Course-wide objectives (5 big ideas that describe the overarching themes of the course)
By the end of the three-course intro lab sequence, students should be able to:

1. Collect data and revise an experimental procedure iteratively and reflectively,
2. Evaluate the process and outcomes of an experiment quantitatively and qualitatively,
3. Extend the scope of an investigation whether or not results come out as expected,
4. Communicate the process and outcomes of an experiment, and
5. Conduct an experiment collaboratively and ethically.

Specific learning objectives (Finer detail involved in the 5 big ideas above)
By the end of the three-course intro lab sequence, students should be able to:

1. Collect data and revise the experimental procedure iteratively, reflectively, and responsively:

- Decide which data to collect, including:
    - which variables to change/vary and how to change them
    - which variables to control and how to control them
    - which variables to measure
- Identify possible sources of:
    - Systematic effects,
    - Variability and uncertainty, and
    - Places mistakes may happen.
- Make predictions about expected measurements, data, and results by:
    - Performing order of magnitude estimations,
    - Checking units and dimensions,
    - Consulting previous data and results, and
    - Collecting preliminary, pilot data.
- Use the predictions about expected data, uncertainties, and systematics to:
    - Identify where the main effect might be,
    - Consider spacing and frequency of data, or
    - Quantify systematics or design tests to quantify them.
- Decide how to measure data, including:
    - how much data to collect (including number of trials, range of each variable, frequency/spacing of data collection) to obtain desirable uncertainty in measured values or calculated parameters
    - what equipment to use
    - Determine ways to reduce sources of uncertainty, systematics, or mistakes.

2. Evaluate the process and outcomes of an experiment quantitatively and qualitatively

- Analyze data using computational methods including (but not limited to) working with software such as spreadsheets, Matlab, or Python.
- Decide how to analyze the quality of the measurements, which involves:

    - Identifying and distinguishing possible sources of uncertainty, either from the measurement model or physical model
    - Distinguish instrumental uncertainty from random uncertainty
    - Determining how to quantify those sources of uncertainty (such as through standard deviation or standard uncertainty of the mean of repeated measurements or instrumental precision)
    - Propagate measurements uncertainties through calculations that use the measurements.
- Compare pairs of measurements by determining the degree to which uncertain measurements are statistically distinguishable,
- Compare data to a model by:
    - Choosing a model to test from theory or predictions,
    - Plotting data and model on traditional x-y plots including appropriate representations of uncertainty,
    - Linearizing data via semi-log or log-log plots,
    - Performing linear and non-linear weighted least-squares fits,
    - Plotting residuals
    - Describing how the least-squares method provides a measure of the best-fit (conceptual understanding)
    - Evaluating the degree to which data fit a model through least squares fitting and residuals graphs
- Reflect (and respond appropriately) throughout the data collection process by:
    - Plotting as data are collected,
    - Checking for additional sources of uncertainty, systematics, or mistakes,
    - Considering and revisiting constraints such as equipment and time, and
    - Checking whether data make sense (quality, trend, size, etc.).

3. Extend the scope of an investigation whether or not results come out as expected
- Using methods above, evaluate the degree to which data agree or disagree with a model
- If data do not agree, determine plausible explanations for the disagreement, such as:
    - A mistake during the measurement process,
    - An issue with the equipment, or
    - An unexpected physical phenomenon (e.g. assumptions, approximations in the model).
- When data and results do not come out as expected:
    - Test whether the results are repeatable or reproducible under the same conditions,
    - Check whether the results are repeatable or reproducible with improved precision or measurement quality,
    - Isolate and test components of the system (troubleshoot), and
    - Design new experiments/tests to explore other explanations for the disagreement.

- When data and results do come out as expected:
    - Test whether the results hold with higher levels of accuracy and precision (improve the quality of measurements), or
    - Extend the scope of the experiment to check if there is “new” physics at these levels.

4. Communicate the process and outcomes of an experiment
    - Describe the experimental goals, process, data, results, and conclusions in a lab notebook including:
        - Justification for all decisions made, and
        - Supplementing, rather than replacing content when changes are made.
    - Use previous notes in their lab notebooks to inform design of future experiments.
    - Explain the experiment, broader context, and uniqueness of the investigation in a more formal format such as a final report, oral presentation, or poster.
    - Present conclusions, claims, and outcomes as arguments that are supported by and follow coherently from evidence (data).

5. Conduct an experiment collaboratively and ethically.
    - Brainstorm with their group to construct a diverse set of ideas when making decisions
    - Share experimentation responsibility with other group members (i.e. rotate roles, allow others to lead)
    - Provide positive and constructive feedback when evaluating peers’ work
    - Consider issues of scientific ethics when analyzing data including:
        - Dealing with outliers,
        - Dealing with data and results that do not match predictions or expectations, and
        - Dealing with data and results that do match predictions or expectations.