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The Basic Competencies of Biological Experimentation: Concept-Skill Statements

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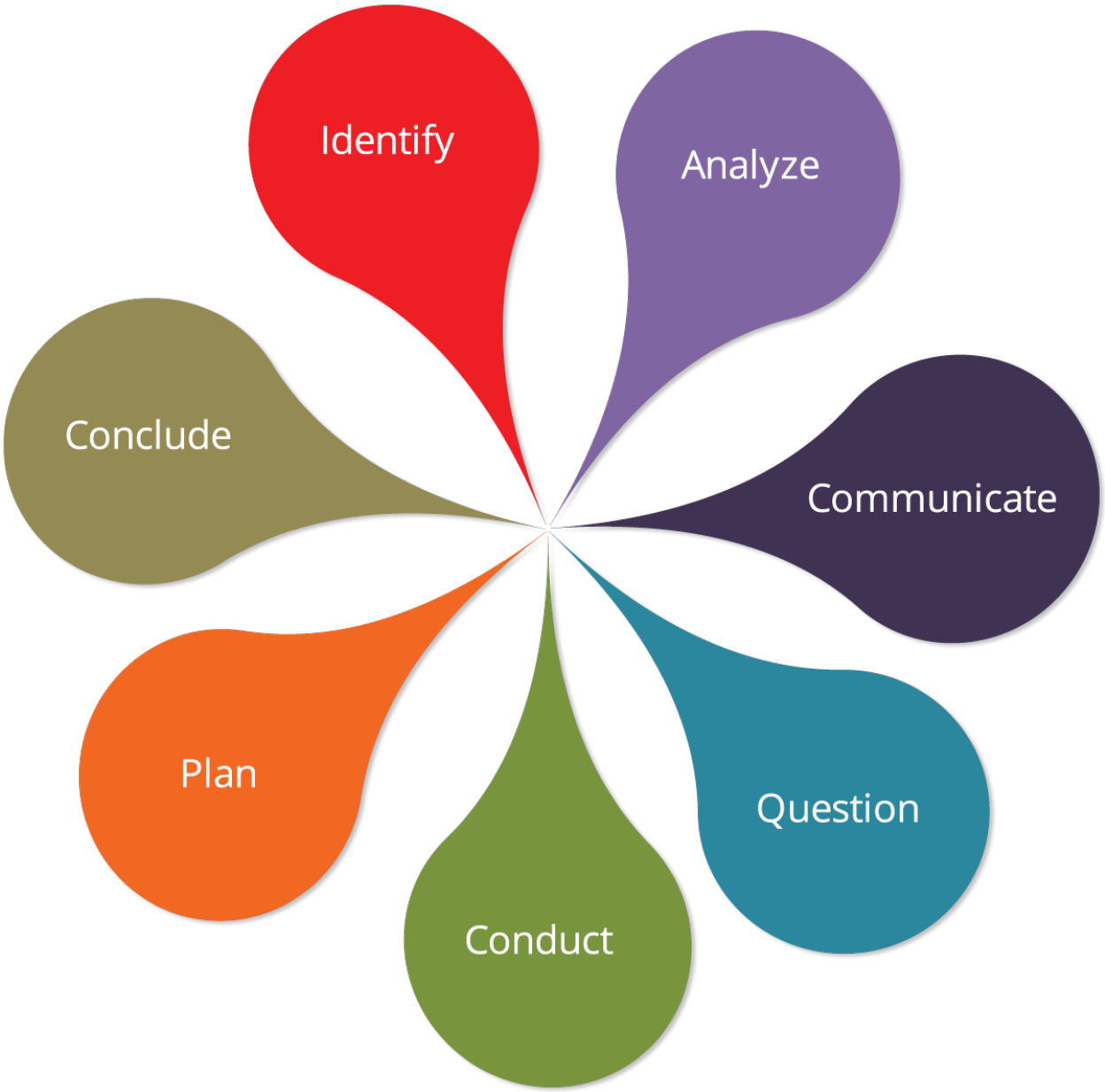
The Basic Competencies of Biological Experimentation
Concept-Skill Statements



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 <u>identify</u> 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	1. ____Find appropriate sources of relevant scientific information (primary, secondary, etc.) 2. ____Filter and evaluate the relevance of information from appropriate sources to the specific research focus 3. ____Evaluate background information with critical scientific skepticism 4. ____Synthesize and apply current knowledge to generate a contextual foundation for the research problem. 5. ____Reflect on the skills and knowledge needed in the relevant field before proceeding to do research.
B. A Gap in Current Knowledge	1. ____Recognize a gap in current scientific knowledge that can be addressed with experimentation 2. ____Reflect on limits of background knowledge related to the gap 3. ____Identify a problem that is timely, relevant, and interesting, and, if addressed, could build on our foundational knowledge of science

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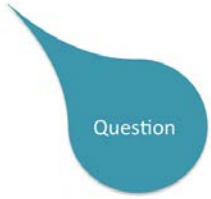

The ability to generate a research question and formulate hypotheses.

The Concept of:	Skills: The ability to use the concept to…
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

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The ability to <u>plan</u> feasible and ethical experiments to answer research questions or test hypotheses.

The Concept of:	Skills: The ability to use the concept to…
A. Representations	1. ____Diagram/cartoon the steps of an experimental method 2. ____Construct a visual representation (e.g. a graph or diagram) of predicted results 3. ____Diagram, label and title components for a proposal to conduct an experiment
B. Experimental Design	1. ____Identify assumptions of the different types of experimental designs (manipulative, observational/discovery, natural) 2. ____Choose the most appropriate design approach to answer the research question(s) raised 3. ____Propose measurable outcomes that would support or refute hypotheses 4. ____Optimize treatments for efficiency 5. ____Identify potential sources of systematic and random error 6. ____Draw a timeline of experimental procedures
C. Variables	1. ____Identify relevant, measurable variables for testing the hypothesis 2. ____Identify dependent and independent variables 3. ____Identify confounding, and/or covariate variables aligned with experiment
D. Controls (if relevant)	1. ____Design controls to anticipate likely sources of error to allow for comparison with experimental treatment groups in the context of the experiment. 2. ____Select appropriate positive and negative controls to define an expected range of outcomes and to allow for comparison with outcomes from experimental treatments. 3. ____Consider what conditions are necessary to perform the experiments. 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. 5. ____Explain the implications of a control that did not show the expected result

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The ability to <u>plan</u> feasible and ethical experiments to answer research questions or test hypotheses.

E. Measurement	1. ____Choose appropriate measurements based on available equipment, population/species, natural variation, and research question(s) 2. ____Align variables appropriately with measurement tools/scale/instruments 3. ____Recognize the limitations of measurement tools/equipment
F. Sampling	1. ____Identify a target population(s) (might be molecules, cells, organisms, or populations) for the planned experiment 2. ____Design the sampling strategy to expose and account for natural variation and measurement error 3. ____Align sampling protocol with the research question or hypothesis 4. ____Sample subjects randomly for control and treatment groups to reduce the effect of unanticipated variables.
G. Variation	1. ____Differentiate between measurement variability and system variability (natural variation or heterogeneous populations) 2. ____Determine replication or repeatability needed to quantify variation
H. Ethics	1. ____Integrate professional and community ethics into research design 2. ____Submit planned research to the Institutional Review Board or Animal Care and Use Committee for evaluation, as appropriate
I. Limitations	1. ____Evaluate assumptions in the experimental design 2. ____Evaluate bias in the experimental design 3. ____Evaluate uncertainty in protocols (e.g. how we measure variables) analytical methods (e.g., assumptions of statistical tests), and interpretations of results 4. ____Evaluate limitations of methods
J. Iteration	1. ____Design the research process to include multiple iterations (or repeated experiments) 2. ____Use feedback from preliminary results to improve protocols in new experiments 3. ____Use feedback from results to refine hypotheses and predictions

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The ability to <u>conduct</u> 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.

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The ability to <u>analyze</u> and process data.

The Concept of:	Skills: The ability to use the concept to…
A. Data curation	1. ____Construct appropriate ways to organize data (e.g. tables, figures) 2. ____Explore and reduce raw data to discern trend and summarize relationships among variables 3. ____Identify outliers and/or errant data by generating criteria for inclusion or rejection of data 4. ____Display appropriate comparisons (i.e. detect natural groupings) 5. ____Conduct transformations that facilitate statistical or other analytic tests 6. ____Conduct computations for summarizing/interpreting findings
B. Data analysis	1. ____Analyze clean data using discipline-appropriate methods based on the measurements collected and the experimental questions.
C. Statistics	1. ____Choose and conduct statistical tests that are appropriate for the type/nature of data 2. ____Choose and conduct statistical tests that are aligned with hypotheses and experimental research methods 3. ____Generate statistics for a sample to summarize and/or describe parameters for a whole population (e.g., mean, median, measures of variance).
D. Data Summary	1. ____Appropriately identify a legend, label axes, and select appropriate scale to graph findings 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.) 3. ____Display findings with a representation that is effective in summarizing trends or major findings, including illustrating contrasts among categorical groups where relevant

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The ability to <u>conclude</u> 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

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The ability to <u>communicate</u> 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	1. ____Distill results into clear numeric and/or graphical forms that are aligned with the experimental objective/question/hypothesis 2. ____Develop a predictive or explanatory model to summarize research findings
B. Scientific Communication	1. ____Construct scientific communications using standard conventions. 2. ____Distinguish typical structure and detail of an oral versus a written presentation 3. ____Tailor structure and content of a presentation to the probable audience (e.g., scientific vs. public) 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 5. ____Select the representation that best depicts the data to allow for appropriate inferences
C. Limitations	1. ____Articulate limitations, unanswered questions, and the tentative nature of results (both positive and negative) 2. ____Contrast results and findings with previously published scientific work 3. ____Offer alternative hypotheses 4. ____Construct a justification and counter-justification argument for each alternative, if possible
D. Synthesis and Reflection	1. ____Evaluate, analyze and explain the significance and implications of the research 2. ____Revise an existing model based on observations or data 3. ____Articulate how findings contribute to new knowledge that can drive further inquiry 4. ____Propose follow up experiments based on inferences from predicted or actual results of experiments.

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