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Q1 Designing and Developing Scientific Modeling Task

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Synonyms

Argumentation; Assessment; Inquiry; Modeling; Rubrics; ~~Science practices~~

Scientists strive to provide causal accounts that explain and predict phenomena. Scientists use models to represent relationships among components to test and explain complex phenomenon. As such, modeling is an integral and common practice across the science disciplines. Scientists continually form, test, evaluate, and revise models to explain and predict phenomena. By testing models against data, scientists evaluate and revise models to better fit the data. When a model can no longer account for the data, the model is revised.

> Observations of the natural world motivate the construction of models, which in turn motivate further observations and drive the resulting interpretations. In this way, models become explanations: that is, stipulations of possible cause and effect relations in the phenomenon under investigation. (Penner et al. 1998, p. 430)

Defining Scientific Modeling

The practice of scientific modeling differs significantly from the way models are often thought of and talked about in everyday life. For example, a model airplane is usually a smaller version of an actual plane. In this colloquial use of the word, a model is a scale representation of an object. However, scientific modeling is more complex and abstract process. A scientific model does include representations, but it does not ~~have to look like the thing~~ it is representing. A model may include invisible components including symbols to indicate the relationships among the components of the model. Although scientific modeling can include representations that look similar to the system that is being modeled, it can also include mathematical representations, graphs, and computer simulations.

All models need to explain and predict phenomena and be consistent with scientific theory; in other words, the model must help explain what, how, or why a phenomenon occurs. Moreover, models need to specify the relationships among components in the system that is being explained to provide a causal account. Scientific modeling is also an iterative process. A scientist will create a model to explain a phenomenon. The model is then used to make predications about related phenomena. Those predications are tested and used to revise the model. The model is refined to design a more robust explanation. The model continually evolves with additional evidence.

One model will not be able to capture all aspects of a phenomenon. In fact, models often simplify the system in order to highlight certain aspects. Thus, different models may be needed to explain different aspects of one particular phenomenon. For example, a lightning strike is a complex phenomenon. One model could highlight movement of particles in the air to explain how large

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charges build up in thunderstorms. Scientists would use another model to explain why light and sound are observed when the lightning strikes. ~~As well, a~~ different model is needed to predict the likelihood that certain weather systems will lead to lightning strikes. Finally, scientists would use a mathematical model to triangulate locations of strikes using information about where and when they were observed. Scientific modeling is a complex process that requires analyzing a variety of evidence and utilizing theory to explain and predict phenomena.

Modeling in Science Classrooms

Scientific modeling is one of the scientific practices identified in the Framework for K-12 Science Education that should be used in conjunction with disciplinary core ideas and crosscutting concepts to help learners form usable understanding of science (National Research Council 2012). The various scientific practices work together to help build our understanding of the world. For instance, scientists often argue that one model better fits the data than another model. Although developing and using models is central to the practice of science and as such should be an important aspect of what occurs in science classrooms, developing, testing, and revising models are seldom seen in the science classroom.

The models that students develop are concrete artifacts that can be shared and critiqued by others. These artifacts provide a window into students' mental models or their understanding of this area. When students develop and test models to explain and predict phenomena, the process of developing models helps learners form ~~their mental models~~. ~~A mental model~~ refers to concepts and connections that students hold and use to represent his or her understanding of phenomenon in the world. Models can be drawings, three-dimensional structures, a set of equations, qualitative descriptions, or a simulation.

Supporting Students in Building Models

Due to the complex nature of the practice of scientific modeling, teachers and curriculum designers need to support students in the process by providing criteria for developing a scientific model. Although models are used in a variety of ways, there are ~~some~~ elements across models:

1. Identification and specification of the components or variables important for the analysis of the system.
2. Description or representation of the relationships or interactions among the components or variables.
3. The collection of relationships provides a causal account of the phenomena under study.

Even a mathematical model includes these elements. For example, $F = ma$ includes variables to represent the amount of force, mass, and acceleration of an object or system of objects. The equation indicates several relationships among these variables. Finally, the equation serves as a model, when it provides a causal account of the phenomena. The equation alone is a simple ~~algebra problem~~; however, it serves as a model if it is used to explain observations or make predictions about the motion of one or more objects.

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Designing Assessment Tasks for Scientific Modeling

The Framework for K-12 Science Education (NRC 2012) and the Next Generation Science Standards (Achieve 2013) define science learning expectations as the blending of scientific practices, crosscutting concepts, and disciplinary core ideas to form performance expectations. A performance expectation defines knowledge in use. Assessing scientific modeling requires the use of scientific ideas. A performance expectation for modeling is developed through crossing the practice with disciplinary core ideas. Finally, a relevant phenomenon is added so the performance expectation will lead to a rich assessment task.

Clear and specific performance expectations provide guidance in writing an assessment task as they point out important elements that need to be included in the assessment. ~~For instance, the above~~ performance expectation contains two critical elements: (1) the scientific practice of developing a model and (2) the use of a disciplinary idea – the structure of an atom. This specificity supports the alignment between the performance expectation and the assessment task. ~~Below is an example of an assessment task that aligns with the performance expectation defined in Table 1.~~ Figure 1 shows an assessment task that aligns to the performance expectation in Table 1. The performance expectation and assessment task are appropriate for ninth or tenth grade physical science.

Draw (or revise) your model of atomic structure	How does this model explain Rutherford's observations?

Note that the assessment task requires that students explain how their model is related to the phenomenon; a diagram alone cannot fully assess all key elements of a model and if students demonstrate understanding of the performance expectation.

Assessing Student Responses

Base Modeling Rubric: A base, modeling rubric provides a general rubric for evaluating scientific models that explain a variety of phenomena. The base rubric includes the three elements of a scientific model and provides guidance about assessing different levels of student achievement for each of the elements. Table 2 provides a general base rubric for assessing students' scientific models.

Developing Specific Rubrics: A specific rubric combines both the general structure of scientific models with the appropriate science ideas and evidence with a particular assessment task. Adapting a base rubric to develop a specific rubric involves aligning the rubric to a particular assessment task. The specific rubric includes determining what would count as appropriate components and

Q3 **Table 1** Defining performance expectation for modeling

Scientific practice: developing and using models	Disciplinary core idea: "Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons" (NRC 2012, p. 107)	Relevant phenomena: Rutherford observed that when alpha particles were shot at a thin sheet of gold foil, most of the particles passed through mostly unaffected, but a few returned close to the direction from which they came	Performance expectation: Develop a scientific model for atomic structure that can account for experimental results related to the structure of the atom

Encyclopedia of Science Education
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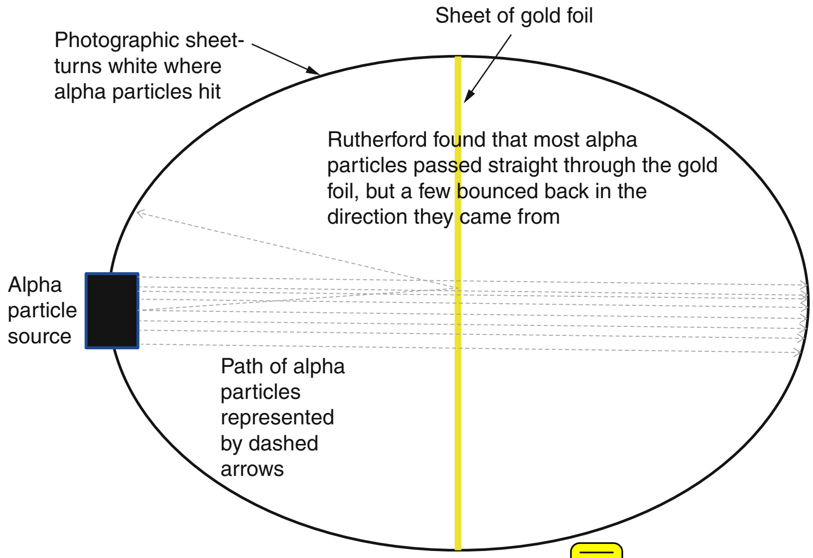

Q4 **Fig. 1** An assessment task. When Rutherford shot positively charged alpha particles at a thin sheet of gold atoms, he observed that most of the particles passed straight through but was surprised to see some that returned to the direction they came from

Table 2 Base rubric for assessing scientific models

Criteria	Levels		
	0	1	2
Components: Model includes identification and specification of appropriate and necessary components, including both visible and invisible	Diagram shows an image of the phenomenon	Model may include both visible and invisible components, but may be missing key components, or components are not clearly labeled leaving uncertainty in the interpretation of the model	Model highlights all necessary components, including both visible and invisible, that are needed for explaining the phenomena. All components are clearly labeled or identified in description
Relationships: Model includes representations or descriptions indicating how various components within the model are related and interact with each other	Model does not indicate relationships or interactions between components of the model	Model is either missing key relationships or includes some inaccurate relationships between component	Model includes all appropriate relationships necessary for the explanation of the phenomena
The collection of relationships provides a causal account of the phenomena: The model is used to explain or predict phenomena or specific aspects of phenomena	Model is not used to explain phenomena	Model is used to try to explain phenomena, but there are some inaccuracies in the explanation of the phenomena	Model is consistent with available evidence and is used to explain phenomena

relationships in the specific task. To develop specific rubrics, begin by using the base rubric and constructing the ideal student response for each element (Modified from McNeill and Krajcik 2008).

To develop the specific rubric for the Rutherford task, the specific components, relationships, and
Q5 the connection to the phenomenon need to be identified. Note that these specifics are being defined

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Table 3 Specific rubric for assessing Rutherford modeling task

Criteria	Levels		
	0	1	2
Components: Model includes identification and specification of appropriate and necessary components, including both visible and invisible	Diagram shows an image representing the outcome of Rutherford's gold foil experiment	Model may include both visible and invisible components, but may be missing key components, or components are not clearly labeled leaving uncertainty in the interpretation of the model. Model may not indicate the charge of particles	Model highlights protons and alpha particles and identifies these particles as positively charged
Relationships: Model includes representations or descriptions indicating how various components within the model are related and interact with each other	Model does not indicate relationships or interactions between components of the model	Model is either missing key relationships or includes some inaccurate relationships between component	Model includes repulsive forces between positively charged alpha particles and protons. Model includes relationship between concentration of protons and strength of electric field
The collection of relationships provides a causal account of the phenomena: Model is used to explain or predict a phenomenon or specific aspects of a phenomenon	Model is not used to explain phenomena	Model is used to try to explain phenomena, but there are some inaccuracies in the explanation of the phenomena	Model is consistent with and used to explain the evidence from Rutherford's experiment that most of the alpha particles pass straight through the gold foil but a few are deflected at a large angle

with respect to the instructional methods used to cover the material in class. In this example, the students learned about Rutherford's gold foil experiment using a simulation where students manipulated the concentration of the positive charges and observed the effect on the electric field and motion of the positive alpha particles. This simulation can be found at http://concord.org/tst/rutherford-model.

Step 1: Identify the object/components: what components need to be specified. The key components needed to explain the results of the Rutherford observations include protons and alpha particles. Additionally, it is necessary to include that these particles are all positively charged. Further, the strength of the electric field around the protons is an important invisible component for explaining how the path of a few of the alpha particles changed so drastically.

Step 2: Specify the specific relationships: what relationships need to be specified. In the Rutherford example, there are two important relationships to include. Since the alpha particles and protons are all positively charged, these particles will repel. An additional relationship that is relevant for explaining Rutherford's observations is the connection between the strength of an electric field and the concentration of charged particles. The electric field is stronger around concentrated charges.

Step 3: Show the connections among the relationships. Do the connections among the relationships provide a causal account for why the phenomenon occurs? Rutherford observed that a few of the positively charged alpha particles returned almost in the direction they originally came from. In order to change the path of the alpha particle this drastically, there must be regions with highly concentrated positive charges. However, the majority of the alpha particles passed almost unaffected

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through the gold foil. Thus, inside the gold atoms, there must be regions with highly concentrated protons and large regions without protons.

Adding these specifications to the base rubric in Table 2 develops the specific rubric. Table 3 displays an example of a specific rubric that would be used to assess students' responses to the task described in Fig. 1.

Example of Assessing Student's Model: ~~Below is~~ an example of a student's representation of atomic structure and her description of how the model related to phenomenon. The assessment task here is a bit different than the task described above. The students drew representations of atomic structures and then were interviewed about the representations and how they related to a variety of phenomena. The example is provided to illustrate the connection between the base rubric, specific rubric, and a specific example. The example includes the representation the student drew, a selection Q6 of the transcript from the interview, and an evaluation of the model using the rubric ~~(Table 4)~~.

Overview of the analysis of the student model: The model includes appropriate components. Plus and minus signs indicate the charges of the various components. Arrows show a relationship between alpha particle and the path of the alpha particle depending if it interacts with a proton or not. However, the model includes inaccurate ideas: The student's model has alpha particles interacting with an individual proton or electron rather than with the strong electric field due to

~~Table 4~~ Student atomic model to explain Rutherford's observations

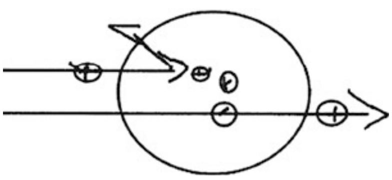
Atomic model to explain Rutherford's observations from the gold foil experiment	
Student's representation 	Transcript from interview: This is like the atom and inside of it is both the positive and the protons and electrons, and when you send out, (an alpha particle) um one would either bounce off or go right through depending on what its charge was. If the alpha particle hits a proton, it will be reflected because they repel; if it hits an electron, it would come right straight through

Table 5 Evaluation of sample student model

Criteria	Evaluation	Description
Components	Level 2	Student included protons and alpha particles. Though these are not explicitly labeled in the diagram, the student identified them in the description of the model during the interview. The protons and alpha particles are all labeled with plus signs indicating they are positively charged
Relationships	Level 1	Student included repulsive forces between the alpha particles and protons. However, the relationship between the concentration of positive protons and the strength of the electric field is missing. Instead, the student relates the path of the alpha particles to the interaction with individual particles rather than electric fields created by collection of particles
Connection to phenomenon	Level 2	The student used ~~her~~ model to explain how some alpha particles were reflected and others passed through. Though the student had an inaccuracy in that she related the path of the alpha particles to individual particles rather than a collection of particles, this inaccuracy was captured in the evaluation of the relationship category. The student's description of the phenomenon is accurate and the model provides a causal account to explain the phenomenon

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a concentration of multiple protons. Table ~~5~~ displays an evaluation of this student's model based on the criteria described in the base and specific rubrics.

Summary Statement

Scientific modeling engages learners in a complex and essential scientific practice. Teachers need to support students in developing and revising models. This includes providing a structure to develop and evaluate student's models. This structure also helps students to evaluate and revise their own models as they gather additional evidence. Due to the complex nature of the practice of scientific modeling, it is important to describe the three elements of the model to evaluate the components included in the model, relationships between these components, and the connection among the components and relationships in the model ~~and phenomena~~ to give a causal account. Additionally, because models explain or predict phenomena, it is important to write assessment tasks that ask students to connect their models to phenomena. Rubrics can monitor students developing ~~mental models~~ as students continue to build and refine their evolving models. The analyses of students' models provide insights into students' ~~mental models~~.

Cross-References

- ► Argumentation Environments
- ► Assessment of Knowing and Doing Science
- ► Enquire, Assessment of the Ability to
- ► Formative Assessment
- ► Inquire, Assessment of the Ability to
- ► Science Practices, Assessment of
- ► Summative Assessment

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