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# The Basic Competencies of Biological Experimentation: Concept-Skill Statements

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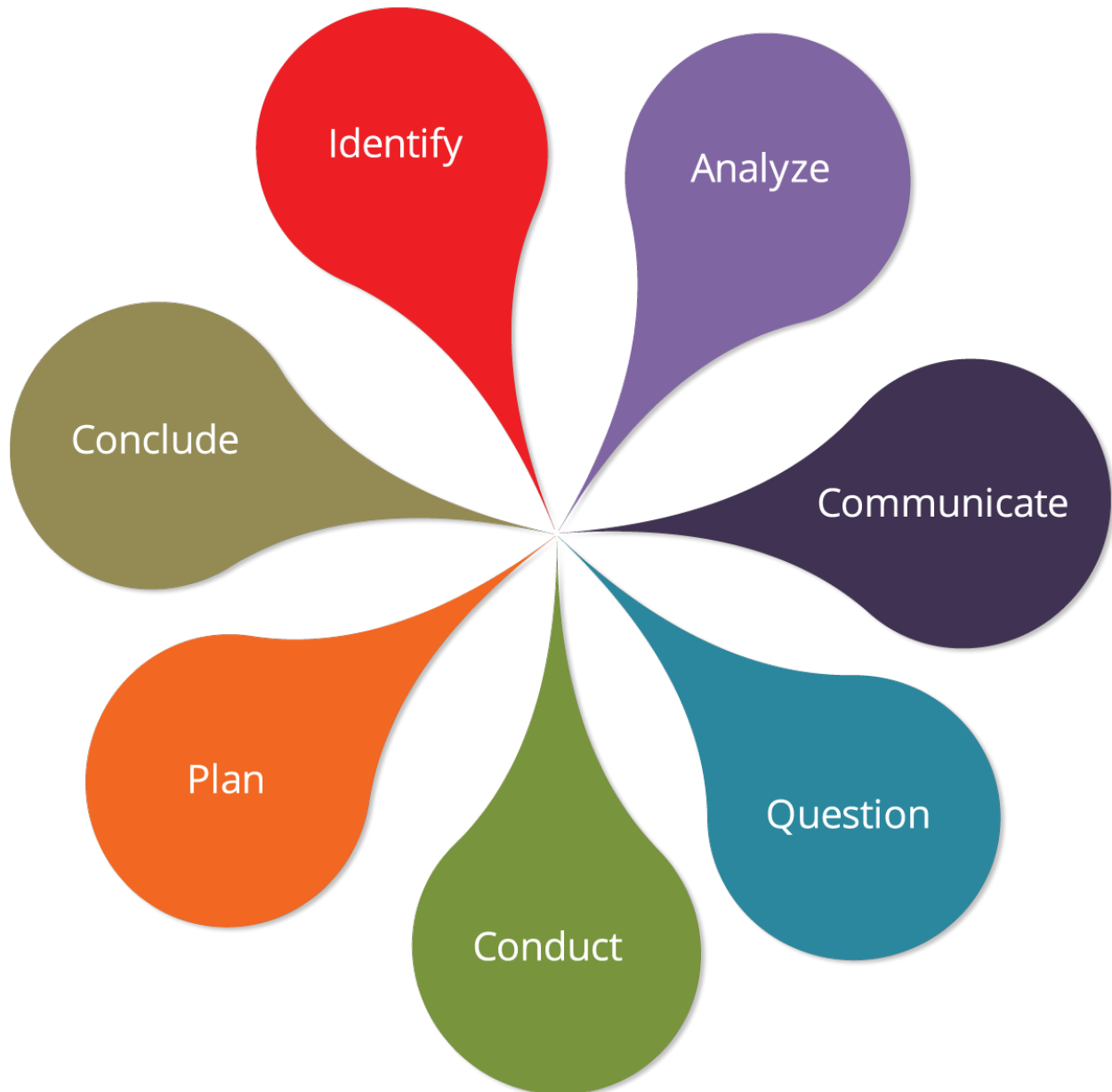
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## The Basic Competencies of Biological Experimentation

### Concept-Skill Statements



The image above is a model of the seven areas a competent biologist calls in when doing experimentation in biology identified by the ACE-Bio Network. Each competency is represented by a summary word on a uniquely colored segment of the model.

For presentation convenience, the seven major areas within experimentation in biology are elaborated below in a linear manner. However, this is not meant to convey a particular order that one must follow during experimentation. The areas are given equal weight and flexible order of their use throughout the process of experimentation.



The ability to **identify** gaps or limitations in current research knowledge through the review, filtering and synthesis of relevant literature.

The Concept of:	Skills: The ability to use the concept to...
A. Relevant Background Knowledge	<ol style="list-style-type: none"> <li>1. ___ Find appropriate sources of relevant scientific information (primary, secondary, etc.)</li> <li>2. ___ Filter and evaluate the relevance of information from appropriate sources to the specific research focus</li> <li>3. ___ Evaluate background information with critical scientific skepticism</li> <li>4. ___ Synthesize and apply current knowledge to generate a contextual foundation for the research problem.</li> <li>5. ___ Reflect on the skills and knowledge needed in the relevant field before proceeding to do research.</li> </ol>
B. A Gap in Current Knowledge	<ol style="list-style-type: none"> <li>1. ___ Recognize a gap in current scientific knowledge that can be addressed with experimentation</li> <li>2. ___ Reflect on limits of background knowledge related to the gap</li> <li>3. ___ Identify a problem that is timely, relevant, and interesting, and, if addressed, could build on our foundational knowledge of science</li> </ol>





**The ability to generate a research question and formulate hypotheses.**

<b>The Concept of:</b>	<b>Skills: The ability to use the concept to...</b>
A. Observations	1. ___ Apply systematic observations to discern variable properties of components of biological systems 2. ___ Compare observations to existing knowledge, models, or theories
B. Research Questions	1. ___ Develop novel, relevant, and testable research questions based on patterns or properties of components observed in biological systems or described in primary literature 2. ___ Evaluate ethical, theoretical, practical and cost constraints associated with a research question
C. Models*	1. ___ Develop a model (i.e. an abstraction or simplification: an equation, computer simulation, conceptual drawing, or other explanatory representation that shows key elements and their relationships) to approximate or represent the behavior of a natural phenomenon 2. ___ Articulate the assumptions and limitations of a model 3. ___ Evaluate a model to identify ways to improve it
D. Hypotheses	1. ___ Use a model (i.e. an abstraction or simplification: an equation, computer simulation, conceptual drawing, or other explanatory representation that shows key elements and their relationships) to generate new hypotheses 2. ___ Generate multiple explanations of the natural world that are testable and potentially falsifiable 3. ___ Predict associations between treatment conditions and outcome variables for the research target 4. ___ Determine whether multiple hypotheses are mutually exclusive and based on predictions of a model





The ability to plan feasible and ethical experiments to answer research questions or test hypotheses.

The Concept of:	Skills: The ability to use the concept to...
A. Representations	<ol style="list-style-type: none"> <li>1. ___ Diagram/cartoon the steps of an experimental method</li> <li>2. ___ Construct a visual representation (e.g. a graph or diagram) of predicted results</li> <li>3. ___ Diagram, label and title components for a proposal to conduct an experiment</li> </ol>
B. Experimental Design	<ol style="list-style-type: none"> <li>1. ___ Identify assumptions of the different types of experimental designs (manipulative, observational/discovery, natural)</li> <li>2. ___ Choose the most appropriate design approach to answer the research question(s) raised</li> <li>3. ___ Propose measurable outcomes that would support or refute hypotheses</li> <li>4. ___ Optimize treatments for efficiency</li> <li>5. ___ Identify potential sources of systematic and random error</li> <li>6. ___ Draw a timeline of experimental procedures</li> </ol>
C. Variables	<ol style="list-style-type: none"> <li>1. ___ Identify relevant, measurable variables for testing the hypothesis</li> <li>2. ___ Identify dependent and independent variables</li> <li>3. ___ Identify confounding, and/or covariate variables aligned with experiment</li> </ol>
D. Controls (if relevant)	<ol style="list-style-type: none"> <li>1. ___ Design controls to anticipate likely sources of error to allow for comparison with experimental treatment groups in the context of the experiment.</li> <li>2. ___ Select appropriate positive and negative controls to define an expected range of outcomes and to allow for comparison with outcomes from experimental treatments.</li> <li>3. ___ Consider what conditions are necessary to perform the experiments.</li> <li>4. ___ Randomize the order in which experimental subjects or units experience treatment or control conditions as a way to reduce the chance of bias in the experiment.</li> <li>5. ___ Explain the implications of a control that did not show the expected result</li> </ol>





The ability to **plan** feasible and ethical experiments to answer research questions or test hypotheses.

E. Measurement	<ol style="list-style-type: none"> <li>1. ___ Choose appropriate measurements based on available equipment, population/species, natural variation, and research question(s)</li> <li>2. ___ Align variables appropriately with measurement tools/scale/instruments</li> <li>3. ___ Recognize the limitations of measurement tools/equipment</li> </ol>
F. Sampling	<ol style="list-style-type: none"> <li>1. ___ Identify a target population(s) (might be molecules, cells, organisms, or populations) for the planned experiment</li> <li>2. ___ Design the sampling strategy to expose and account for natural variation and measurement error</li> <li>3. ___ Align sampling protocol with the research question or hypothesis</li> <li>4. ___ Sample subjects randomly for control and treatment groups to reduce the effect of unanticipated variables.</li> </ol>
G. Variation	<ol style="list-style-type: none"> <li>1. ___ Differentiate between measurement variability and system variability (natural variation or heterogeneous populations)</li> <li>2. ___ Determine replication or repeatability needed to quantify variation</li> </ol>
H. Ethics	<ol style="list-style-type: none"> <li>1. ___ Integrate professional and community ethics into research design</li> <li>2. ___ Submit planned research to the Institutional Review Board or Animal Care and Use Committee for evaluation, as appropriate</li> </ol>
I. Limitations	<ol style="list-style-type: none"> <li>1. ___ Evaluate assumptions in the experimental design</li> <li>2. ___ Evaluate bias in the experimental design</li> <li>3. ___ Evaluate uncertainty in protocols (e.g. how we measure variables) analytical methods (e.g., assumptions of statistical tests), and interpretations of results</li> <li>4. ___ Evaluate limitations of methods</li> </ol>
J. Iteration	<ol style="list-style-type: none"> <li>1. ___ Design the research process to include multiple iterations (or repeated experiments)</li> <li>2. ___ Use feedback from preliminary results to improve protocols in new experiments</li> <li>3. ___ Use feedback from results to refine hypotheses and predictions</li> </ol>





The ability to **conduct** an investigation to achieve research goals.

The Concept of:	Skills: The ability to use the concept to...
A. Measurement	1. ___ Record observational data carefully and appropriately. 2. ___ Measure the response of the subjects to the treatment conditions carefully and appropriately.
B. Variable outcomes	1. ___ Monitor study for unexpected outcomes due to technical errors, equipment failure, subject characteristics, and unplanned factors. 2. ___ Evaluate potential for non-treatment causes for differences or similarities in research outcomes. 3. ___ Troubleshoot technical errors.
C. Data Documentation	1. ___ Maintain a written or digital laboratory notebook or field journal that provides a record describing how, when, where, and why data were collected. 2. ___ Archive important and sensitive data in an accessible format that is intelligible, secure, and ethical. 3. ___ Record data in an organized and systematic way using appropriate tables, forms, etc. 4. ___ Enter data with appropriate labels, units of measure, and levels of precision.







The ability to analyze and process data.

The Concept of:	Skills: The ability to use the concept to...
A. Data curation	<ol style="list-style-type: none"> <li>1. ___ Construct appropriate ways to organize data (e.g. tables, figures)</li> <li>2. ___ Explore and reduce raw data to discern trend and summarize relationships among variables</li> <li>3. ___ Identify outliers and/or errant data by generating criteria for inclusion or rejection of data</li> <li>4. ___ Display appropriate comparisons (i.e. detect natural groupings)</li> <li>5. ___ Conduct transformations that facilitate statistical or other analytic tests</li> <li>6. ___ Conduct computations for summarizing/interpreting findings</li> </ol>
B. Data analysis	<ol style="list-style-type: none"> <li>1. ___ Analyze clean data using discipline-appropriate methods based on the measurements collected and the experimental questions.</li> </ol>
C. Statistics	<ol style="list-style-type: none"> <li>1. ___ Choose and conduct statistical tests that are appropriate for the type/nature of data</li> <li>2. ___ Choose and conduct statistical tests that are aligned with hypotheses and experimental research methods</li> <li>3. ___ Generate statistics for a sample to summarize and/or describe parameters for a whole population (e.g., mean, median, measures of variance).</li> </ol>
D. Data Summary	<ol style="list-style-type: none"> <li>1. ___ Appropriately identify a legend, label axes, and select appropriate scale to graph findings</li> <li>2. ___ Considering the variables intended for comparisons, select an appropriate graphical type for the particular data type (e.g. contingency tables, bar graphs, histograms, scatterplots, etc.)</li> <li>3. ___ Display findings with a representation that is effective in summarizing trends or major findings, including illustrating contrasts among categorical groups where relevant</li> </ol>




 Conclude

The ability to **conclude** about data with inferences that are limited to the scope inherent in the experimental design.

The Concept of:	Skills: The ability to use the concept to...
A. Patterns and Relationships	1. ___ Describe trends in numeric and visual representations of data 2. ___ Interpret whether the results suggest a causal mechanism beyond simple correlation 3. ___ Distinguish biologically-meaningful trends from expected natural biological variability
B. Inferences and Conclusions	1. ___ Generalize results to an appropriate level (more than single experiment, less than universal) 2. ___ Connect analysis of results with valid claims or conclusion in a logical way 3. ___ Evaluate limitations of the findings and limitations that determine scope of inference (experimental and practical limitations) 4. ___ Compare results to other previously reported results and reconcile differences 5. ___ Align conclusion with analyses, hypotheses, research question(s), and existing knowledge 6. ___ Determine and articulate whether data support or refute hypotheses and predictions 7. ___ Express uncertainty by discussing limitations of data analysis (sources of error, inaccurate measurement, and sample bias, statistical significance vs. biological relevance ) 8. ___ Identify future directions that will make conclusions more certain 9. ___ Understand that scientific knowledge is tentative





The ability to **communicate** research work in professionally appropriate modes, including visual, written, and oral formats.

The Concept of:	Skills: The ability to use the concept to...
A. Representations	<ol style="list-style-type: none"> <li>1. ___ Distill results into clear numeric and/or graphical forms that are aligned with the experimental objective/question/hypothesis</li> <li>2. ___ Develop a predictive or explanatory model to summarize research findings</li> </ol>
B. Scientific Communication	<ol style="list-style-type: none"> <li>1. ___ Construct scientific communications using standard conventions.</li> <li>2. ___ Distinguish typical structure and detail of an oral versus a written presentation</li> <li>3. ___ Tailor structure and content of a presentation to the probable audience (e.g., scientific vs. public)</li> <li>4. ___ Construct a wide range of representations such as tables, graphs, slides, diagrams, animations and simulations to present main points clearly in written and oral presentations</li> <li>5. ___ Select the representation that best depicts the data to allow for appropriate inferences</li> </ol>
C. Limitations	<ol style="list-style-type: none"> <li>1. ___ Articulate limitations, unanswered questions, and the tentative nature of results (both positive and negative)</li> <li>2. ___ Contrast results and findings with previously published scientific work</li> <li>3. ___ Offer alternative hypotheses</li> <li>4. ___ Construct a justification and counter-justification argument for each alternative, if possible</li> </ol>
D. Synthesis and Reflection	<ol style="list-style-type: none"> <li>1. ___ Evaluate, analyze and explain the significance and implications of the research</li> <li>2. ___ Revise an existing model based on observations or data</li> <li>3. ___ Articulate how findings contribute to new knowledge that can drive further inquiry</li> <li>4. ___ Propose follow up experiments based on inferences from predicted or actual results of experiments.</li> </ol>

