Science Process Skills Learning Framework

Adapted from Clemmons AW, Timbrook J, Herron JC, Crowe AJ. 2020. BioSkills guide: Development and national validation of a tool for interpreting the *Vision and Change* core competencies. CBE Life Sci Educ 19:ar53. doi:10.1187/cbe.19-11-0259.

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| **Topic** | **Learning Goals (see below for Sample Learning Objectives)** |
| Process of Science | Explain how science generates knowledge of the natural world. |
| Locate, interpret, and evaluate scientific information and primary literature. |
| Pose testable questions and hypotheses to address gaps in knowledge. |
| Plan, evaluate, and implement scientific investigations. |
| Interpret, evaluate, and draw conclusions from data. |
| Construct explanations and make evidence-based arguments about the natural world. |
| Address novel questions through authentic research experiences. |
| Modeling/ Developing and Using Models | Recognize the important roles that scientific models, of many different types (conceptual, mathematical, physical, etc.), play in predicting and communicating biological phenomena. |
| Make inferences and solve problems using models and simulations. |
| Build and evaluate models of biological systems. |
| Quantitative Reasoning/ Using Mathematics and Computational Thinking | Use basic mathematics (*e.g.,* algebra, probability, unit conversion) in biological contexts. |
| Apply the tools of graphing, statistics, and data science to analyze biological data. |
| Interdisciplinary Nature of Science | Integrate concepts across other STEM disciplines (*e.g.,* chemistry, physics) and multiple fields of biology (*e.g.,* cell biology, ecology). |
| Consider interdisciplinary solutions to real-world problems. |
| Communication and Collaboration | Share ideas, data, and findings with others clearly and accurately. |
| Work productively in teams with people who have diverse backgrounds, skill sets, and perspectives. |
| Provide and respond to constructive feedback in order to improve individual and team work. |
| Reflect on your own learning, performance, and achievements. |
| Science and Society | Demonstrate the ability to critically analyze ethical issues in the conduct of science. |
| Consider the potential impacts of outside influences (historical, cultural, political, technological) on how science is practiced. |
| Apply scientific reasoning in daily life and recognize the impacts of science on a local and global scale. |

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| **Topic** | **Learning Goals** | **Sample Learning Objectives** |
| Process of Science | Explain how science generates knowledge of the natural world. | Explain how scientists use inference and evidence-based reasoning to generate knowledge. |
| Describe the iterative nature of science and how new evidence can lead to the revision of scientific knowledge. |
| Locate, interpret, and evaluate scientific information and primary literature. | Find and evaluate the credibility of a variety of sources of scientific information, including popular science media and scientific journals. |
| Interpret, summarize, and evaluate evidence in primary literature. |
| Evaluate claims in scientific papers, popular science media, and other sources using evidence-based reasoning. |
| Pose testable questions and hypotheses to address gaps in knowledge. | Recognize gaps in our current understanding of a biological system or process and identify what specific information is missing. |
| Develop research questions based on your own or others’ observations. |
| Formulate testable hypotheses and state their predictions. |
| Plan, evaluate, and implement scientific investigations. | Compare the strengths and limitations of various study designs. |
| Design controlled experiments, including plans for analyzing the data. |
| Execute protocols and accurately record measurements and observations. |
| Identify methodological problems and suggest how to troubleshoot them. |
| Evaluate and suggest best practices for responsible research conduct (*e.g.,* lab safety, record keeping, proper citation of sources). |
| Interpret, evaluate, and draw conclusions from data. | Analyze data, summarize resulting patterns, and draw appropriate conclusions. |
| Describe sources of error and uncertainty in data. |
| Construct explanations and make evidence-based arguments about the natural world. | Make evidence-based arguments using your own and others’ findings. |
| Relate conclusions to original hypothesis, consider alternative hypotheses, and suggest future research directions based on findings. |
| Address novel questions through authentic research experiences. | Identify a novel research question and propose an appropriate study design to test it. |
| Given a research question, formulate a hypothesis, identify a relevant online data set, and run appropriate analyses to test hypothesis. |
| Follow protocols to gather data in the field or lab, summarize and find patterns, and identify follow-up questions to address uncertainty in results. |
| After attempting an experiment or study, reflect on its success and failures and repeat with adjustments. |
| Modeling/ Developing and Using Models | Recognize the important roles that scientific models, of many different types (conceptual, mathematical, physical, etc.), play in predicting and communicating biological phenomena. | Describe why biologists use simplified representations (models) when solving problems and communicating ideas. |
| Given two models of the same biological process or system, compare their strengths, limitations, and assumptions. |
| Make inferences and solve problems using models and simulations. | Summarize relationships and trends that can be inferred from a given model or simulation. |
| Use models and simulations to make predictions and refine hypotheses. |
| Build and evaluate models of biological systems. | Build and revise conceptual models to propose how a biological system or process works. |
| Identify important components of a system and describe how they influence each other (*e.g.,* positively or negatively). |
| Evaluate conceptual, mathematical, or computational models by comparing their predictions with empirical data. |
| Quantitative Reasoning/ Using Mathematics and Computational Thinking | Use basic mathematics (*e.g.,* algebra, probability, unit conversion) in biological contexts. | Perform basic calculations (*e.g.,* percentages, frequencies, rates, means). |
| Select and apply appropriate equations (*e.g.,* Hardy-Weinberg, Nernst, Gibbs free energy) to solve problems. |
| Interpret and manipulate mathematical relationships (*e.g.,* scale, ratios, units) to make quantitative comparisons. |
| Use probability and understanding of biological variability to reason about biological processes and statistical analyses. |
| Use rough estimates informed by biological knowledge to check quantitative work. |
| Describe how quantitative reasoning helps biologists understand the natural world. |
| Apply the tools of graphing, statistics, and data science to analyze biological data. | Record, organize, and annotate simple data sets. |
| Create and interpret informative graphs and other data visualizations. |
| Select, carry out, and interpret statistical analyses. |
| Describe how biologists answer research questions using databases, large data sets, and data science tools. |
| Interpret the biological meaning of quantitative results. |
| Interdisciplinary Nature of Science | Integrate concepts across other STEM disciplines (*e.g.,* chemistry, physics) and multiple fields of biology (*e.g.,* cell biology, ecology). | Given a biological problem, identify relevant concepts from other STEM disciplines or fields of biology. |
| Build models or explanations of simple biological processes that include concepts from other STEM disciplines or multiple fields of biology. |
| Consider interdisciplinary solutions to real-world problems. | Describe examples of real-world problems that are too complex to be solved by applying biological approaches alone. |
| Suggest how collaborators in STEM & non-STEM disciplines could contribute to solutions of real-world problems. |
| Be able to explain biological concepts, data, and methods, including their limitations, using language understandable by collaborators in other disciplines. |
| Communication and Collaboration | Share ideas, data, and findings with others clearly and accurately. | Use appropriate language and style to communicate science effectively to targeted audiences (*e.g.,* general public, biology experts, collaborators in other disciplines). |
| Use a variety of modes to communicate science (*e.g.,* oral, written, visual). |
| Work productively in teams with people who have diverse backgrounds, skill sets, and perspectives. | Work with teammates to establish and periodically update group plans and expectations (*e.g.,* team goals, project timeline, rules for group interactions, individual and collaborative tasks). |
| Elicit, listen to, and incorporate ideas from teammates with different perspectives and backgrounds. |
| Work effectively with teammates to complete projects. |
| Provide and respond to constructive feedback in order to improve individual and team work. | Evaluate feedback from others and revise work or behavior appropriately. |
| Critique others’ work and ideas constructively and respectfully. |
| Reflect on your own learning, performance, and achievements. | Evaluate your own understanding and skill level. |
| Assess personal progress and contributions to your team and generate a plan to change your behavior as needed. |
| Science and Society | Demonstrate the ability to critically analyze ethical issues in the conduct of science. | Identify and evaluate ethical considerations (*e.g.,* use of animal or human subjects, conflicts of interest, confirmation bias) in a given research study. |
| Critique how ethical controversies in biological research have been and can continue to be addressed by the scientific community. |
| Consider the potential impacts of outside influences (historical, cultural, political, technological) on how science is practiced. | Describe examples of how scientists’ backgrounds and biases can influence science and how science is enhanced through diversity. |
| Identify and describe how systemic factors (*e.g.,* socioeconomic, political) affect how and by whom science is conducted. |
| Apply scientific reasoning in daily life and recognize the impacts of science on a local and global scale. | Apply evidence-based reasoning and biological knowledge in daily life (*e.g.,* consuming popular media, deciding how to vote). |
| Use examples to describe the relevance of science in everyday experiences. |
| Identify and describe the broader societal impacts of biological research on different stakeholders. |
| Describe the roles scientists have in facilitating public understanding of science. |