chair, computer, and a demonstration table that includes a sink, natural gas connection, and a safety shield. Safety equipment includes a hands-free eye wash station, a master cut-off switch for electrical power, a master shut-off switch for gas, a fire blanket, a fire extinguisher(s), a first-aid kit, and a goggle sanitizer. A telephone with an outside line must be available in case of emergency.

A wireless network allows computers, printers, electronic display boards, and video projection systems to be connected. Room darkeners may be necessary. A portable cart with 12 to 24 personal electronic devices can be shared with several other classrooms. This technology will connect students with classrooms around the world, scientific facilities, 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. To prevent clutter, storage for students' personal items is necessary. Bookcases, storage cabinets that are master-keyed, and shelves are needed for classroom supplies. Wall space should be provided for a periodic table display and reference charts, dry-erase boards, tack boards, and for showing student work.

The Laboratory

The chemistry classroom often serves as a laboratory. This room is an integral part of the high school chemistry experience. It allows students to explore chemical concepts, view changes in matter, and acquire scientific skills in an atmosphere similar to a professional scientific environment.

The laboratory should be arranged so that instruction and lab skills may be practiced safely and effectively. Classrooms devoted to science instruction containing scientific equipment and supplies should not be used for other activities or nonscience courses. The classroom/laboratory needs to be vacant one period per day for safe lab setup and proper cleanup. Teachers must have adequate preparation time. Lab activities should only be conducted in a science classroom/lab that is outfitted with proper hardware and safety equipment.

Each laboratory should contain a fully equipped teacher station suitable for demonstrations and lab work. Student workstations should be arranged throughout the remaining work area. The chemistry laboratory may contain moveable lab stations or fixed lab stations. The latter allows for a more productive use of time because the facility is always available. To ensure student safety with adequate supervision, the ACS and the National Science Teachers Association (NSTA) recommend a maximum of 24 students per classroom based on 60 square feet per student. The NSTA has produced a position statement on the liability of science educators for laboratory safety (NSTA, 2007).

The square footage per pupil must meet state regulations. Different state mandates may require additional square footage. Space may also be based on building and fire safety codes, appropriate supervision, and the special needs of students. Additional areas should include a safety station and a station for students with disabilities. The arrangement of furniture must allow for adequate flexibility and supervision. For safety reasons, stools should not be in the walkways during laboratory investigations.

Workstations should have access to natural gas, water, and electricity. Electrical outlets built into the frame of the workstation and equipped with a ground-fault circuit interrupter (GFCI) must be away from water and gas outlets and should be plentiful enough to accommodate computers and technology equipment.

Containers should be clearly labeled for the disposal of chemicals and broken glassware. Cabinetry within the workstations, or placed around the perimeter of the room, should be used to store supplies and serve as storage for additional lab equipment and computers. Cabinets used for storing laboratory equipment should be selected to accommodate long glassware, as well as heavy equipment.

At a minimum, laboratory equipment should include:

Category	Equipment
Glassware	Beakers, graduated cylinders, funnels, flasks (assorted), burettes, gas collecting tubes, storage bottles, glass stirring rods, test tubes, glass tubing
Laboratory hardware	Ring stands, assorted clamps, wire gauze, strikers, scoopulas, tongs, triangular files, brushes
Ceramic ware	Evaporating dishes, crucibles, triangles, mortars and pestles, spot plates
Heating elements	Bunsen burners, hot plates
Connections and storage	Tubing (rubber and polypropylene), rubber stoppers (assorted sizes)
Electronic	Balances

The Recommended Minimum Core Inventory to Support Standards-Based Instruction for Chemistry developed by the California Science Teachers Association (CSTA) provides a more detailed list of equipment and consumables (CSTA, 2008). Refer to the teacher's edition of the classroom textbook and laboratory manual for a list of equipment, reagents, and quantities needed for class activities.

Fume hoods suitable for demonstrations should be clearly visible in all areas of the laboratory. The fume hoods must have proper ventilation according to laboratory safety standards. Access to the fume hoods will be for the teacher, students, and individuals with disabilities.

The need for proper ventilation in the laboratory is of utmost importance. OSHA Laboratory Standard 1910 states: "Four–12 room air exchanges per hour is adequate general ventilation if local exhaust systems such as hoods are used as the primary method of control." Air that is exhausted from the lab must be vented to the outdoors and not recirculated (OSHA 2012).

Schools may prefer to have computers and technological equipment located at desks along the perimeter of the room. These desks should be at seat height with accompanying chairs. Desks for individuals with disabilities should be at a height specified by state standards.

The instructor's computer should have interactive connections for activities and visualizations on an electronic display board. The demonstration portion of the teacher's station should be equipped with a proper supply of gas, water, and electricity.

All laboratories should contain the following safety equipment:
- Unobstructed access to an eye wash station with a continuous water supply that can flush both eyes at the same time and that is within reach in 10 seconds;
- Safety shower;
- Chemical Splash Goggles (American National Standards Institute (ANSI) Z 87.1) and a sanitizing goggle cabinet;
- First-aid station which includes a first-aid kit and blood clean-up items;
- Fire blanket;
- Fire extinguishers (as established by building code);
- Acid spill clean-up station;
- Broken glass disposal container;
- Safety and chemical inventory software;
- Chemical and flame-resistant aprons or lab coats; and
- Nonlatex gloves.

To ensure a safe learning environment, administrators, teachers, students, and parents will establish a comprehensive safety agreement which will be implemented in every science classroom. The American Chemical Society's Committee on Chemical Safety provides a sample agreement on its Web site (ACS, 2009).

Prep Room and Chemical Storage Closet

The teacher preparation room should be convenient and preferably adjacent to the classroom/lab. This facility can be shared between two classrooms. It should have a sink, proper ventilation, a fume hood, an eye wash station, and a fire extinguisher. Check state and local codes for space requirements. An outside telephone line is needed for emergencies. Recommended appliances for the area include a full-sized laboratory glassware washer and refrigerator with ice maker. Room for equipment, such as a deionized or distilled water source and storage carts, should be made available.

The school superintendent, science department chairperson, and chemistry teachers are accountable for developing a comprehensive and responsible chemical management program that protects students, teachers, staff, and the environment from potentially hazardous chemicals. Typically, the superintendent appoints a chemical safety officer to oversee the program (OSHA, 2012).

Chemicals are to be stored in a separate storage closet that has a door lock. The closet must be properly vented and the fan must be spark proof. No electrical receptacle outlets should be permitted as they may present a shock or an electrical fire hazard to users. Safety materials include an eye wash and fire extinguisher. There must be separate commercial storage units for acids, flammables, and corrosives. Properly supported shelves for general storage should be noncorrosive and must be properly secured to the walls. They should have a maximum depth of 12 inches and at least one-half inch lip on the shelf edge.

It is important to keep a current inventory of chemicals. Outdated and unknown chemicals should be properly discarded. The Flinn Science Catalog Reference Manual (Flinn Scientific, 2011) and ScholAR Chemistry provide guidelines for proper disposal. Chemicals should be dated when received and opened. Organize chemicals into compatible chemical families, rather than alphabetically. The School Chemistry Laboratory Safety Guide (National Institute for Occupational Safety and Health, 2006) provides guidelines for safely storing chemicals. It is recommended that all Material Safety Data Sheets (MSDS) be organized in a three-ring binder and that the binder be stored in a place that is accessible to all chemistry teachers.

Professional Preparations and Responsibilities

Nationwide, teachers of science are expected to be well qualified in their field. In some states this will mean that chemistry teachers are expected to have degrees in chemistry, while in others it will mean teachers must have a degree in any field of science along with a minimum number of college chemistry courses. In addition, it is expected that any qualified chemistry teacher has completed specific training in chemical and laboratory preparation and safety, including the ability to conduct hazard reviews of laboratory experiments and class demonstrations. Classroom teachers are advised that assistance may be provided by the district chemical safety officer.

Safety training is critical for any chemistry teacher, for his or her own legal and physical protection, and, of course, for the safety of all students. Knowledge of local and school district waste disposal and fire code requirements is essential. Resources for safety training are available through some vendors of scientific supplies such as VWR International, LLC, or Flinn Scientific, Inc. The Laboratory Safety Institute provides multiple online and print resources covering all areas of chemical safety. Some states may require and provide additional, specific training related to the storage, use, and disposal of chemicals in the academic laboratory.

Equity

The ACS has produced many publications that explain the organization's beliefs and values with respect to equity. This document is not intended to supersede the previous version of the ACS guidance document, titled "ACS High School Chemistry Guidelines and Recommendations," only to apply it to the context of the classroom setting. "Science for All," a phrase used by many—most notably the American Association for the Advancement of Science—is the cornerstone of the vision for high school chemistry. The ACS fully supports the goal of a scientifically literate society and maintains that one way to achieve this goal is by providing equal opportunities for *all* students to learn chemistry.

The implications of this position extend well beyond the needs of a single classroom. Schools and the states that support them are responsible for supplying the resources needed for the development and enactment of a chemistry program that is inquiry-based, student-centered, and accessible so that *all* learners have an equal opportunity for success.

The resources needed to provide this education include, but are not necessarily limited to, facilities, funding for materials, appropriate instructional time for planning and enactment, and professional development for the instructors. Schools are charged with the responsibility of hiring professional teachers whose values align with the Science for All philosophy, who possess the pedagogical content knowledge required to enact this curriculum, and who view themselves as lifelong learners.

Some of the research-based strategies that will enable chemistry teachers to grow toward this vision of equity, include the following:

- Being aware of the research on best practices aimed at teaching and reaching *all* students;
- Transforming and adapting instructional practices to promote student learning;
- Serving as equity role models in their classrooms and in the larger community;
- Recognizing and teaching to their students' strengths;
- Providing a learning environment focused on trust and fairness; and
- Connecting with the culture of their students, the students' families, and the community.

Ethics

Chemistry teachers work as both professional teachers and as science professionals. In addition to adopting an ethical practice as science professionals, chemistry teachers are also responsible for adhering to ethical conduct within the scope of their practice in the classroom. The disclaimer found in the beginning of the above section on equity applies equally to ethics.

Ethical chemistry teachers model within their instructional practices a safe and productive learning environment with equal opportunities for *all* students, and present course content without "distortion, bias, or personal prejudice." Educators must maintain confidential information and show fiscal responsibility. They shall refrain from misrepresentation of self and others, and not engage in fabrication, falsification, or plagiarism of ideas or information.

Chemistry teachers should make conscious decisions to limit the negative environmental impact in the design and enactment of their curriculum. They should model environmentally responsible actions for their students. Teachers should consider how they and their students consume energy and other natural resources. Similarly, in the laboratory, an environmentally responsible curriculum includes, but is not limited to: the appropriate selection, storage, use and disposal of chemical reagents; and the use of micro procedures, where suitable. Resources from the ACS GCI may be helpful for teachers in designing a green curriculum.

Professional Development

The ACS recognizes that teaching is a complex and intellectually challenging profession. Chemistry teachers must adopt the stance of lifelong learning and be willing to collaborate and share their expertise with other education and science professionals.

Professional development should encompass disciplinary content knowledge, pedagogical content knowledge, and how students understand content knowledge. Education research finds that the most effective professional development is sustained throughout the teacher's practice, teacher led, and focused on improved student leaning.

Other characteristics of effective professional development for chemistry teachers include:

- Active learning opportunities for teachers;
- Opportunities to develop skills and knowledge, use it in practice, reflect, and share;
- Deep understanding of focus area;
- Collaborative learning;
- Learning opportunities derived from both research and practice;
- Systemic initiatives for school and education reform; and
- Support for teachers in leadership roles.

Effective professional development opportunities also involve collaboration with members of the greater educational and scientific communities. Professional networking can be accomplished in meetings and workshops, or via online communication. Affiliations with local and state professional organizations are another possible source of important regional support. It should be noted that the ACS expects the full support of each chemistry teacher's school in their effort to grow as a professional educator. Support includes developing a school environment that encourages teachers' inquiry into their own practice, providing the resources to promote teacher leadership in professional learning communities, as well as providing opportunities for teachers to network with other professionals.

Professional Organizations and Resources

Membership and active participation in professional organizations provide chemistry teachers with a host of opportunities to network with other education professionals on multiple levels. This can be accomplished through active membership, use of online resources, and attendance at local, state, and national conferences associated with such professional organizations. In addition to the ACS, teachers have opportunities to be members of organizations at the local, state, and national levels. Organizations such as these provide many opportunities for continued teacher learning, including resources, workshops, grant announcements, and so forth, as a means to provide teachers with ideas for their classes.

Select association and professional development organizations include the following:

- ACS Division of Chemical Education (DivCHED);
- ACS Green Chemistry Institute (GCI);
- American Association for the Advancement of Science (AAAS);
- Association for Supervision and Curriculum Development (ASCD);
- National Academy of Science (NAS);
- National Association for Research in Science Teaching (NARST);
- National Science Foundation (NSF); and
- National Science Teachers Association (NSTA).

SOCED is another ACS resource that supports the development and implementation of programs that bring the wonder, excitement, opportunities, and challenges of modern chemical science to students of all ages. SOCED maintains a program of national and regional conferences in which teachers can network with other teachers and come into contact with the ideas being promoted by leaders in the field of chemical education. It is always helpful to be aware of current science education research and to anticipate common student misconceptions in chemistry. The ACS *Journal of Chemical Education* (JCE, 2011) provides a variety of articles, as well as a Chemistry Concepts Inventory.

Extracurricular Activities

Chemistry teachers 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 will be positioned to provide students with enriching activities designed to ignite the interest and imagination of the participants. A few examples of extracurricular opportunities sponsored by the ACS available to chemistry teachers and their students include the ChemClub, Chemistry Olympiad, Project SEED, *ChemMatters* magazine, the Scholars Program, college planning resources, and summer research programs for students and teachers.

The ACS ChemClub provides fun, authentic, and hands-on opportunities 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. Project SEED is a summer research program for economically disadvantaged students. Also, teachers may consider encouraging his/her students to apply to one of the many summer research programs that provide students with academic enrichment and real-world experience working alongside scientists in a research laboratory.

The following organizations offer summer research programs for high school students:

- ACS Project SEED Summer Research Internship Program;
- Research Science Institute (RSI) at the Massachusetts Institute of Technology (MIT);
- Science and Engineering Apprenticeship Program (SEAP), American Society for Engineering Education (ASEE); and
- Summer Internship Program in Biomedical Research (SIP),National Institutes of Health (NIH).

ChemMatters is an award-winning magazine that demystifies chemistry for high school students. The ACS also promotes the ACS Scholars Program for African American, Hispanic, and American Indian students pursuing a college degree in the chemical sciences or chemical technology. These students are eligible to apply for a scholarship through the ACS Scholars Program. For additional college planning, the ACS Web site provides information on what it takes to earn a degree in chemistry, the benefits of finding a mentor and building a professional network, and much more.

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Glossary of Acronyms

AAAS	American Association for the Advancement of Science
ACS	American Chemical Society
ACSD	Association for Supervision and Curriculum Development
ANSI	American National Standards Institute
AP	Advanced Placement
ASEE	American Society for Engineering Education
DivCHED	ACS Division of Chemical Education
GCI	ACS Green Chemistry Institute
GFCI	Ground-Fault Circuit Interrupter
IB	International Baccalaureate
IT	Information Technology
JCE	Journal of Chemical Education
MIT	Massachusetts Institute of Technology
MSDS	Material Safety Data Sheet
NARST	National Association for Research in Science Teaching
NAS	National Academy of Science
NIH	National Institutes of Health
NRC	National Research Council
NSES	National Science Education Standards
NSF	National Science Foundation
NSTA	National Science Teachers Association
OSHA	Occupational Safety and Health Administration
RIS	MIT Research Science Institute
SEAP	Science and Engineering Apprenticeship Program
SEED	ACS Summer Research Internship Program
SIP	NIH Summer Internship Program in Biomedical Research
SOCED	ACS Society Committee on Education
UDL	Universal Design for Learning