Score	A / 4.0	B / 3.0	C / 2.0	D / 1.0 to F / 0.0
Assessment	*Masterful, fully engaged, able to generate new ideas*	*Proficient, skilled, competent, meeting expectations; engaged*	*Possessing of some skill, but still practicing; not fully engaged*	*Not yet proficient or unable to assess; not engaged*
Written framework	Written work **generates a new idea** that goes beyond the expectations of the assignment; report is **suitable for use as a model** for future students; report could be **easily read and understood** by a person with no access to the lab instructions	Writing **meets grade-level standards**; all **core components** of the report are easy for a fellow student to read and understand; and relate to one another in a logical way; layout is **clean and easy to follow**; tables, charts, and graphs are **informative** and well-designed	Writing may not meet grade-level standards; work may contain **substantial errors in communication**, including in overall layout, flow, units, significant figures, equations, tables, charts and/or graphs	Incomplete or poorly written framework; student requires **review of fundamental concepts** and methods; or missing core components; or reader is unable to assess work
Laboratory procedure	Procedure **transcends or exceed expectations** in some insightful and unique way; student demonstrates **fluency** in the scientific method; procedure demonstrates **deep understanding** of the limitations of the equipment or data set	The work is **grounded in the scientific method**; experiment is designed to include **adequate controls**; enough **trials** are performed to reduce error; reader has **direct access to the data** in question	Work is **lacking in one or more aspects** of the scientific method; procedure **lacks adequate controls** or **sufficient trials** to reduce error; reader cannot **fully and independently evaluate** the procedure	Work does not demonstrate **competency** in the scientific method; or the results are not reliable; or reader is unable to assess work
Analysis	In addressing any apparent difference between the predictions of theory and the experimental results, the student's analysis **generates new hypotheses** and suggests **new experiments**; the report closes some doors while opening others	The results of the experiment **clearly support** (or **clearly fail to support**) the hypothesis; errors are **addressed** and accounted for; theory and experiment are compared in a **logical** way; suggestions for **improvement** of the experiment are offered; analysis of error is taken seriously	**Some care** was taken to account for and reduce errors; however, review and analysis of errors during the experiment should have led the student to experimental **redesign** or **repetition**; analysis of error is treated as an afterthought	Analysis of experimental results and errors is **incomplete** or **missing**; or the experimental results are not **clearly related** to the hypothesis; or reader is unable to assess work
Level-specific expectations (AP Physics)	Student goes beyond the expectations of the teacher and course by **broadening the scope** of the experiment to include novel, **scientifically valid** hypotheses, procedures, and analyses	A **quantitative** analysis of experimental error is made; graphs are **linearized** when appropriate and include **best-fit lines**; student demonstrates competency in the use of **graphical analysis software**; probes and sensors are **properly calibrated**; student is heavily involved in the **design** of the experiment itself	Analysis of experimental error lacks a quantitative component; analysis is not grade-level appropriate; improper or missing calibration and testing of equipment; student is not **involved** in experimental design	Level-specific expectations **have not been met**; or, reader is unable to assess work

The Scientific Method – a guide for SI students

What is a scientific theory?	A scientific theory is an explanation of how the natural world works. A theory must have *predictive power*, meaning that it can tell you what will happen next in a given situation. A theory can be considered *credible*, but must always be understood to be *conditional* (never "proven"). In other words, we must always be open to the idea that a theory will later be replaced by a more accurate theory that explains the world even better. Key theories include: that, over long periods of time, random mutations in the genetic code of a species can lead to beneficial changes that better allow the species to survive and prosper in its environment (*biology*); that the organization of the electrons in an oxygen atom make it a volatile substance – when oxygen is combined with hydrogen gas and a spark, an explosion will occur that produces pure water (*chemistry*); and that the apparent force of gravity can be explained as a curvature in the fabric of space-time – near massive objects, both space and time are stretched and distorted in measurable ways (*physics*). The scientific method is grounded in the notion of cause-and-effect – just because two things happened together doesn't mean one caused the other; both could be due to some other, unknown underlying cause.
How is a scientific theory tested?	A scientist makes careful experimental observations to confirm a certain prediction of a theory. The process typically begins with the formation of a hypothesis. Several things are required: the experiments must be *controlled* to make sure the hypothesis is being *uniquely* tested. For example, if it is my hypothesis that a certain gene leads to breast cancer, I might study the lives of identical twins separated at birth so that I can distinguish hereditary effects from environmental effects. A theory is said to be *confirmed* if the predictions made by the theory come true under experiment. A theory is said to be *falsified* if the predictions do not come true. Sometimes a theory that has been confirmed under a certain set of conditions but falsified under other conditions, is still useful. (For instance, we still use Newton's theory of gravity when calculating simple spacecraft trajectories even though we know the theory is false in certain extreme conditions.)
When should we amend a theory?	Discrepancies between theory and experiment can be *real* (meaning that the theory is wrong, and must be amended), or can be due to *experimental error*. Experimental error can be separated into two types: statistical and systematic. *Statistical errors* arise when too few measurements are made to fully represent the range of possible experimental outcomes. (For instance, if you poll 100 random students about how they feel about the dress code, your results will be less accurate than if you polled 500 random students.) *Systematic errors* are related to the accuracy of measurement. (For example, if you are using a balance to measure the weight of a liquid sample but the balance reads 5 g high due to a problem with its calibration.) When a scientist discovers a discrepancy between theory and experiment that cannot be explained by experimental error, a new discovery has been made and the theory must be amended. Scientists constantly strive to reduce all error so the comparison between theory and experiment can be accurately made. All types of error must be qualitatively and quantitatively accounted for and understood – vague references to unknown and uncorrected mistakes are not scientific.
How do we share our scientific results?	Formal lab repots include the following *core components*: an **abstract** (a brief, to-the-point summary of the entire report), an **introduction** (detailing the theory & hypothesis), a discussion of **experimental procedure** (explaining how the experiment is performed in detail), a presentation of the **experimental results** (often, but not always, presented in data tables or graphs), an **analysis** of the results (including but not limited to a discussion of experimental error), and a series of **conclusions** (summarizing the report). Scientists reading a report expect your methods to be clear, truthful, and reliable. Others should be able to understand and repeat your work just based on your descriptions, and they should expect to arrive at the same conclusions you did. There are no hidden data or secret techniques. Everything is out in the open. This transparency generates honesty, accountability, and accuracy in the scientific community. All observations must be clear and truthful, and each measurement must be accompanied by estimates of the corresponding experimental errors. (*Note*: not all scientific endeavors require formal lab reports. At times at SI you'll be asked to complete worksheets, informal lab reports, work on "lab practical" exams, participate in challenges, and the like.)

Statement of Problem

Example: What is the effect of exposure to UV radiation on cancer rates?

- ❑ Not a yes/no question
- ❑ Statement narrows down a topic area
- ❑ Generalized variables included
- ❑ Problem is clearly testable

Hypothesis

Example: We predict increased cancer rates as a result of longer exposure to UV radiation, which can cause mutations in DNA molecules.

- ❑ Statement predicts a relationship or trend
- ❑ Statement gives specific direction to the prediction: a stand is taken
- ❑ Prediction includes both independent and dependent variables
- ❑ A rationale is given for the hypothesis

Variables

Example: The independent variable is exposure time; the dependent variable is cancer rate.

- ❑ Independent variable correctly identified
- ❑ Independent variable correctly defined
- ❑ Dependent variable correctly identified
- ❑ Dependent variable correctly defined

Experimental Controls

Example: Our experimental subjects will be of the same age, all non-smokers, and of roughly equivalent socioeconomic status.

- ❑ Number of controlled variables identified: ____
- ❑ Experimental controls correctly identified
- ❑ Experimental controls make logical sense

Qualitative Observations

Example: When we heated substance A with a flame, thick white smoke was generated and charred ash was produced

- ❑ Observations are made during the procedure
- ❑ Deviations from expectations are noted
- ❑ Observations and discussion of results are provided

Quantitative Data

Example: Data tables and data graphs

- ❑ All raw data is provided
- ❑ All data has units
- ❑ All data is reported with correct significant figures
- ❑ A condensed table with the most important data is included
- ❑ Tables are properly labeled and include header rows
- ❑ Example calculations are provided
- ❑ Appropriate graph types are used
- ❑ Graphs are titled
- ❑ Graphs are labeled properly (axes & series)
- ❑ Units are included in all graphs
- ❑ Trends in data are represented by best-fit curves
- ❑ Appropriate scales are used in graphs

Materials and Procedure

Example: Lists of materials; well-organized procedure that can be followed by a novice reader; useful diagrams and sketches

- ❑ All materials used are listed properly
- ❑ Materials are listed separately from procedure
- ❑ Procedure is well-organized, in a logical sequence
- ❑ Enough information is given so another student could repeat the procedure
- ❑ Helpful diagrams and sketches are used
- ❑ Repeated trials are performed

Statistics

Example: Measured accelerations ranged from 0.51 m/s^2 to 0.82 m/s^2 with an average of 0.66 m/s^2

- ❑ Measure of central tendency (average / mean)
- ❑ Measure of variation (range / deviation / spread)
- ❑ Regression analysis (best-fit line)
- ❑ Other appropriate statistic used

Experimental Error

Example: Since we surveyed 100 people, our statistical error is $1 / \sqrt{(100)} = 0.1 = 10\%$.

- ❑ Systematic errors are discussed
- ❑ Statistical (random) errors are discussed
- ❑ Human mistakes are addressed and/or corrected during the experiment
- ❑ The effect the errors had on the data are discussed
- ❑ Errors are quantified

Analysis and Interpretation

Example: Among those with 4 or more hours of directly sunlight per day, the average cancer rate was 20.5 per 10,000.

- ❑ All data presented and discussed
- ❑ All data interpreted for meaning
- ❑ Unusual data points pointed out
- ❑ Unusual data points explained
- ❑ Trends in data pointed out
- ❑ Trends in data explained
- ❑ Enough detail provided to understand data
- ❑ Response is clear and concise
- ❑ All statements are supported by the data

Conclusion

Example: Our results confirmed our hypothesis: those with higher exposure levels to UV radiation were indeed more likely to develop cancer.

- ❑ Hypothesis is evaluated according to data
- ❑ Hypothesis is re-stated
- ❑ Reasons to accept/reject the hypothesis are given
- ❑ All statements are supported by the data

Recommendations

Example: Future improvements to this experiment would include …

- ❑ Suggestions for improvement of experiment are given
- ❑ Suggestions for future experiments are given

Common mistakes among those new to writing scientific reports

Presentation of methods & results	*Common mistakes include …* • Student fails to put all relevant data in easily accessible charts and/or tables • Student fails to organize his or her writing into a report format, instead using an essay format with in-line calculations and data • Student fails to use numbers when writing out measurements or results (for instance, writing 'fifty-three percent' instead of 53%) • Student fails to limit data to only significant digits (for instance, writing out 0.123747323 N instead of 0.12 N) – the number of significant digits is determined by the accuracy / precision of experimental measurements • Student fails to use super- or subscripts for exponents and labels (for instance, writing out 9.8 m/s2 or 9.8 m/s^2 instead of 9.8 m/s^2) • An overly familiar or candid tone in writing; a research paper is an attempt to confirm or invalidate the predictions of a theory through the scientific method – little effort should be spent trying to charm the reader or obfuscate the underlying facts & procedures.
Scientific methodology & state of mind	*Common mistakes include …* • Student uses the term 'human error', which is much too vague a term. If the experimenter made a mistake, they should fix it before moving on with the experiment. Otherwise, the error in question should be explained and quantified. If the error generated is very large – say there is a 30% discrepancy between prediction and result, then the theory must be modified to either explain the error (thereby reducing the discrepancy) OR the theory must be discarded. • Student accepts poor data & results without attempting to "dig in" and fix the issue. In AP Physics, for instance, the lab equipment is good to 5% or 10% accuracy (some is even better), meaning that a 25% discrepancy between prediction and experiment is not an acceptable end result: either you (a) have made a measurement error which needs to be tenaciously tracked down and eliminated OR (b) you've discovered something new about the universe, and our theory needs to be amended. It is not enough to say "Well it didn't work so well." • Students writes that his or her results "prove" something – scientific claims can never aim to 'prove' anything – they can support or confirm a hypothesis (which can then be later overturned!) or they reject a hypothesis. No measurements which confirm your hypothesis can ever be said to 'prove it' – all scientific theories are tentative, never final, and can be overturned at any time through the results of a single well-designed experiment.
Transparency & accuracy	*Common mistakes include …* • Student fails to provide the reader with access to the raw data and/or any processing methods or calculations the author has made with this data. The reader should be able to go through and find experimental mistakes – this is the contract between the author and the reader: the author is claiming that everything is true & transparent, and the reader should be able to rely on the results. • Student fails to take his or her own work seriously, manipulates data or generates fictitious data, or otherwise fails to maintain a very high ethical standard.