General Information

There are three types of Investigative Science Learning Environment (ISLE) labs: observation experiments, testing experiments, and application experiments. Observation experiments are intended to help learn skills such as changing one variable at a time, recording and representing observations, and making accurate observations without mixing them with explanations. This is the first step of the experimental cycle, and allows one to observe phenomena, look for patterns in data, and start to devise explanations once observations are carefully completed.

The next step, once explanations have been devised, is to perform testing experiments, which are designed to test hypotheses based on specific explanations and/or rules. This helps practice making predictions about the outcome of an experiment. For a testing experiment, one can't just perform the experiment and record what happens. There must be predicted outcomes based on explanations. If the outcome of the experiment agrees with the prediction, then it gives confidence that the explanation may be correct, but if it disagrees, then one knows the explanation is incorrect. In order to make this judgment, one also needs to apply basic uncertainty calculations. A guide for determining uncertainty is included in these documents.

The third type of experiment is the application experiment, where some explanation and/or rule, which has been tested enough that one has confidence that it is correct, is applied to understand a new situation. Some application experiments require determining some unknown quantity multiple ways in order to determine if the methods are consistent. Again, it is necessary to apply basic uncertainty analysis.

By performing these sequences of experiments, it is possible to explore and devise physical relationships, test them, and when convinced that they are correct, apply them to understand new situations. By designing experiments, one acquires creative control, and assures that one understands the steps that are performed, as they are done by choice, and not by following instructions or by trial-and-error.

Lab write-ups:

Each group submits one lab report per lab. Each group member must put his or her name and student ID at the top of the report to earn credit. Since the ISLE labs are designed, and are intended to help learn specific skills such as justifying conclusions, comparing results, and understanding how uncertainty comes into play, it is important to explain carefully. The lab report is written during lab. The report is not formal, but it does need to be clear. There may be specific questions to be answered, or specific statements of tasks to complete. The lab instructions include bullet points that always need to be addressed in the report. The bullet points are specific to the type of experiment: observation, testing, or application.

The lab reports shouldn't be too lengthy or wordy. They can include complete mathematical equations, complete sentences, bullet points, and/or diagrams. The required bullet points should be addressed succinctly and clearly. Keeping the reports relatively short is good practice for science writing and will save valuable time. It will also help the reader to more easily see the main points.

Lab grade:

100 points are earned for attending and conducting all of the labs, and obtaining an average of at least two-thirds of the possible points for the lab reports over the course of the term. Each student must pass lab in order to pass the course. There is opportunity to make-up one or two labs during dead week.

Grading:

The lab TAs will grade the lab reports based on a subset of the required items. Each item will be graded as follows. No points are awarded if the item is not included in the report. One point is awarded if the item is included, but incompletely, or incorrectly. Two points are awarded if the item is included, but with some small mistake, or it isn’t completely explained. Three points are awarded if the item is correct and complete. Roughly five to nine items will be chosen for grading each week. For the items which are specific to the three types of ISLE experiments (observation, testing, and application), there is a set of rubrics used to evaluate the reports. After writing the lab reports, check them with the rubrics before submitting them.

Other information:

Lab is not for testing knowledge, but for developing it. Take advantage of the time to explore the physical relationships, make sure things make sense, and use the TAs as resources.

In order to be counted as present for the lab, you must arrive on time and stay until the lab report is submitted. During the first and the last lab, assessments may be given. These assessments must be completed in order to be counted as present for the lab, but they do not count toward the course grade. The responses are used only to assess how much students learned during the course.

Lab Grading Rubrics

General Tips and Definitions for the Lab Grading Rubrics

- These labs are likely very different from those done in the past. They are somewhat open-ended. These tips and definitions should help, but always feel free to ask the lab TAs for clarification.
- The first section of each set of rubrics is in order of how one would do an experiment, but the bottom few that fall below the solid line (seven to nine of the observation and application rubrics) are over-arching goals for this type of lab, and may not happen in a specific order. In addition, some pieces of the rubric correspond to multiple bullet points in the lab instructions. The critical rubrics to use for most labs are specified in each bullet point, though in a few labs you do not have bullet points to follow. The questions are intentionally quite general, and in those cases all the rubrics should be addressed.
- A physical representation is a graph or diagram such as a free-body diagram or an energy bar chart. A sketch of an experimental set-up is a view of the equipment in use. These are different.
- A hypothesis is a proposed general explanation, rule, or law. A prediction is a statement of a specific outcome for a specific context that would hold true if the hypothesis were correct. A prediction should have the form: If this hypothesis is true, then this will happen.
- It is always easier to falsify a hypothesis by finding a case that goes against the prediction based on a hypothesis. A hypothesis can never be proved to be true. One can only show that predictions based on it are consistent.
- An assumption is a specific way of simplifying a specific situation being modeled for the purposes of making the problem feasible to solve. For instance, if you are using the particle model for a rolling ball, then you need to justify why it is reasonable to assume that the rolling motion can be ignored.
- Independent variables are specified before the experiment is performed, such as the initial elevation. They can be thought of as the cause. Some of them are held fixed so that only one independent variable changes at a time. Dependent variables are results of the experiment. They can be thought of as the effect. For example, if a ball is being rolled down a ramp and its speed is measured at the bottom, then the initial elevation of the ball and the slope of the ramp are the independent variables and the final speed of the ball is the dependent variable. In an observation experiment you might not know which variables depend on which. It is important to change one variable at a time in order to observe its impact on the outcome of the experiment.
- If you are trying to find the relationship between an independent variable and a dependent variable, then you can always ask, “How many data points are necessary?” For the example above, one might want to make multiple measurements for the same initial elevation and slope to determine the statistical error.

- Any curve fit that is chosen should make physical sense. The critical part of determining a relationship from data is to be able to tie it to the physical situation. An R-value in a graphing program does indicate whether or not the fit actually makes sense. Do not rely on a program to determine the mathematical relationship. It is critical to reason about the physical situation and make sure the curve fit makes sense in that situation. The physical model, data, and mathematical model all need to be consistent and make sense.

Observational Experiment Rubrics

Ability to design and conduct an observational experiment					
	Scientific Ability	**Missing**	**Inadequate**	**Needs some improvement**	**Adequate**
1	**Is able to identify the phenomenon to be investigated**	No mention is made of the phenomenon to be investigated.	An attempt is made to identify the phenomenon to be investigated but is described in a confusing manner.	The phenomenon to be investigated is described but there are minor omissions or vague details.	The phenomenon to be investigated is clearly stated.
2	**Is able to design a reliable experiment that investigates the phenomenon**	The experiment does not investigate the phenomenon.	The experiment involves the phenomenon but due to the nature of the design it is likely the data will not contain any interesting patterns.	The experiment investigates the phenomenon and it is likely the data will contain interesting patterns, but due to the nature of the design some features of the patterns will not be observable.	The experiment investigates the phenomenon and there is a high likelihood the data will contain interesting patterns. All features of the patterns have a high likelihood of being observable.
3	**Is able to decide what is to be measured and identify independent and dependent variables**	The chosen measurements will not produce data that can be used to achieve the goals of the experiment.	The chosen measurements will produce data that can be used at best to partially achieve the goals of the experiment.	The chosen measurements will produce data that can be used to achieve the goals of the experiment. However, independent and dependent variables are not clearly distinguished.	The chosen measurements will produce data that can be used to achieve the goals of the experiment. Independent and dependent variables are clearly distinguished.
4	**Is able to use available equipment to make measurements**	At least one of the chosen measurements cannot be made with the available equipment.	All chosen measurements can be made, but no details are given about how it is done.	All chosen measurements can be made, but the details of how it is done are vague or incomplete.	All chosen measurements can be made and all details of how it is done are clearly provided.
5	**Is able to describe what is observed without trying to explain, both in words and by means of a picture of the experimental set-up.**	No description is mentioned.	A description is mentioned but it is incomplete. No picture is present. Or, most of the observations are mentioned in the context of prior knowledge.	A description exists, but it is mixed up with explanations or other elements of the experiment. A labeled picture is present. Or some observations are mentioned in the context of prior knowledge.	Clearly describes what happens in the experiments both verbally and by means of a labeled picture.

6	**Is able to identify the shortcomings in an experimental design and suggest improvements**	No attempt is made to identify any shortcomings of the experimental design.	An attempt is made to identify shortcomings, but they are described vaguely and no suggestions for improvements are made.	Some shortcomings are identified and some improvements are suggested, but not all aspects of the design are considered.	All major shortcomings of the experiment are identified and specific suggestions for improvement are made.
Ability to construct, modify, and apply relationships or explanations					
7	**Is able to construct a mathematical (if applicable) relationship that represents a trend in data**	No attempt is made to construct a relationship that represents a trend in the data.	An attempt is made, but the relationship does not represent the trend.	The relationship represents the trend but no analysis of how well it agrees with the data is included (if applicable), or some features of the relationship are missing.	The relationship represents the trend accurately and completely and an analysis of how well it agrees with the data is included (if applicable).
8	**Is able to devise an explanation for an observed relationship**	No attempt is made to explain the observed relationship.	An explanation is made but it is vague, not testable, or contradicts the observations.	An explanation is made and is based on simplifying the phenomenon, but uses flawed reasoning.	A reasonable explanation is made and is based on simplifying the phenomenon.
9	**Is able to identify the assumptions made in devising the explanation**	No attempt is made to identify any assumptions.	An attempt is made to identify assumptions, but most are missing, described vaguely, or incorrect.	Most assumptions are correctly identified.	All assumptions are correctly identified.

Testing Experiment Rubrics

Ability to design and conduct a testing experiment (testing an idea/hypothesis/explanation or mathematical relation)					
Scientific Ability		**Missing**	**Inadequate**	**Needs some improvement**	**Adequate**
1	**Is able to identify the hypothesis to be tested**	No mention is made of a hypothesis.	An attempt is made to identify the hypothesis to be tested but is described in a confusing manner.	The hypothesis to be tested is described but there are minor omissions or vague details.	The hypothesis is clearly stated.
2	**Is able to design a reliable experiment that tests the hypothesis**	The experiment does not test the hypothesis.	The experiment tests the hypothesis, but due to the nature of the design it is likely the data will lead to an incorrect judgment.	The experiment tests the hypothesis, but due to the nature of the design there is a moderate chance the data will lead to an inconclusive judgment.	The experiment tests the hypothesis and has a high likelihood of producing data that will lead to a conclusive judgment.
3	**Is able to distinguish between a hypothesis and a prediction**	No prediction is made. The experiment is not treated as a testing experiment.	A prediction is made but it is identical to the hypothesis.	A prediction is made and is distinct from the hypothesis but does not describe the outcome of the designed experiment.	A prediction is made, is distinct from the hypothesis, and describes the outcome of the designed experiment
4	**Is able to make a reasonable prediction based on a hypothesis**	No attempt to make a prediction is made.	A prediction is made that is distinct from the hypothesis but is not based on it.	A prediction is made that follows from the hypothesis but does not incorporate assumptions.	A prediction is made that follows from the hypothesis and incorporates assumptions.

5	**Is able to identify the assumptions made in making the prediction**	No attempt is made to identify any assumptions.	An attempt is made to identify assumptions, but the assumptions are irrelevant or are confused with the hypothesis.	Relevant assumptions are identified but are not significant for making the prediction.	All assumptions are correctly identified.
6	**Is able to determine specifically the way in which assumptions might affect the prediction**	No attempt is made to determine the effects of assumptions.	The effects of assumptions are mentioned but are described vaguely.	The effects of assumptions are determined, but no attempt is made to validate them.	The effects of the assumptions are determined and the assumptions are validated.
7	**Is able to decide whether the prediction and the outcome agree/disagree**	No mention of whether the prediction and outcome agree/disagree.	A decision about the agreement/disagreement is made but is not consistent with the outcome of the experiment.	A reasonable decision about the agreement/disagreement is made but experimental uncertainty is not taken into account.	A reasonable decision about the agreement/disagreement is made and experimental uncertainty is taken into account.
8	**Is able to make a reasonable judgment about the hypothesis**	No judgment is made about the hypothesis.	A judgment is made but is not consistent with the outcome of the experiment.	A judgment is made and is consistent with the outcome of the experiment but assumptions are not taken into account.	A reasonable judgment is made and assumptions are taken into account.
9	**Is able to revise the hypothesis when necessary**	A revision is necessary but none is made.	A revision is made but the new hypothesis is not consistent with the results of the experiment.	A revision is made and is consistent with the results of the experiment but other relevant evidence is not taken into account.	A revision is made and is consistent with all relevant evidence.

Application Experiment Rubrics

Ability to design and conduct an application experiment					
	Scientific Ability	**Missing**	**Inadequate**	**Needs some improvement**	**Adequate**
1	**Is able to identify the problem to be solved**	No mention is made of the problem to be solved.	An attempt is made to identify the problem to be solved but it is described in a confusing manner.	The problem to be solved is described but there are minor omissions or vague details.	The problem to be solved is clearly stated.
2	**Is able to design a reliable experiment that solves the problem**	The experiment does not solve the problem.	The experiment attempts to solve the problem but due to the nature of the design the data will not lead to a reliable solution.	The experiment attempts to solve the problem but due to the nature of the design there is a moderate chance the data will not lead to a reliable solution.	The experiment solves the problem and has a high likelihood of producing data that will lead to a reliable solution.
3	**Is able to use available equipment to make measurements**	At least one of the chosen measurements cannot be made with the available equipment.	All of the chosen measurements can be made, but no details are given about how it is done.	All of the chosen measurements can be made, but the details about how they are done are vague or incomplete.	All of the chosen measurements can be made and all details about how they are done are provided and clear.

4	**Is able to make a judgment about the results of the experiment**	No discussion is presented about the results of the experiment	A judgment is made about the results, but it is not reasonable or coherent.	An acceptable judgment is made about the result, but the reasoning is flawed or incomplete.	An acceptable judgment is made about the result, with clear reasoning. The effects of assumptions and experimental uncertainties are considered.
5	**Is able to evaluate the results by means of an independent method**	No attempt is made to evaluate the consistency of the result using an independent method.	A second independent method is used to evaluate the results. However there is little or no discussion about the differences in the results due to the two methods.	A second independent method is used to evaluate the results. Some discussion about the differences in the results is present, but there is little or no discussion of the possible reasons for the differences.	A second independent method is used to evaluate the results. The discrepancy between the results of the two methods, and possible reasons are discussed. A percentage difference is calculated in quantitative problems.
6	**Is able to identify the shortcomings in an experimental design and suggest specific improvements**	No attempt is made to identify any shortcomings of the experimental design.	An attempt is made to identify shortcomings, but they are described vaguely and no specific suggestions for improvements are made.	Some shortcomings are identified and some improvements are suggested, but not all aspects of the design are considered.	All major shortcomings of the experiment are identified and specific suggestions for improvement are made.
Ability to construct, modify, and apply relationships or explanations					
7	**Is able to choose a productive mathematical procedure for solving the experimental problem**	Mathematical procedure is either missing, or the equations written down are irrelevant to the design.	A mathematical procedure is described, but it is incomplete, due to which the final answer cannot be calculated.	Correct and complete mathematical procedure is described but an error is made in the calculations.	Mathematical procedure is fully consistent with the design. All quantities are calculated correctly. Final answer is meaningful.
8	**Is able to identify the assumptions made in using the mathematical procedure**	No attempt is made to identify any assumptions.	An attempt is made to identify assumptions, but most are missing, described vaguely, or incorrect.	Most assumptions are correctly identified.	All assumptions are correctly identified.
9	**Is able to determine specifically the way in which assumptions might affect the results**	No attempt is made to determine the effects of assumptions.	An attempt is made to determine the effects of some assumptions, but most are missing, described vaguely, or incorrect.	The effects of most assumptions are determined correctly, though a few contain errors, inconsistencies, or omissions.	The effects of all assumptions are correctly determined.

Experimental Uncertainties

No physical quantity can be measured exactly. One can only know its value with a certain range of uncertainty. This fact can be expressed in the standard form X ± dX. This means X is between X – dX and X + dX.

Uncertainties of Measurements

1. Instrumental Uncertainties

Every measuring instrument has an inherent uncertainty that is determined by the precision of the instrument. Usually this value is taken as a half of the smallest increment of the instrument scale. For example, 0.5 mm is the precision of a meterstick and 0.5 s is precision of a watch.

2. Random Uuncertainties

When the quantity is measured multiple times, different values are measured. This happens because uncontrollable factors affect the measurements randomly. This type of uncertainty, random uncertainty, can be determined by repeating the measurement several times. For example, if the distance an object travels is measured, then the distances could be 50 m, 51 m, and 49 m.

Determine the average

X = (50 m + 51 m + 49 m)/3 = 50 m

and the uncertainty

dX = 1 m

and combine

X = 50 ± 1 m.

3. Effects of Assumptions

Assumptions inherent in models may also contribute to the uncertainty. For example, the speed of a ball moving on a floor is measured. It is assumed that the ball moves along a straight line, while in fact the surface of the floor is bumpy and the bumps contribute significantly to the distance that the ball covers and thus decreases the calculated speed. Repeating the measurement will not get rid of the bumpiness of the floor and will contribute to the uncertainty of the speed. This type of uncertainty is not so easy to recognize and to evaluate. First, one determines whether the assumption increases the value of the quantity, decreases it, or affects it randomly. Then, one estimates the size of the uncertainty. It is difficult to give strict rules and instructions on how to estimate uncertainties in general. Each case is unique and requires thoughtful approach. Be ingenious and reasonable.

Comparison Uncertainties

If you are comparing the uncertainties in the values of two quantities, then by analyzing the absolute uncertainty you cannot tell which of the measurements is more accurate because the units of the measured quantities are different. In order to resolve this issue, determine the relative uncertainty which is the ratio of the absolute uncertainty and the average:

Relative Uncertainty = dX/X

Express as a percentage by multiplying by 100.

Reducing Uncertainties

The same absolute uncertainty yields a smaller relative uncertainty if the average value is larger.

Suppose you have a bob attached to a spring and want to measure time for it to oscillate up and down, back to its starting position. If you are using a watch to measure some time interval, then the absolute uncertainty of the measurement will be 0.5 s. If you measure the time for one oscillation to be 5 s, then the relative uncertainty is 10%. If you measure the time for five oscillations to be 25 s, and the instrumental uncertainty is still 0.5 s, then the relative uncertainty is lowered to 2%.

Remember to also reduce relative uncertainties by minimizing absolute uncertainty with better designs, decreasing the effects of assumptions, and/or increasing the accuracy of the instruments if possible.

Uncertainties in Calculated Values

It is important to estimate data uncertainties because they propagate through calculations to produce uncertainties in results. The average mass of one apple m with uncertainty dm. The mass of 100 apples is then:

$M \pm dM = 100m \pm 100dm$

Notice that the relative uncertainty of M is the same as the relative uncertainty of m:

$dM/M = dm/m$

If you have more than one measurement, then estimating the uncertainty of the result may be more complicated. However, if one of the sources of uncertainty is much larger than the others by comparing their relative uncertainties, then you can neglect other sources and use the weakest link rule.

The Weakest Link Rule

The percent uncertainty in the calculated value is at least as great as the greatest percentage uncertainty of the values used.

To estimate uncertainty in calculated values:

1. Estimate the absolute uncertainty in each measured quantity used to determine the calculated quantity.

2. Calculate the relative uncertainty for each measured quantity.

3. Identify the largest relative uncertainty and use it as the relative uncertainty of the calculated quantity.

Comparable Uncertainties

If the measured values have comparable uncertainties, then the rules are more complicated. They depend on the type of the mathematical relationship used. When multiplying two values, their relative uncertainties add. One of the consequences of this rule is that the raising to the second power doubles the relative uncertainty and the raising to the third power triples it. Thus, in the example above, the relative uncertainty in the calculated volume of the baseball will be three times larger then the relative uncertainty in the measured radius.

Why do you need to know about uncertainty?

Is the measured value in agreement with the prediction? Do the data fit the physical model? Are two measured values the same? You cannot answer these questions without considering the uncertainties of the measurements.

To compare two values X and Y, find their ranges. If the ranges $X \pm dX$ and $Y \pm dY$ overlap, then X and Y are the same within the experimental uncertainty.

Summary

* Decide which factors affect the result most. * Try to reduce the effects of these factors. * Try to reduce uncertainties by measuring larger values. * Determine the absolute uncertainties of each measurement. * Determine the relative uncertainties of each measurement. * If one uncertainty is much larger than the others, then ignore all other sources and use this uncertainty to determine the uncertainty of the calculated quantity. * Determine the ranges of the quantities and compare them.