Scientific Abilities Assessment Rubrics (SAAR)

Version 5

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Format: Rubric
Duration: any minutes
Focus: Scientific reasoning (represent information in multiple ways, design and conduct experiments, communicate scientific ideas, collect and analyze experimental data, evaluate experimental results)
Level: Upper-level, Intermediate, Intro college, High school

How to give the test

The SAARs can be used in three ways: 1) A student or a group of students can use the rubric to help self-assess her or their own work, and then revise it 2) An instructor can use the rubric to evaluate students' responses and to provide feedback. 3) A researcher can use them to monitor students progress and to compare students from different courses.

In all cases, choose the rubric that assesses the scientific ability you are interested in. Use the descriptors on the scoring rubrics to assign a rating from 0–3 to describe the student work (0, missing; 1, inadequate; 2, needs some improvement; and 3, adequate).

How to score the test

The goal of the rubrics is formative self-assessment and assessment. Therefore the students need to be able to revise their work using rubric's feedback. The developers recommend using no more than 5-6 rubrics per lab. The rubrics can be used as a summative assessment tool, but only if the students are familiar with them through formative assessment. They can also be used for research purposes.

To use the rubric in a summative fashion, and calculate a score, use the descriptors in each rubric to assign either a numerical score or a descriptive score for a portion of student writing related to a certain sub-ability. Give students a descriptive score and the rubric, as numerical scores were found to have a negative effect on student learning.

RUBRIC A: Ability to represent information in multiple ways					
	Scientific Ability	Missing	Inadequate	Needs improvement	Adequate
A1	**Is able to extract the information from representation correctly**	No visible attempt is made to extract information from the problem text.	Information that is extracted contains errors such as labeling quantities incorrectly, mixing up initial and final states, choosing a wrong system, etc. Physical quantities have no subscripts (when those are needed).	Some of the information is extracted correctly, but not all of the information. For example physical quantities are represented with numbers there are no units. Or directions are missing. Subscripts for physical quantities are either missing or inconsistent.	All necessary information has been extracted correctly, and written in a comprehensible way. Objects, systems, physical quantities, initial and final states, etc. are identified correctly and units are correct. Physical quantities have consistent subscripts.
A2	**Is able to construct new representations from previous representations**	No attempt is made to construct a different representation.	Representations are attempted, but use incorrect information or the representation does not agree with the information used.	Representations are created without mistakes, but there is information missing, i.e. labels, variables.	Representations are constructed with all given (or understood) information and contain no major flaws.
A3	**Is able to evaluate the consistency of different representations and modify them when necessary**	No representation is made to evaluate the consistency.	At least one representation is made but there are major discrepancies between the constructed representation and the given one. There is no attempt to explain consistency.	Representations created agree with each other but may have slight discrepancies with the given representation. Or there is no explanation of the consistency.	All representations, both created and given, are in agreement with each other and the explanations of the consistency are provided.
A4	**Is able to use representations to solve problems**	No attempt is made to solve the problem.	The problem is solved correctly but no representations other than math were used.	The problem is solved correctly but there are only two representations: math and words explaining the solution.	The problem is solved correctly with at least three different representations (sketch, physics representation and math or sketch, words and math, or some other combination)
A5	**Force Diagram**	No representation is constructed.	FD is constructed but contains major errors such as incorrect mislabeled or not labeled force vectors, length of vectors, wrong direction, extra incorrect vectors are added, or vectors are missing.	FD contains no errors in vectors but lacks a key feature such as labels of forces with two subscripts or vectors are not drawn from single point, or axes are missing.	The diagram contains no errors and each force is labeled so that it is clearly understood what each force represents.
A6	**Motion Diagram**	No representation is constructed.	Diagram does not show proper motion: either lengths of arrows (both velocity and velocity change) are incorrect or missing and or spacing of dots are incorrect.	Diagram has correct spacing of the dots but us missing velocity arrows or velocity change arrows.	The diagram contains no errors and it clearly describes the motion of the object. Dots, velocity arrows and velocity change arrows are correct.

A7	**Sketch**	No representation is constructed.	Sketch is drawn but it is incomplete with no physical quantities labeled, or important information is missing, or it contains wrong information, or coordinate axes are missing.	Sketch has no incorrect information but has either no or very few labels of given quantities. Subscripts are missing or inconsistent. Majority of key items are drawn.	Sketch contains all key items with correct labeling of all physical quantities have consistent subscripts; axes are drawn and labeled correctly.
A8	**Energy bar chart**	No representation is constructed.	Bar chart is either missing energy values, bars drawn do not show the conservation of energy or are drawn in the wrong places. Bars could also be labeled incorrectly. The system is not identified.	Bar chart has the energy bars drawn correctly, but some labels are missing or the system is not identified. The bar chart matches the process described with some other representation.	Bar chart is properly labeled and has energy bars of appropriate magnitudes. The system is clearly identified.
A9	**Mathematical**	No representation is constructed.	Mathematical representation lacks the algebraic part (the student plugged the numbers right away) has the wrong concepts being applied, signs are incorrect, or progression is unclear. The first part should be applied when it is appropriate.	No error is found in the reasoning, however they may not have fully completed steps to solve problem or one needs effort to comprehend the progression. No evaluation of the math in the problem is present.	Mathematical representation contains no errors and it is easy to see progression of the first step to the last step in solving the equation. The solver evaluated the mathematical representation.
A10	**Ray diagram**	No representation is constructed.	The rays that are drawn in the representation do not follow the correct paths. Object or image may be located at wrong position.	Diagram is missing key features but contains no errors. One example could be the object is drawn with the correct lens/mirror but rays are not drawn to show image. Or the rays are too far from the main axis to have a small-angle approximation. Or the diagram is drawn without a ruler.	Diagram has object and image located in the correct spot with the proper labels. Rays are correctly drawn with arrows and contain at least two rays. The ruler was used to draw the images.
A11	**Graph**	No graph is present.	A graph is present but the axes are not labeled. There is no scale on the axes. The data points are connected.	The graph is present and axes are labeled but the axes do not correspond to the independent and dependent variable or the scale is not accurate. The data points are not connected but there is no trendline.	The graph has correctly labeled axes, independent variable is along the horizontal axis and the scale is accurate. The trendline is correct.

RUBRIC B: Ability to design & conduct an observational experiment					
	Scientific Ability	Missing	Inadequate	Needs improvement	Adequate
B1	**Is able to identify the phenomenon to be investigated**	No phenomenon is mentioned.	The description of the phenomenon to be investigated is confusing, or it is not the phenomena of interest.	The description of the phenomenon is vague or incomplete.	The phenomenon to be investigated is clearly stated.
B2	**Is able to design a reliable experiment that investigates the phenomenon**	The experiment does not investigate the phenomenon.	The experiment may not yield any interesting patterns.	Some important aspects of the phenomenon will not be observable.	The experiment might yield interesting patterns relevant to the investigation of the phenomenon.
B3	**Is able to decide what physical quantities are to be measured and identify independent and dependent variables**	The physical quantities are irrelevant.	Only some of physical quantities are relevant.	The physical quantities are relevant. However, independent and dependent variables are not identified.	The physical quantities are relevant and independent and dependent variables are identified.
B4	**Is able to describe how 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.
B5	**Is able to describe what is observed without trying to explain, both in words and by means of a picture of the experimental setup.**	No description is mentioned.	A description is incomplete. No labeled sketch is present. Or, observations are adjusted to fit expectations.	A description is complete, but mixed up with explanations or pattern. The sketch is present but is difficult to understand.	Clearly describes what happens in the experiments both verbally and with a sketch. Provides other representations when necessary (tables and graphs).
B6	**Is able to identify the shortcomings in an experimental and suggest improvements**	No attempt is made to identify any shortcomings of the experimental.	The shortcomings are described vaguely and no suggestions for improvements are made.	Not all aspects of the design are considered in terms of shortcomings or improvements.	All major shortcomings of the experiment are identified and reasonable suggestions for improvement are made.
B7	**Is able to identify a pattern in the data**	No attempt is made to search for a pattern	The pattern described is irrelevant or inconsistent with the data	The pattern has minor errors or omissions. Terms proportional are used without clarity- is the proportionality linear, quadratic, etc.	The patterns represents the relevant trend in the data. When possible, the trend is described in words.
B8	**Is able to represent a pattern mathematically (if applicable)**	No attempt is made to represent a pattern mathematically	The mathematical expression does not represent the trend.	No analysis of how well the expression agrees with the data is included, or some features of the pattern are missing.	The expression represents the trend completely and an analysis of how well it agrees with the data is included.
B9	**Is able to devise an explanation for an observed pattern**	No attempt is made to explain the observed pattern.	An explanation is vague, not testable, or contradicts the pattern.	An explanation contradicts previous knowledge or the reasoning is flawed.	A reasonable explanation is made. It is testable and it explains the observed pattern.

RUBRIC C: Ability to design & conduct an experiment to *test* an idea/hypothesis/explanation or mathematical relation					
	Scientific Ability	Missing	Inadequate	Needs improvement	Adequate
C1	**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.
C2	**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.
C4	**Is able to make a reasonable prediction based on a hypothesis**	No prediction is made. The experiment is not treated as a testing experiment.	A prediction is made but it is identical to the hypothesis, OR Prediction is made based on a source unrelated to hypothesis being tested, or is completely inconsistent with hypothesis being tested, OR Prediction is unrelated to the context of the designed experiment.	Prediction follows from hypothesis but is flawed because * relevant experimental assumptions are not considered and/or * prediction is incomplete or somewhat inconsistent with hypothesis and/or * prediction is somewhat inconsistent with the experiment.	A prediction is made that * follows from hypothesis, * is distinct from the hypothesis, * accurately describes the expected outcome of the designed experiment, * incorporates relevant assumptions if needed.
C5	**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.	Sufficient assumptions are correctly identified, and are significant for the prediction that is made.
C6	**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.
C7	**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.
C8	**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, is consistent with the outcome of the experiment, but assumptions are not taken into account.	A judgment is made, consistent with the experimental outcome, and assumptions are taken into account.

Rubric C3 no longer exists. It has been merged into C4. To preserve references the rubrics have not been renumbered.

RUBRIC D: Ability to design & conduct an application experiment					
	Scientific Ability	Missing	Inadequate	Needs improvement	Adequate
D1	**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.
D2	**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.
D3	**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.
D4	**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. Or uncertainties are not taken into account. Or assumptions are not discussed. The result is written as a single number.	An acceptable judgment is made about the result, with clear reasoning. The effects of assumptions and experimental uncertainties are considered. The result is written as an interval.
D5	**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. The results of the two methods are compared correctly using experimental uncertainties. But there is little or no discussion of the possible reasons for the differences when the results are different.	A second independent method is used to evaluate the results and the evaluation is correctly done with the experimental uncertainties. The discrepancy between the results of the two methods, and possible reasons are discussed.
D7	**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 is incorrect or incomplete, due to which the final answer cannot be calculated. Or units are inconsistent.	Correct and complete mathematical procedure is described but an error is made in the calculations. All units are consistent.	Mathematical procedure is fully consistent with the design. All quantities are calculated correctly with proper units. Final answer is meaningful.
D8	**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 the assumptions are irrelevant or incorrect for the situation.	Relevant assumptions are identified but are not significant for solving the problem.	All relevant assumptions are correctly identified.
D9	**Is able to determine specifically the way in which assumptions might affect the results**	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.

RUBRIC F: Ability to communicate scientific ideas					
	Scientific Ability	Missing	Inadequate	Needs improvement	Adequate
F1	**Is able to communicate the details of an experimental procedure clearly and completely**	Diagrams are missing and/or experimental procedure is missing or extremely vague.	Diagrams are present but unclear and/or experimental procedure is present but important details are missing. It takes a lot of effort to comprehend.	Diagrams and/or experimental procedure are present and clearly labeled but with minor omissions or vague details. The procedure takes some effort to comprehend.	Diagrams and/or experimental procedure are clear and complete. It takes no effort to comprehend.
F2	**Is able to communicate the point of the experiment clearly and completely**	No discussion of the point of the experiment is present.	The experiment and findings are discussed but vaguely. There is no reflection on the quality and importance of the findings.	The experiment and findings are communicated but the reflection on their importance and quality is not present.	The experiment and findings are discussed clearly. There is deep reflection on the quality and importance of the findings.

RUBRIC G: Ability to collect and analyze experimental data					
	Scientific Ability	Missing	Inadequate	Needs improvement	Adequate
G1	**Is able to identify sources of experimental uncertainty**	No attempt is made to identify experimental uncertainties.	An attempt is made to identify experimental uncertainties, but most are missing, described vaguely, or incorrect.	Most experimental uncertainties are correctly identified. But there is no distinction between random and experimental uncertainty.	All experimental uncertainties are correctly identified. There is a distinction between experimental uncertainty and random uncertainty.
G2	**Is able to evaluate specifically how identified experimental uncertainties may affect the data**	No attempt is made to evaluate experimental uncertainties.	An attempt is made to evaluate experimental uncertainties, but most are missing, described vaguely, or incorrect. Or only absolute uncertainties are mentioned. Or the final result does not take the uncertainty into the account.	The final result does take the identified uncertainties into account but is not correctly evaluated. The weakest link rule is not used or is used incorrectly.	The experimental uncertainty of the final result is correctly evaluated. The weakest link rule is used appropriately and the choice of the biggest source of uncertainty is justified.
G3	**Is able to describe how to minimize experimental uncertainty and actually do it**	No attempt is made to describe how to minimize experimental uncertainty and no attempt to minimize is present.	A description of how to minimize experimental uncertainty is present, but there is no attempt to actually minimize it.	An attempt is made to minimize the uncertainty in the final result is made but the method is not the most effective.	The uncertainty is minimized in an effective way.
G4	**Is able to record and represent data in a meaningful way**	Data are either absent or incomprehensible.	Some important data are absent or incomprehensible. They are not organized in tables or the tables are not labeled properly.	All important data are present, but recorded in a way that requires some effort to comprehend. The tables are labeled but labels are confusing.	All important data are present, organized, and recorded clearly. The tables are labeled and placed in a logical order.
G5	**Is able to analyze data appropriately**	No attempt is made to analyze the data.	An attempt is made to analyze the data, but it is either seriously flawed or inappropriate.	The analysis is appropriate but it contains minor errors or omissions.	The analysis is appropriate, complete, and correct.

RUBRIC I: Ability to evaluate models, equations, solutions, and claims					
Scientific Ability		Missing	Inadequate	Needs some improvement	Adequate
I1	**Is able to conduct a unit analysis to test the self-consistency of an equation**	No meaningful attempt is made to identify the units of each quantity in an equation.	An attempt is made to identify the units of each quantity, but the student does not compare the units of each term to test for self-consistency of the equation.	An attempt is made to check the units of each term in the equation, but the student either misremembered a quantity's unit, and/or made an algebraic error in the analysis.	The student correctly conducts a unit analysis to test the self-consistency of the equation.
I2	**Is able to analyze a relevant special case for a given model, equation, or claim.**	No meaningful attempt is made to analyze a relevant special case.	An attempt is made to analyze a special case, but the identified special case is not relevant. OR major steps are missing from the analysis (e.g., no conclusion is made)	An attempt is made to analyze a relevant special case, but the student's analysis is flawed. OR the student's judgment is inconsistent with their analysis.	A relevant special case is correctly analyzed and a proper judgment is made.
I3	**Is able to identify the assumptions a model, equation, or claim relies upon. = C8**	No assumptions are correctly identified.	Some assumptions are correctly identified by student, but some of the identified assumptions are incorrect.	All of the student's identified assumptions are correct, but some important assumptions are not identified by student.	All significant assumptions are correctly identified, and no identified assumptions are incorrect.
I4	**Is able to evaluate another person's problem solution or conceptual claim by direct comparison with their own solution or conceptual understanding**	No meaningful attempt is made to evaluate by direct comparison.	The student states his/her own problem solution/conceptual claim, but does not methodically compare it with the other person's solution/claim, and so does not state a judgment about the validity of the other person's solution/claim. OR a judgment is made regarding the other person's solution/claim, but no justification is given.	The student states their own solution/claim and compares it with the other person's solution/claim, but does not make any concluding judgment based on this comparison. OR the student does everything correctly, but their presentation is incomplete (i.e., skipping logical steps)	Student clearly states their own solution/conceptual understanding, and methodically compares it with the other person's work. Based on this comparison, the student makes a sound judgment about the validity of the other person's work.
I5	**Is able to use a unit analysis to correct an equation which is not self-consistent**	No meaningful attempt is made to correct the equation, even though it failed a unit analysis	Student proposes a corrected equation, but their proposal still does not pass a unit analysis	Student proposes a corrected equation which passes unit analysis, but their proposal is incorrect (i.e., the student failed to remember the proper equation, and therefore proposed an equation which is not physical)	Student proposes a corrected equation which is correct, at least up to unit-less constants.
I6	**Is able to use a special-case analysis to correct a model, equation, or claim**	No meaningful attempt is made to correct the model, equation, or claim even though it failed a special-case analysis	An attempt is made to modify the model, equation, or claim, but the modifications have nothing to do with the special-case that was analyzed.	An attempt is made to modify the model, equation, or claim based on the special-case analysis, but some mistakes are made in the modification.	The model, equation, or claim is correctly modified in accordance with the special-case that was analyzed.

RUBRIC SC: Ability to evaluate models, equations, solutions, and claims (Special Cases)					
	Scientific Ability	Missing	Inadequate	Needs some improvement	Adequate
SC1	**Is able to identify an optimally relevant special-case for analysis**	No attempt is made to identify a relevant special case	An attempt is made, but the identified special case is either irrelevant or ill-defined	A relevant special case is identified, but it is not an optimal special case (i.e., there are other special cases which give a stronger, more clear-cut analysis of the solution)	A optimally relevant special case is identified and clearly stated
SC2	**Is able to state and justify a conceptual expectation for the special case**	No attempt is made to state or justify a conceptual expectation	A conceptual expectation is stated, but its justification is either absent or missing major steps	A conceptual expectation is stated, but its justification is either missing minor steps, or is inconsistent with the expectation	A conceptual expectation is stated, fully justified, and the expectation is consistent with its justification
SC3	**Is able to use a given solution (or a solution they made up) to predict what would happen for the special case**	No attempt is made to state or explain what the given solution predicts for the special case	A prediction is stated, but its derivation from the given solution is either absent or missing major steps	A predication is stated, but its derivation from the given solution is either missing minor steps, or is inconsistent with the derivation	A prediction is stated and clearly derived from the given solution
SC4	**Is able to make, and justify, a reasonable conclusion regarding their conceptual expectation and the solution.**	No attempt is made to state or justify a conclusion	A conclusion is stated, but its justification is either absent, missing major steps, or containing major mistakes	A conclusion is stated and justified, but it is inconsistent with the results of the student's analysis, or it is incomplete	A conclusion is stated and justified, and is consistent with the results of the student's analysis