

Students and the Science Practices: Developing Skills

Students come into the classroom with their own ideas of how chemistry works. Sometimes their ideas are scientifically correct and other times they are partially or completely mismatched with the scientific concept. These mismatched concepts have been called misconceptions, or alternative concepts. Research has shown that the most effective pedagogic approach to changing these alternative concepts is through experiences that challenge students to reevaluate their current way of thinking. By giving students opportunities to test their own ideas or concepts about how chemistry works, they develop more scientifically accurate mental models.

This way of teaching reflects the way that scientific knowledge actually evolves over time. For example, many students have ideas about matter that match the ideas the best minds in history had before experiments revealed data that required an improved concept of matter. Science has always posed real challenges that do not have predictable outcomes. To develop scientific thinking skills, students need to have experiences that are more creative; for their own learning to progress, they need to become the scientists that drive the investigation forward.

Throughout the study of history and philosophy of science, there are nine key points that have emerged about the development of scientific thought. In total, these ideas have one key conclusion — that science is not a body of facts, but rather a system of understanding observations that allows us to make sense of the world around us. If we think about these key ideas, they can help us understand the reasoning behind using inquiry in the chemistry laboratory.

Key points about the nature of science:

- Scientific theories are tentative in nature, not hierarchal relative to each other.
- Laws and theories serve different roles in science.
- There is no universal step-by-step scientific method.
- Observations are theory laden.
- Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, creativity, and skepticism.
- Scientific progress is characterized by competition between rival theories.
- Scientists can interpret the same experimental data differently.
- Development of scientific theories at times is based on inconsistent foundations.
- Scientific ideas are affected by their social and historical milieu.

ROAD MAP FOR BUILDING SCIENCE SKILLS

Exploring scientific questions through inquiry requires many skills. Students come into AP Chemistry with a range of skills related to inquiry. Other skills needed for experimental work at the AP level need to be developed through the investigative labs in the course. The table below provides examples of the types of skills needed for inquiry in the AP Chemistry lab, classified as prior skills and developing skills. Note that different students have different skills coming into the course, so it is important for teachers to assess their own students' prior skills as they plan for each laboratory investigation. Each lab in this manual clearly identifies the specific skills used in the lab in the Skills section in order to facilitate teacher planning and formative assessment. You may find that your students lack some prior skills or already have some developing skills (or both, depending on the particular lab).

Skill Type	Prior Skill Examples	Developing Skill Examples
Measuring	Using balances, basic glassware, and thermometers appropriately	Using volumetric glassware and electronic devices (pH meters, spectrophotometers) appropriately
Forming scientific questions	Writing a hypothesis	Writing scientific questions and designing an experiment to answer such questions
Data collection	Collecting data according to directions, filling in data tables	Making decisions about data to collect and creating data tables
Communicating laboratory findings	Making a graph according to directions	Making decisions on the graphs to best illustrate the trends in data
Analyzing data	Writing a conclusion or answering questions about the lab	Presenting data and conclusion to peers and applying concepts developed in class or other labs to further understand the lab results
Working with scientific explanations and theories	Answering questions at end of the lab connecting class content to the lab	Using theories discussed in class to form foundation for experimental design and questions asked, using these theories to form explanations for the observations and data gathered in the lab
Connecting and relating knowledge across domains	Connecting previous science class to current content	Using chemistry understanding of matter on the level of atoms to better understand behavior of atoms in physics, biology, geology, and medicine

SCIENCE PRACTICES IN THIS MANUAL

Science practices (SPs) are an assortment of laboratory and thinking skills that students will be using when they are doing inquiry and guided-inquiry laboratories. The science practices:

- Represent important aspects of the work of scientists;

- Are a vitally important part of learning science;
- Should be incorporated into laboratory experiences; and
- Form the foundation of scientific reasoning skills that AP Chemistry students should master by completion of the class.

Below are descriptions of each practice and an explanation of how it is used in the investigative labs in this manual, followed by one or two specific examples from the manual. Teachers can use this information to ensure that the SPs are used in the labs that they design themselves, if they choose to.

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems. One area of many student misconceptions is incomplete understanding of how atoms connect to the observable macroscopic changes. In each laboratory, students use their mental model of atoms and then refine or redefine their mental model as a result of the laboratory data. The teacher's role throughout this process is to probe students' understanding, specifically looking at their model as represented with words and drawings. This is an ongoing process throughout the course with the objective of helping students reach more clearly defined and scientifically accurate mental models.

EXAMPLES

- Lab #5: Students draw models of molecules that explain their different macroscopic observations with chromatography.
- Lab #14: Students draw models of particles showing how the particles differ at different points in the titration.

Science Practice 2: Students can use mathematics appropriately. There will be measurements generated in the experiments, and when collecting data it is important that students use accuracy and precision in the correct scientific sense. Consistent use of significant figures is also important when students share their data as a class and are trying to establish trends in data. All of these measurement concerns are informed by the allowable levels of error. In all laboratories, students should be able to justify their selection of a mathematical routine to solve a problem in the laboratory setting, rather than simply attempting to solve all laboratory problems with an algorithmic approach.

EXAMPLES

- Lab #1: Students calculate concentration of a dye based on the absorbance.
- Lab #8: Students calculate the concentration of the unknown solution using oxidation–reduction titration data and stoichiometric ratios.

Science Practice 3: Students can engage in scientific questioning to extend thinking or guide investigations within the context of the AP course. The ability to develop scientific questions forms the foundation of scientific thinking skills and it requires using mental models and scientific knowledge to formulate a question that can be investigated. Such questions inevitably require students to explore experimentally how to best design an experiment.

EXAMPLE

- Lab #4: Students design a plan for collecting data of an acid-base titration to answer their own scientific question.

Science Practice 4: The student can plan and implement data-collection strategies in relation to a particular scientific question. In every laboratory, students should understand what data they need to gather and the underlying scientific concept they are trying to prove or disprove with the data. Once a scientific question has been created, the experimenter must be able to focus on the independent and dependent variable, as well as the predicted relationship between the two. The independent variable is the variable that will be changed in the experiment and the dependent variable will be measured in relationship to the change done in the experiment.

EXAMPLES

- Lab #6: Students design and execute an experiment to deduce the type of bonding found in different substances.
- Lab #12: Students design and carry out an experiment to determine the identity and amount of substances needed to make an ideal hand warmer.

Science Practice 5: Students can perform data analysis and evaluation of evidence. Often students can collaborate in creating a class data set to clarify trends or patterns in data, as well as outliers in data that may represent lab error.

EXAMPLE

- Lab #10: Students graph data to see the relationships between variables and use the information to make decisions about what variables to change if the reaction goes too quickly or slowly.

Science Practice 6: The students can work with scientific explanations and theories, in which students should be able to use these better models that are improved through laboratory data to employ scientific theories in their own explanations of the phenomena they observe. The investigative labs each contain learning tasks in which students apply their knowledge of scientific explanations and ideas to characterize and analyze their data, and then to explain their data explicitly in terms of those scientific explanations and ideas.

EXAMPLES

- Lab #9: Students use macroscopic observations to infer whether a chemical or physical change occurred and then explain their choice.
- Lab #13: Students use Le Châtelier's principle to identify stresses caused to a system in equilibrium and connect the stresses to the observed changes in color.

Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across the domains. As students' mental models become more sophisticated and scientifically aligned through their work in the lab, students will be able to connect the deeper conceptual knowledge across scientific domains.



EXAMPLE

- Lab #16: Students apply their understanding of acids and bases to design a biological buffering system.

Together, these science practices lead students to develop the range of skills that are used through the guided-inquiry laboratories in this manual. The ultimate goal is for students, through the process of inquiry in AP Chemistry, to become more sophisticated scientific thinkers who are prepared and eager to continue studying and experimenting at the college level. Rich laboratory experiences play a crucial role in achieving this level of engagement and understanding in science.

■ REFERENCES

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