CHAPTER 1

How to Use This Lab Manual

THE AP® CHEMISTRY CURRICULUM FRAMEWORK

The Advanced Placement® Chemistry course is designed to promote student learning of essential chemistry content and development of deep conceptual understanding through an inquiry-based model of instruction. In this model, students learn by engaging in science practices that develop their experimental and reasoning skills. A practice is a way to coordinate knowledge and skills in order to accomplish a goal or task. The science practices enable students to establish lines of evidence and use them to develop and refine testable explanations and predictions of natural phenomena. A further discussion of inquiry is found in Chapter 2, and the science practices are detailed in Chapter 3 and Appendix D.

The key concepts and related content that define the AP Chemistry course and exam are organized around six underlying principles called the big ideas, which address (1) atoms and elements, (2) properties of matter, (3) chemical reactions, (4) kinetics, (5) thermodynamics, and (6) equilibrium. The big ideas encompass the core scientific principles, theories, and processes governing matter and chemical systems. For each big idea, enduring understandings, which incorporate the core concepts that students should retain from the learning experience, are also identified.

Learning objectives for each big idea clearly define what students are expected to know and be able to do. Because content, inquiry, and reasoning are equally important in AP Chemistry, each learning objective combines content with inquiry and reasoning skills described in the science practices. Each lab focuses on one specific primary learning objective under one of the six big ideas and also addresses at least one secondary objective. The investigations are organized by primary learning objectives as ordered under the six big ideas of the curriculum framework.

GOALS OF THE LABORATORY INVESTIGATIONS

These student-directed, inquiry-based lab experiences support the AP Chemistry course and curricular requirements by providing opportunities for students to engage in the seven science practices as they design plans for experiments, collect data, apply mathematical routines, develop explanations, make predictions, and communicate about their work. This manual not only contains laboratory investigations that are inquiry based and student directed but also supports the content and science practices within the AP Chemistry course.

The 16 laboratory investigations in this lab manual support the recommendation by the National Science Foundation (NSF) that science teachers build into their curriculum opportunities for students to develop skills in communication, teamwork, critical thinking, and commitment to lifelong learning (Waterman 2008, NSF 1996). The manual's engaging, inquiry-based approach will inspire students to investigate meaningful questions about the real world. They align with best practices reported in *America's Lab Report*, a comprehensive synthesis of research about student learning in the science laboratory from the National Research Council.

Development of the Lab Investigations

To create a model of excellence for the lab component in AP science courses, the College Board, in conjunction with the Lab Vision Team and Chemistry Lab Development Team, worked to create an innovative vision and approach to lab investigations. Both teams of subject matter experts consisted of AP Chemistry teachers and higher education faculty members as well as experts in the field of inquiry instruction, quantitative skill application, and lab investigations to create *AP Chemistry Guided-Inquiry Experiments: Applying the Science Practices*.

How to Use the Lab Investigations in Your AP Chemistry Course

The AP Chemistry course emphasizes depth over breadth of content. The scope of the course affords educators time to develop students' conceptual understanding and engage them in inquiry-based learning experiences. It also enables teachers to spend time differentiating instruction and targeting the interests of their students.

The AP Exam will assess students' abilities to apply the science practices to the learning objectives addressed by the labs in this manual, and inquiry in the laboratory best supports students' development of the skills needed to apply the science practices (see Chapter 3 for a discussion of the science practices). Because inquiry-based labs typically take more time than traditional labs, the number of recommended labs has been reduced from 22 to 16. At least six of the 16 experiments in an AP Chemistry course should utilize an inquiry-based model of instruction, chosen either from this manual or from another source of guided-inquiry experiments for AP Chemistry. Teachers may continue to use traditional experiments to support the learning objectives of the course for 10 of the 16 lab experiments of their choosing. Ideally, the six inquiry labs will address a range of content areas and laboratory techniques, so that, for example, not all of the inquiry labs are titrations or address stoichiometry, but rather touch on several of the big ideas.

The labs in this manual are intended to serve as exemplars, not as required activities; teachers are encouraged to develop their own student-directed, inquiry-based labs that address the learning objectives in the curriculum framework. To assist and support teachers in this process, the College Board operates the online AP Teacher Community, which provides opportunities for collaboration and sharing of resources and ideas, and professional development workshops and summer institutes that focus specifically on using inquiry in the laboratory. There are multiple strategies that can be applied to change a traditional, confirmation lab investigation into a guided inquiry lab, and several different models of guided inquiry that can be used, as explained in Chapter 2. Chapter 2 also provides specific ideas for traditional-to-inquiry lab modifications. Regardless of your approach, the key is to engage students in the investigative process of science to allow them to discover knowledge for themselves in a self-reflective, safe, organized manner.

The labs are categorized under the six big ideas of the AP Chemistry curriculum, but they can be conducted in any order. The chart that follows provides an overview of the investigative labs and a mapping to the curriculum framework. The chart includes the primary learning objective for each experiment. Each experiment addresses one or more additional objectives to some degree, and as such, some of the labs' learning objectives overlap to some degree. Teachers may find that they do not want to do both overlapping labs, particularly if they are pressed for laboratory time. Pairs of overlapping labs include labs 1 and 2, 10 and 11, 4 and 14, and 15 and 16. The chart is designed to help you decide the order in which to introduce the labs, and whether to adopt a "lab first" approach, in which students carry out an investigation on a topic before having studied it in other parts of the course, or after being introduced to the relevant content. Ideally, whether a lab first approach is used or not, labs can be sequenced so that they align with the work students are doing in other parts of the course, as suggested by *America's Lab Report*. Teachers are expected to devote 25 percent of instructional time to lab investigations. Complete curricular requirements can be found in the *AP Chemistry Course and Exam Description.*

OVERVIEW OF THE INVESTIGATIVE LABS

Lab	*Student Time Estimate	**Teacher Prep Time Estimate	Primary Learning Objective (LO)
Big Idea 1: Atoms and Elements			
1. Spectroscopy: *What Is the Relationship Between the Concentration of a Solution and the Amount of Transmitted Light Through the Solution?*	120 min	20 min	LO 1.15 The student can justify the selection of a particular type of spectroscopy to measure properties associated with vibrational or electronic motions of molecules.
2. Spectrophotometry: *How Can Color Be Used to Determine the Mass Percent of Copper in Brass?*	180 min	45 min	LO 1.16 The student can design and/or interpret the results of an experiment regarding the absorption of light to determine the concentration of an absorbing species in a solution.
3. Gravimetric Analysis: *What Makes Hard Water Hard?*	140 min	40 min	LO 1.19 The student can design, and/or interpret data from, an experiment that uses gravimetric analysis to determine the concentration of an analyte in a solution.
4. Titration: *How Much Acid Is in Fruit Juice and Soft Drinks?*	140–170 min	70 min	LO 1.20 The student can design, and/or interpret data from, an experiment that uses titration to determine the concentration of an analyte in a solution.
Big Idea 2: Structure and Properties of Matter			
5. Chromatography: *Sticky Question: How Do You Separate Molecules That Are Attracted to One Another?*	110 min	30 min	LO 2.10 The student can design and/or interpret the results of a separation experiment (filtration, paper chromatography, column chromatography, or distillation) in terms of the relative strength of interactions among and between the components.
6. Bonding in Solids: *What's in That Bottle?*	105–140 min	40 min	LO 2.22 The student is able to design or evaluate a plan to collect and/or interpret data needed to deduce the type of bonding in a sample of a solid.

Lab	*Student Time Estimate	**Teacher Prep Time Estimate	Primary Learning Objective (LO)
Big Idea 3: Chemical Reactions			
7. Stoichiometry: *Using the Principle That Each Substance Has Unique Properties to Purify a Mixture: An Experiment in Applying Green Chemistry to Purification*	200 min	40 min	LO 3.5 The student is able to design a plan in order to collect data on the synthesis or decomposition of a compound to confirm the conservation of matter and the law of definite proportions.
8. Redox Titration: *How Can We Determine the Actual Percentage of H_2O_2 in a Drugstore Bottle of Hydrogen Peroxide?*	120 min	45 min	LO 3.9 The student is able to design and/or interpret the results of an experiment involving a redox titration.
9. Physical and Chemical Changes: *Can the Individual Components of Quick Ache Relief Be Used to Resolve Consumer Complaints?*	180 min	40 min	LO 3.10 The student is able to evaluate the classification of a process as a physical change, chemical change, or ambiguous change based on both macroscopic observations and the distinction between rearrangement of covalent interactions and noncovalent interactions.
Big Idea 4: Kinetics			
10. Kinetics: Rate of Reaction: *How Long Will That Marble Statue Last?*	190 min	45 min	LO 4.1 The student is able to design and/or interpret the results of an experiment regarding the factors (i.e., temperature, concentration, surface area) that may influence the rate of a reaction.

Lab	*Student Time Estimate	**Teacher Prep Time Estimate	Primary Learning Objective (LO)
11. Kinetics: Rate Laws: *What Is the Rate Law of the Fading of Crystal Violet Using Beer's Law?*	165–195 min	60 min	LO 4.2 The student is able to analyze concentration vs. time data to determine the rate law for a zeroth-, first-, or second-order reaction. In cases in which the concentration of any other reactants remains essentially constant during the course of the reaction, the order of a reaction with respect to a reactant concentration can be inferred from plots of the concentration of reactant versus time.
Big Idea 5: Thermodynamics			
12. Calorimetry: *The Hand Warmer Design Challenge: Where Does the Heat Come From?*	140 min	30 min	LO 5.7 The student is able to design and/or interpret the results of an experiment in which calorimetry is used to determine the change in enthalpy of a chemical process (heating/cooling, phase transition, or chemical reaction) at constant pressure.
Big Idea 6: Equilibrium			
13. Equilibrium: *Can We Make the Colors of the Rainbow? An Application of Le Châtelier's Principle*	115 min	80 min	LO 6.9 The student is able to use LeChâtelier's principle to design a set of conditions that will optimize a desired outcome, such as product yield.
14. Acid-Base Titration: *How Do the Structure and the Initial Concentration of an Acid and a Base Influence the pH of the Resultant Solution During a Titration?*	185 min	40 min	LO 6.13 The student can interpret titration data for monoprotic or polyprotic acids involving titration of a weak or strong acid by a strong base (or a weak or strong base by a strong acid) to determine the concentration of the titrant and the pK_a for a weak acid, or the pK_b for a weak base.
15. Buffering Activity: *To What Extent Do Common Household Products Have Buffering Activity?*	125 min	45 min	LO 6.20 The student can identify a solution as being a buffer solution and explain the buffer mechanism in terms of the reactions that would occur on addition of acid or base.

Lab	*Student Time Estimate	**Teacher Prep Time Estimate	Primary Learning Objective (LO)
16. Buffer Design: *The Preparation and Testing of an Effective Buffer: How Do Components Influence a Buffer's pH and Capacity?*	180 min	60 min	LO 6.18 The student can design a buffer solution with a target pH and buffer capacity by selecting an appropriate conjugate acid-base pair and estimating the concentrations needed to achieve the desired capacity.

*NOTE: Each lab contains a more detailed breakdown of time requirements for various components of the experiments. Some components of some labs can be completed outside of school (e.g., postlab assessments) or can be omitted at teacher discretion.

**The teacher prep time estimate does not include time for teachers to conduct the experiments themselves. This essential preparatory step should be taken prior to implementing any of the labs with students for the first time.

THE FORMAT OF THE LABORATORY INVESTIGATIONS

Although each lab investigation in this manual is unique and focuses on specific concepts and science practices, the structure of each lab is essentially identical in order to provide clarity and consistency. As detailed in the table that follows, many components appear in both the Student Manual (SM) and Teacher Manual (TM), while other components only appear in the Teacher Manual, such as information about prior skills students need, how the lab develops the science practices, how to prepare needed materials, and suggestions for extending the investigation. The Teacher Manual also includes teaching tips, sample data, and sample answers for all activities and questions.

Components of the Laboratory Investigations		
Component	**Description and Purpose**	**Teacher Manual Only OR Teacher and Student Manuals (Both)**
Title	An introduction to the focus of the lab; most are framed as a question to engage students.	Both
Timing and Length of Investigation	A listing of the amount of teacher preparation time and student time required, with suggestions for how to carry out the lab over more than one day; allows teachers to plan to do lab within the constraints of their class's schedule.	Teacher Manual
Central Challenge	A brief description of the challenge or problem students will solve orients students and teacher to the investigation.	Both

Components of the Laboratory Investigations		
Component	**Description and Purpose**	**Teacher Manual Only OR Teacher and Student Manuals (Both)**
Context for this Investigation	Background and context in the form of real-world applications or a fictional scenario related to the lab and to demonstrate the relevance of the lab to real-world contexts.	Both
Alignment to the AP Chemistry Curriculum Framework	A listing of the primary and secondary learning objectives for the lab provides information about what students should know and be able to do as they conduct their laboratory investigations. Each learning objective integrates science practices with specific concepts and enduring understandings outlined in the curriculum framework as well as information about how students will be expected to demonstrate their knowledge and abilities.	Teacher Manual
Prior Skills	A list of skills students need in order to successfully carry out the lab allows teachers to ensure that students are well-prepared to conduct the investigation beforehand.	Teacher Manual
Developing Science Practices, Instrumentation, and Procedural Skills	A chart showing the different activities students will engage in during the lab and explaining how each of those activities relates to the science practices in the curriculum framework.	Teacher Manual
Preparation: Materials, Safety and Disposal, and Prelab Preparation	A list of materials needed, and a description of safety and disposal concerns and procedures, provides teachers and students with information they need to successfully and safely complete the lab and properly dispose of waste generated. A description of how to make solutions and prepare other needed supplies guides teachers through the steps necessary to get materials ready for the lab.	Both (Materials, Safety and Disposal); Teacher Manual (Prelab Preparation)
Prelab Guiding Questions/ Simulations	Activities including computer simulations and animations, or pencil and paper modeling and guiding questions, that ask students to hypothesize and work in groups to construct an understanding of the concept needed to engage in guided inquiry and to understand macroscopic phenomena involved in the lab on the particulate scale. Teaching tips, sample data, and student answers are provided in the Teacher Manual.	Both

Components of the Laboratory Investigations		
Component	**Description and Purpose**	**Teacher Manual Only OR Teacher and Student Manuals (Both)**
Explanation to Strengthen Student Understanding (in most labs)	The background information related to the lab that is essential — and only that which is essential — for students to know in order to carry out the student-directed inquiry, prepares students to do the lab while allowing them to develop their own knowledge related to the learning objectives through the science practices. In some labs, this section is identical in both the Teacher Manual and the Student Manual, while in others the Teacher Manual is more extensive so teachers can decide how much information to provide students.	Both
Practice with Instrumentation and Procedure (in some labs)	An activity that guides students to practice procedures and learn to use instruments needed to carry out the main guided-inquiry portion of the lab and that separates the relatively prescriptive skill development from the more student-directed inquiry that follows. Sample data and student answers are provided in the Teacher Manual.	Both
Investigation	Activities that guide students to address the Central Challenge engage students in developing and carrying out procedures to collect data and evidence in the laboratory. Teaching tips and sample data are provided in the Teacher Manual.	Both
Microscale Alternative (only in some labs)	A description of how to carry out the guided inquiry in microscale and thus minimize chemical usage and waste generation provides teachers with information needed to decide if they are able to and want to use this procedure instead of the macroscale one.	Teacher Manual
Data Collection and Computation	Activities and questions that guide students to present and quantitatively analyze the data and evidence collected. This section separates out the skills of Science Practices 2 and 4. Sample answers are provided in the Teacher Manual.	Both
Argumentation and Documentation	Activities and questions that guide students to qualitatively analyze their work, to synthesize it with scientific models and theories and to connect it to particulate representations of phenomena. This section separates out the science practice skills of 5, 6, and 7. Sample work is provided in the Teacher Manual.	Both

Components of the Laboratory Investigations		
Component	**Description and Purpose**	**Teacher Manual Only OR Teacher and Student Manuals (Both)**
Postlab Assessment	Questions to measure students' understanding of the concepts, development of science practices, and gain in thinking skills *after* students conduct their lab investigations and analyze their results allow teachers to assess student learning in a summative fashion. Sample answers are provided in the Teacher Manual.	Teacher Manual
Next Steps: Extension Activity and Follow-up Experiment	Classroom and laboratory activities connected to the investigation provide the teacher with options to further guide students to achieve related learning objectives and develop the science practices.	Teacher Manual
Supplemental Resources	A listing of websites, books, and other sources that provide teachers and students with options for obtaining additional information and suggestions related to the lab.	Both

THE LABORATORY ENVIRONMENT

Safety, Safety Contracts, and Supervision

Teachers have an obligation to provide a safe environment in which their students can learn and explore. The equipment and chemicals used in the laboratory work for AP Chemistry could cause harm if not used appropriately. Therefore, it is very important that you follow the following guidelines:

1. The laws and regulations regarding safety and chemical management vary from one locale to another. It is critical that you be informed and up-to-date on the rules for your school, district, and state, and that you adhere to them. Ensure that you get safety training even if your school does not require it.
2. You must have basic safety equipment in your classroom: a fire extinguisher, fire blanket, eyewash, chemical spill kit, safety goggles or glasses for every student (goggles are generally preferred, as they provide more complete protection), and a first-aid kit. All of this safety equipment should be checked regularly, and, if appropriate, tested to ensure everything is in working order.
3. Develop a safety contract for your students. The students and their parents or guardians should sign the contract before beginning any laboratory work. Sample safety contracts are available through scientific supply companies and school districts.
4. Use Material Safety Data Sheets (MSDS) to guide ordering, storage, preparation, usage, and disposal of chemicals. Introduce students to the MSDS structure and show them how to read and understand them. MSDS for all commonly used chemicals are readily

available online. Please note that in the future, MSDS will be titled SDS. You may refer your students to the following link to review these future changes and the importance of implementing such changes:
http://www.nsta.org/publications/news/story.aspx?id=59696

5. Teach about safety at the beginning of the year and each time you begin a lab activity. Review the safety section of the investigation with students to ensure understanding. Explain what could happen if safety instructions are not followed correctly. With more student-directed lab activities, it is even more important to provide strict guidelines because different groups of students will be doing different activities and using different materials and equipment.
6. Be consistent in enforcing the safety guidelines. Do not allow exceptions to the rules.

Materials and Equipment

This course is a college-level course in chemistry, and the equipment needed for the labs in this guide is reasonable. Your school and district should support you and your classroom in order to provide an adequate learning environment in which to conduct laboratory investigations. Each laboratory investigation includes a list of materials and equipment needed. It is assumed that each class has access to basic lab equipment and glassware (e.g., beakers, Bunsen burners, and balances), in addition to some specialized equipment, such as spectrophotometers and pH meters.

However, it is recognized that many classes do not have access to more expensive equipment, particularly probes and sensors with computer interfaces. None of the labs requires the use of probes or computer sensors for data collection, though some do provide an option for using these tools. Computer-based animations and simulations are part of the prelab activities for most of the investigations, and they require a computer and projector so that the instructor can show them. A paper-based alternative is provided in case this equipment is unavailable. Students may use computers or graphing calculators to analyze data and present their findings, but they do not need to do so. It is worth noting that facility with computerized data analysis, especially using Excel spreadsheets, is a valuable skill for students to learn.

Teachers can explore means of gaining access to more expensive equipment such as computers, spectrophotometers, high-quality analytical balances, and probes. Expensive equipment such as spectrophotometers can be rented for short periods. Chemical companies often have equipment for classrooms to borrow, and representatives from the companies should have this information. Alternatively, local colleges or universities may allow your students to complete a lab as a field trip on their campus or borrow equipment, or they may even donate their old equipment to your school. Some schools have partnerships with local businesses that can help with laboratory equipment and materials. It never hurts to ask and to make your laboratory needs known. There are many grant programs that chemistry teachers are eligible to apply to for funds to purchase equipment and supplies, including Hach grants from the American Chemical Society and online donation sites such as Donors Choose and Adopt-A-Classroom.

Additional Safety Resources for Further Information

General safety information resources:

- An excellent online resource from the National Institute for Occupational Safety and Health:
  http://www.cdc.gov/niosh/docs/2007-107/pdfs/2007-107.pdf
- A book from the National Science Teachers' Association: Texley, Juliana, Terry Kwan, and John Summers. *Investigating Safely: A Guide for High School Teachers*. Arlington, VA: National Science Teachers Association Press, 2004.

Resources for safety training:

- The Laboratory Safety Institute, a provider of safety training for schools and teachers:
  http://www.labsafetyinstitute.org/

Resources with information about safe storage and disposal of chemicals in the laboratory:

- University of South Carolina:
  http://ehs.sc.edu/guides/Chemstorage_g.pdf

Materials Safety Data Sheets (MSDS) resources:

- MSDS database:
  http://www.ehso.com/msds.php

REFERENCE

Singer, Susan R., Margaret L. Hilton, and Heidi A. Schweingruber. *America's Lab Report: Investigations in High School Science.* Washington, DC: The National Academies Press, 2006.