

downloaded from PhysPort.org

Developed by: Eugenia Etkina, Alan Van Heuvelen, Suzanne White-Brahmia, David T. Brookes, Michael Gentile, Sahana Murthy, David Rosengrant, and Aaron Warren

Format: Rubric

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

	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.		
В3	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 <i>test</i> an idea/hypothesis/explanation or mathematical relation						
	Scientific Ability	Missing	Inadequate	Needs improvement	Adequate		
C1	Is able to identify	No mention is	An attempt is made to identify the	The hypothesis to be tested is	The hypothesis is clearly stated.		
	the hypothesis to be	made of a	hypothesis to be tested but is described	described but there are minor			
	tested	hypothesis.	in a confusing manner.	omissions or vague details.			
C2	Is able to design a	The experiment	The experiment tests the hypothesis, but	The experiment tests the	The experiment tests the		
	reliable experiment	does not test the	due to the nature of the design it is likely	hypothesis, but due to the nature	hypothesis and has a high		
	that tests the	hypothesis.	the data will lead to an incorrect	of the design there is a moderate	likelihood of producing data		
	hypothesis		judgment.	chance the data will lead to an	that will lead to a conclusive		
				inconclusive judgment.	judgment.		
C4	Is able to make a	No prediction is	A prediction is made but it is identical to	Prediction follows from	A prediction is made that		
	reasonable	made. The	the hypothesis, OR Prediction is made	hypothesis but is flawed because	* follows from hypothesis,		
	prediction based on	experiment is not	based on a source unrelated to	* relevant experimental	* is distinct from the		
	a hypothesis	treated as a testing	hypothesis being tested, or is completely	assumptions are not considered	hypothesis,		
		experiment.	inconsistent with hypothesis being	and/or	* accurately describes the		
			tested, OR Prediction is unrelated to the	* prediction is incomplete or	expected outcome of the		
			context of the designed experiment.	somewhat inconsistent with	designed experiment,		
				hypothesis and/or	* incorporates relevant		
				* prediction is somewhat	assumptions if needed.		
				inconsistent with the experiment.			
C5	Is able to identify	No attempt is made	An attempt is made to identify	Relevant assumptions are	Sufficient assumptions are		
	the assumptions	to identify any	assumptions, but the assumptions are	identified but are not significant	correctly identified, and are		
	made in making the	assumptions.	irrelevant or are confused with the	for making the prediction.	significant for the prediction		
	prediction		hypothesis.		that is made.		
C6	Is able to determine	No attempt is made	The effects of assumptions are mentioned	The effects of assumptions are	The effects of the assumptions		
	specifically the way	to determine the	but are described vaguely.	determined, but no attempt is	are determined and the		
	in which	effects of		made to validate them.	assumptions are validated.		
	assumptions might	assumptions.					
	affect the prediction						
C7	Is able to decide	No mention of	A decision about the	A reasonable decision about the	A reasonable decision about the		
	whether the	whether the	agreement/disagreement is made but is	agreement/disagreement is made	agreement/disagreement is		
	prediction and the	prediction and	not consistent with the outcome of the	but experimental uncertainty is	made and experimental		
	outcome	outcome	experiment.	not taken into account.	uncertainty is taken into		
	agree/disagree	agree/disagree.			account.		
C8	Is able to make a	No judgment is	A judgment is made but is not consistent	A judgment is made, is consistent	A judgment is made, consistent		
1	reasonable	made about the	with the outcome of the experiment.	with the outcome of the	with the experimental outcome,		
1	judgment about the	hypothesis.		experiment, but assumptions are	and assumptions are taken into		
	hypothesis			not taken into account.	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			
D1Is 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.			
D2Is 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.			
D4Is 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.			
D9Is 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			Inadequate	Needs improvement	Adequate		
F1	Is able to communicate	Diagrams are missing	Diagrams are present but	Diagrams and/or experimental	Diagrams and/or		
	the details of an	and/or experimental	unclear and/or experimental	procedure are present and clearly	experimental procedure are		
	experimental procedure	procedure is missing or	procedure is present but	labeled but with minor omissions or	clear and complete. It takes		
	clearly and completely	extremely vague.	important details are missing. It	vague details. The procedure takes	no effort to comprehend.		
			takes a lot of effort to	some effort to comprehend.			
			comprehend.				
F2	Is able to communicate	No discussion of the	The experiment and findings are	The experiment and findings are	The experiment and findings		
	the point of the	point of the experiment	discussed but vaguely. There is	communicated but the reflection on	are discussed clearly. There		
	experiment clearly and	is present.	no reflection on the quality and	their importance and quality is not	is deep reflection on the		
	completely		importance of the findings.	present.	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	No attempt is made to	An attempt is made to identify	Most experimental	All experimental		
	sources of	identify experimental	experimental uncertainties, but most	uncertainties are correctly	uncertainties are correctly		
	experimental	uncertainties.	are missing, described vaguely, or	identified. But there is no	identified. There is a		
	uncertainty		incorrect.	distinction between	distinction between		
				random and experimental	experimental uncertainty and		
				uncertainty.	random uncertainty.		
G2	Is able to evaluate	No attempt is made to	An attempt is made to evaluate	The final result does take	The experimental uncertainty		
	specifically how	evaluate experimental	experimental uncertainties, but most	the identified uncertainties	of the final result is correctly		
	identified	uncertainties.	are missing, described vaguely, or	into account but is not	evaluated. The weakest link		
	experimental		incorrect. Or only absolute	correctly evaluated. The	rule is used appropriately and		
	uncertainties may		uncertainties are mentioned. Or the	weakest link rule is not	the choice of the biggest		
	affect the data		final result does not take the	used or is used incorrectly.	source of uncertainty is		
			uncertainty into the account.		justified.		
G3	Is able to describe	No attempt is made to	A description of how to minimize	An attempt is made to	The uncertainty is minimized		
	how to minimize	describe how to minimize	experimental uncertainty is present,	minimize the uncertainty	in an effective way.		
	experimental	experimental uncertainty	but there is no attempt to actually	in the final result is made			
	uncertainty and	and no attempt to minimize	minimize it.	but the method is not the			
	actually do it	is present.		most effective.			
G4	Is able to record and	Data are either absent or	Some important data are absent or	All important data are	All important data are		
	represent data in a	incomprehensible.	incomprehensible. They are not	present, but recorded in a	present, organized, and		
	meaningful way		organized in tables or the tables are	way that requires some	recorded clearly. The tables		
			not labeled properly.	effort to comprehend. The	are labeled and placed in a		
				tables are labeled but	logical order.		
				labels are confusing.			
G5	Is able to analyze	No attempt is made to	An attempt is made to analyze the data,	The analysis is appropriate	The analysis is appropriate,		
	data appropriately	analyze the data.	but it is either seriously flawed or	but it contains minor	complete, and correct.		
			inappropriate.	errors or omissions.			

	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.	
12	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.	
13	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.	
14	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.	
15	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.	
16	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	No attempt is made to identify a	An attempt is made, but the	A relevant special case is	A optimally relevant special case		
	optimally relevant	relevant special case	identified special case is either	identified, but it is not an optimal	is identified and clearly stated		
	special-case for analysis		irrelevant or ill-defined	special case (i.e., there are other			
				special cases which give a			
				stronger, more clear-cut analysis			
				of the solution)			
SC2	Is able to state and	No attempt is made to state or	A conceptual expectation is	A conceptual expectation is	A conceptual expectation is		
	justify a conceptual	justify a conceptual expectation	stated, but its justification is	stated, but its justification is	stated, fully justified, and the		
	expectation for the		either absent or missing major	either missing minor steps, or is	expectation is consistent with its		
	special case		steps	inconsistent with the expectation	justification		
SC3	Is able to use a given	No attempt is made to state or	A prediction is stated, but its	A predication is stated, but its	A prediction is stated and clearly		
	solution (or a solution	explain what the given solution	derivation from the given	derivation from the given	derived from the given solution		
	they made up) to predict	predicts for the special case	solution is either absent or	solution is either missing minor			
	what would happen for		missing major steps	steps, or is inconsistent with the			
	the special case			derivation			
SC4	Is able to make, and	No attempt is made to state or	A conclusion is stated, but its	A conclusion is stated and	A conclusion is stated and		
	justify, a reasonable	justify a conclusion	justification is either absent,	justified, but it is inconsistent	justified, and is consistent with		
	conclusion regarding		missing major steps, or	with the results of the student's	the results of the student's		
	their conceptual		containing major mistakes	analysis, or it is incomplete	analysis		
	expectation and the						
	solution.						