Differentiating Theory and Law

Competency

Student can explain the difference between theories and laws.

Focus of this assessment:

- ☑ Declarative knowledge
- ☐ Procedural knowledge
- ☐ Problem solving

Evidence

The student explains aspects of scientific theories and laws, including their characteristics, similarities and differences, applications, and processes of development. Explanations are framed in response to dialogues in which individuals exhibit specific misconceptions about scientific theories and laws. In response, the student must provide details to correct the misconceptions presented in the dialogues.

The work reported in this paper is supported through a grant from Education Research Programs at the Institute of Education Sciences (IES), award number R305A110121, administered by the U.S. Department of Education. Faranak Rohani is the principal investigator for this research. Related information is available at http://cala.fsu.edu/ies/. Findings and opinions do not reflect the positions or policies of IES or the U.S. Department of Education.

Example Task

Some students are talking after their science class. Some of what they say is incorrect. Read each conversation below. Then, follow the instructions.

Conversation 1

These students have a misconception about the *definition* of a scientific theory.

Student 1: *"Scientific theories are just some scientists' opinions."*

Student 2: *"Yeah, what makes their opinions better than anyone else's*?"

Help the students understand why scientific theories are NOT just opinions by answering the following:

1. Describe two characteristics of scientific theories.

2. Give an example of a scientific theory and explain how it has two characteristics of scientific theories.

3. Use your example theory to explain why scientific theories are NOT just opinions.

Example Task (continued)

Conversation 2

These students have a misconception about the *similarities and differences* between scientific theories and scientific laws.

> Student 1: *"Do you think there will ever be enough evidence for that scientific theory to become a scientific law?"*
>
> Student 2: *"Maybe, but scientists will have to collect a whole lot more evidence."*

Help the students understand why scientific theories never become scientific laws by answering the following:

1. Describe two ways in which scientific theories and scientific laws are **similar**.

2. Describe two ways in which scientific theories and scientific laws are **different**.

3. Give an example of a scientific theory and scientific law. Use your examples to explain why scientific theories never become scientific laws.

Example Task (continued)

Conversation 3

These students share a misconception about the *application* of scientific theories.

Student 1: *"I'd care about scientific theories if they actually affected something."*

Student 2: *"Scientific theories don't really have any real-world use, anyway."*

Help the students understand why scientific theories are NOT useless by answering the following:

1. Describe two ways in which all scientific theories can be applied in general.

2. Give a specific example of how a scientific theory has been or could be applied. Use your example to explain why scientific theories are not useless.

Example Task (continued)

Conversation 4

These students share a misconception about the *development* of scientific laws.

Student 1: *"Scientific laws have been proven to be true."*

Student 2: *"That's why we can trust them. They are proven."*

Help the students understand why scientific laws are never proved by answering the following:

1. Describe two things scientists do, or might do, to develop a scientific law.

2. Describe two things scientists did, or might have done, to develop a particular scientific law.

3. Explain why scientific laws are never proven.

Scoring Plan for the Example Task

Note: Credit for scoring items within a conversation is awarded if scoring criteria are met by any part of the response to that conversation.

Conversation 1: Definition of Theory

Definition Characteristics

Student describes <u>one or more</u> characteristics of a scientific theory. Examples: *These responses would receive credit:* • *Theories are based on inferences from data.* • *Theories explain a broad range of observations.* • *Theories have never been disproved.* *These responses would not receive credit:* • *Theories are used in science to describe the relationships between variables in nature.* (This statement describes scientific laws.) • *Theories are used by science*. (This statement is too vague to be meaningful.) • *Theories have been proved*. (This statement is incorrect because science is always tentative—theories may eventually be disproved.)	1 pt.
Student describes <u>two or more</u> characteristics of a scientific theory.	1 pt.

Illustration of Definition

Student provides an example of a scientific theory ***and*** describes how it has <u>one or more</u> of the characteristics of scientific theories. Examples: *These responses would receive credit:* • *The theory of evolution explains many observations from biology and geology.* • *The big bang theory was formed as information from space was gathered and scientists started to debate its meaning.* *These responses would not receive credit:* • *The theory of evolution does that.* ("That" refers to the student's previous explanation of the definition of theories. This statement does not explain how the example theory has the characteristics of theories described.) • *The theory of evolution is used by scientists.* (This statement is too vague to be meaningful). *Student does not have to provide the standard scientific name of the theory if the theory can be inferred from the student's response.*	1 pt.
Student provides an example of a scientific theory ***and*** describes how it has <u>two or more</u> of the characteristics of scientific theories. *Student may use the same or a different example of a scientific theory to describe a second characteristic; the second characteristic described must be unique to receive credit.*	1 pt.

Scoring Plan for the Example Task (continued)

Misconception Rectification

Student provides details related to his or her example theory that rectify the misconception that theories are just opinions. Examples: *These responses would receive credit:* • *The theory of evolution is based on observations, such as homologous structures.* • *The plate tectonics theory is supported by fossil evidence, such as the distribution of fossils across continents.* *These responses would not receive credit:* • *The theory of evolution is based on data.* (This statement is too vague to be meaningful.) • *Scientists used lots of facts to make the plate tectonics theory.* (This statement is too vague to be meaningful.) *Student does not have to provide the standard scientific name of the theory if the theory can be inferred from the student's response.* *Point is awarded if student rectifies the misconception but does not specifically reference the misconception.*	2 pts.

Scoring Plan for the Example Task (continued)

Conversation 2: Relationships between Theories and Laws

Similarities between Theories and Laws

Student describes one or more similarities between theories and laws. Examples: *These responses would receive credit:* • *Both theories and laws are based on scientific observation and examination.* • *Both theories and laws are used by science to predict new phenomena.* *These responses would not receive credit:* • *Both theories and laws are used by scientists.* (This statement is too vague to be meaningful.) • *Both theories and laws have to do with natural phenomena.* (This statement is too vague to be meaningful.) • *Both theories and laws involve reasoning.* (This statement is too vague to be meaningful.)	1 pt.
Student describes two or more similarities between theories and laws.	1 pt.

Differences between Theories and Laws

Student describes one or more differences between theories and laws. Examples: *These responses would receive credit:* • *Laws are used to describe phenomena, and theories are used to explain phenomena.* • *Theories are often based on indirect evidence, while laws are often based on direct evidence.* *These responses would not receive credit:* • *We can be more confident of laws than we can of theories.* (This is not always true.) • *Theories can change over time, but laws remain the same.* (Both theories and laws are subject to revision.)	1 pt.
Student describes two or more differences between theories and laws.	1 pt.

Scoring Plan for the Example Task (continued)

Misconception Rectification

Student provides details related to an example of a scientific theory or law that rectify the misconception that theories become laws. Examples: *These responses would receive credit:* • *Theories explain phenomena and laws describe them. If the theory of evolution were to turn into a law of evolution, it would cease to be an explanation.* • *The theory of evolution explains how organisms change over time. The law of conservation of mass describes how matter interacts. They each have different roles in science and one cannot turn into the other.* *These responses would not receive credit:* • *Theories do not become laws.* (This information is already given to the student and adds no new information.) • *Theories and laws are different.* (This statement is too vague to be meaningful.) *Student does not have to provide the standard scientific name of the theory or law if the theory or law can be inferred from the student's response.* *Point is awarded if student rectifies the misconception but does not specifically reference the misconception.*	2 pts.

Scoring Plan for the Example Task (continued)

Conversation 3: Application

Scientific Application

Student describes one or more applications of scientific theories in general. Examples: *These responses would receive credit:* • *Theories are used by scientists to help make predictions and control outcomes.* • *Theories are used to explain phenomena.* *These responses would not receive credit:* • *Scientists use theories to talk about natural phenomena.* (This statement is too vague to be meaningful.) • *Scientists use theories to do science.* (This statement is too vague to be meaningful.)	1 pt.
Student describes two or more applications of scientific theories in general.	1 pt.

Misconception Rectification

Student provides a specific example of how a scientific theory has been or could be applied that rectifies the misconception that theories are useless. Examples: *These responses would receive credit:* • *The theory of evolution can be used to explain why bacteria can become resistant to antibiotics.* • *The plate tectonics theory helps predict earthquakes.* *These responses would not receive credit:* • *The theory of evolution explains how life changes over time.* (This does not describe a specific application of the theory of evolution). • *The theory of evolution is used by scientists in many different ways.* (This statement is too vague to be meaningful.) *Student does not have to provide the standard scientific name of the theory if the theory can be inferred from the student's response.* *Point is awarded if student rectifies the misconception but does not specifically reference the misconception.*	2 pts.

Scoring Plan for the Example Task (continued)

Conversation 4: Development

Developmental Stages

Student describes one or more stages of the development of scientific laws. Examples: *These responses would receive credit:* • *Scientists gather data before making laws.* • *Scientists make inferences about data to create laws.* *These responses would not receive credit:* • *Scientists use a very thorough process to create laws.* (This statement is too vague to be meaningful.) • *There are many steps in the process of making a law.* (This statement is too vague to be meaningful.) • *A law can eventually be disproved.* (This is not a stage of development of scientific laws because it would cease to be a law if disproved.)	1 pt.
Student describes two or more stages of the development of scientific laws.	1 pt.

Illustration of Developmental Stages

Student provides an example of one or more stages of how a particular scientific law has been or could be developed. Examples: *These responses would receive credit:* • *The law of gravity was formed after observing the behavior of many different objects and the planets.* • *The law of conservation of mass has been refined as our understanding that mass can turn into energy has improved.* *These responses would not receive credit:* • *The law of gravity was formed after scientists made many observations.* (This statement could be made concerning any law and does not illustrate the stage of *observation* specific to the law of gravity.) • *It was a long process to form the law of conservation of energy.* (This statement is too vague to be meaningful.) *Student does not have to provide the standard scientific name of the law if the law can be inferred from the student's response.*	1 pt.
Student provides an example of two or more stages of how a particular scientific law has been or could be developed. *Student may use the same or a different example of a scientific law to describe a second characteristic; the second characteristic described must be unique to receive credit.*	1 pt.

Scoring Plan for the Example Task (continued)

Misconception Rectification

Student explains that scientific laws can never be proven. Examples: *These responses would receive credit:* • *A law can be further supported over time as new data are gathered, but science can never prove something.* • *For a law to be "proven," it implies that no discovery could ever be found that disproves the law, and science has to always remain open to that possibility.* *These responses would not receive credit:* • *A law cannot be proven.* (This information is already given to the student and adds no new information.) • *A law will require more evidence for it to be proven.* (Science cannot prove laws. It can only produce evidence.) *Student does not have to provide the standard scientific name of the law if the law can be inferred from the student's response.* *Point is awarded if student rectifies the misconception but does not specifically reference the misconception or a particular scientific law.*	2 pts.

Procedure for Creating Parallel Tasks

Misconception Conversations

- You will create four hypothetical conversations between two students in which each conversation represents a common misconception concerning the nature of scientific theories and/or laws for each of the following categories:
    1. **Conversation 1** deals with the *definition* of scientific theory or law.
    2. **Conversation 2** deals with the *relationships between scientific theories and laws*, including their similarities and differences.
    3. **Conversation 3** deals with the *application* of scientific theories or laws.
    4. **Conversation 4** deals with the *development* of scientific theories or laws.
- For each of conversations 1, 3, and 4, you may address either scientific theories or laws, but not both within one conversation. However, you cannot address only theories or laws for all three conversations. For example, you can choose theories for conversations 1 and 3 and laws for conversation 4, but you cannot choose theories for all three conversations. Conversation 2 will include comparing and contrasting theories and laws.
- For each of the four misconceptions, write a hypothetical conversation between two students who each make one statement. Each conversation should address a single, distinct misconception concerning theories and/or laws. Within a conversation, the first student is to make a statement representing a misconception concerning theories and/or laws, and the second student responds with a different statement that conveys the **same** misconception. The second student's response may include, but is not limited to, rephrasing the misconception, elaborating on the misconception, or continuing the logic of the misconception. Avoid only having the second student agree with the first student.
- The students' statements in the conversations should not correct the misconceptions presented. The prompt following the conversation will identify the misconception and direct the student to explain why the students are mistaken.
- The conversations cannot reference specific theories, laws, evidence, or data.

Scoring Plan for Parallel Tasks

Note: Credit for scoring items within a conversation is awarded if scoring criteria are met by any part of the response to that conversation.

Scoring plan used for the example task	Generic scoring criteria for all parallel tasks

Conversation 1: Definition of Theory

Definition Characteristics

Student describes one or more characteristics of a scientific theory. Examples: *These responses would receive credit:* • *Theories are based on inferences from data.* • *Theories explain a broad range of observations.* • *Theories have never been disproved.* *These responses would not receive credit:* • *Theories are used in science to describe the relationships between variables in nature.* (This statement describes scientific laws.) • *Theories are used by science.* (This statement is too vague to be meaningful.) • *Theories have been proved*. (This statement is incorrect because science is always tentative—theories may eventually be disproven.)	Student describes one or more characteristics of a scientific *[theory/law]*.	1 pt.
Student describes two or more characteristics of a scientific theory.	Student describes two or more characteristics of a scientific *[theory/law]*.	1 pt.

Scoring Plan for Parallel Tasks (continued)

Illustration of Definition

Student provides an example of a scientific theory ***and*** describes how it has <u>one or more</u> of the characteristics of scientific theories. Examples: *These responses would receive credit:* • *The theory of evolution explains many observations from biology and geology.* • *The big bang theory was formed as information from space was gathered and scientists started to debate its meaning.* *These responses would not receive credit:* • *The theory of evolution does that.* ("That" refers to the student's previous explanation of the definition of theories. This statement does not explain how the example theory has the characteristics of theories described.) • *The theory of evolution is used by scientists.* (This statement is too vague to be meaningful). *Student does not have to provide the standard scientific name of the theory if the theory can be inferred from the student's response.*	Student provides an example of a scientific *[theory/law]* ***and*** describes how it has <u>one or more</u> of the characteristics of scientific *[theories/laws]*. *Student does not have to provide the standard scientific name of the [theory/law] if the [theory/law] can be inferred from the student's response.*	1 pt.
Student provides an example of a scientific theory ***and*** describes how it has <u>two or more</u> of the characteristics of scientific theories. *Student may use the same or a different example of a scientific theory to describe a second characteristic; the second characteristic described must be unique to receive credit.*	Student provides an example of a scientific *[theory/law]* ***and*** describes how it has <u>two or more</u> of the characteristics of scientific *[theories/laws]*. *Student may use the same or a different example of a scientific [theory/law] to describe a second characteristic; the second characteristic described must be unique to receive credit.*	1 pt.

Scoring Plan for Parallel Tasks (continued)

Misconception Rectification

Student provides details related to his or her example theory that rectify the misconception that theories are just opinions. Examples: *These responses would receive credit:* • *The theory of evolution is based on observations, such as homologous structures.* • *The plate tectonics theory is supported by fossil evidence, such as the distribution of fossils across continents.* *These responses would not receive credit:* • *The theory of evolution is based on data.* (This statement is too vague to be meaningful.) • *Scientists used lots of facts to make the plate tectonics theory*. (This statement is too vague to be meaningful.) *Student does not have to provide the standard scientific name of the theory if the theory can be inferred from the student's response.* *Point is awarded if student rectifies the misconception but does not specifically reference the misconception.*	Student provides details related to his or her example *[theory/law]* that rectify the misconception that *[state misconception]*. *Student does not have to provide the standard scientific name of the [theory/law] if the [theory/law] can be inferred from the student's response.* *Point is awarded if student rectifies the misconception but does not specifically reference the misconception.*	2 pts.

Scoring Plan for Parallel Tasks (continued)

Conversation 2: Relationships between Theories and Laws

Similarities between Theories and Laws

Student describes one or more similarities between theories and laws. Examples: *These responses would receive credit:* • *Both theories and laws are based on scientific observation and examination.* • *Both theories and laws are used by science to predict new phenomena.* *These responses would not receive credit:* • *Both theories and laws are used by scientists.* (This statement is too vague to be meaningful.) • *Both theories and laws have to do with natural phenomena.* (This statement is too vague to be meaningful.) • *Both theories and laws involve reasoning.* (This statement is too vague to be meaningful.)	Student describes one or more similarities between theories and laws.	1 pt.
Same as generic.	Student describes two or more similarities between theories and laws.	1 pt.

Differences between Theories and Laws

Student describes one or more differences between theories and laws. Examples: *These responses would receive credit:* • *Laws are used to describe phenomena, and theories are used to explain phenomena.* • *Theories are often based on indirect evidence, while laws are often based on direct evidence.* *These responses would not receive credit:* • *We can be more confident of laws than we can of theories.* (This is not always true.) • *Theories can change over time, but laws remain the same.* (Both theories and laws are subject to revision.)	Student describes one or more differences between theories and laws.	1 pt.
Same as generic.	Student describes two or more differences between theories and laws.	1 pt.

Scoring Plan for Parallel Tasks (continued)

Misconception Rectification

Student provides details related to an example of a scientific theory or law that rectify the misconception that theories become laws. Examples: *These responses would receive credit:* • *Theories explain phenomena and laws describe them. If the theory of evolution were to turn into a law of evolution, it would cease to be an explanation.* • *The theory of evolution explains how organisms change over time. The law of conservation of mass describes how matter interacts. They each have different roles in science and one cannot turn into the other.* *These responses would not receive credit:* • *Theories do not become laws.* (This information is already given to the student and adds no new information.) • *Theories and laws are different.* (This statement is too vague to be meaningful.) *Student does not have to provide the standard scientific name of the theory or law if the theory or law can be inferred from the student's response.* *Point is awarded if student rectifies the misconception but does not specifically reference the misconception.*	Student provides details related to an example of a scientific theory or law that rectify the misconception that *[state misconception]*. *Student does not have to provide the standard scientific name of the theory or law if the theory or law can be inferred from the student's response.* *Point is awarded if student rectifies the misconception but does not specifically reference the misconception.*	2 pts.

Scoring Plan for Parallel Tasks (continued)

Conversation 3: Application

Scientific Application

Student describes <u>one or more</u> applications of scientific theories in general. Examples: *These responses would receive credit:* • *Theories are used by scientists to help make predictions and control outcomes.* • *Theories are used to explain phenomena.* *These responses would not receive credit:* • *Scientists use theories to talk about natural phenomena.* (This statement is too vague to be meaningful.) • *Scientists use theories to do science.* (This statement is too vague to be meaningful.)	Student describes <u>one or more</u> applications of scientific *[theories/laws]* in general.	1 pt.
Student describes <u>two or more</u> applications of scientific theories in general.	Student describes <u>two or more</u> applications of scientific *[theories/laws]* in general.	1 pt.

Misconception Rectification

Student provides a specific example of how a scientific theory has been or could be applied that rectifies the misconception that theories are useless. Examples: *These responses would receive credit:* • *The theory of evolution can be used to explain why bacteria can become resistant to antibiotics.* • *The plate tectonics theory helps predict earthquakes.* *These responses would not receive credit:* • *The theory of evolution explains how life changes over time*. (This does not describe a specific application of the theory of evolution). • *The theory of evolution is used by scientists in many different ways.* (This statement is too vague to be meaningful.) *Student does not have to provide the standard scientific name of the theory if the theory can be inferred from the student's response.* *Point is awarded if student rectifies the misconception but does not specifically reference the misconception.*	Student provides a specific example of how a scientific *[theory/law]* has been or could be applied that rectifies the misconception that *[state misconception]*. *Student does not have to provide the standard scientific name of the [theory/law] if the [theory/law] can be inferred from the student's response.* *Point is awarded if student rectifies the misconception but does not specifically reference the misconception*	2 pts.

Scoring Plan for Parallel Tasks (continued)

Conversation 4: Development

Developmental Stages

Student describes one or more stages of the development of scientific laws. Examples: *These responses would receive credit:* • *Scientists gather data before making laws.* • *Scientists make inferences about data to create laws.* *These responses would not receive credit:* • *Scientists use a very thorough process to create laws.* (This statement is too vague to be meaningful.) • *There are many steps in the process of making a law.* (This statement is too vague to be meaningful.) • *A law can eventually be disproved.* (This is not a stage of development of scientific laws because it would cease to be a law if disproved.)	Student describes one or more stages of the development of scientific *[theories/laws]*.	1 pt.
Student describes two or more stages of the development of scientific laws.	Student describes two or more stages of the development of scientific *[theories/laws]*.	1 pt.

Scoring Plan for Parallel Tasks (continued)

Illustration of Developmental Stages

Student provides an example of <u>one or more</u> stages of how a particular scientific law has been or could be developed. Examples: *These responses would receive credit:* • *The law of gravity was formed after observing the behavior of many different objects and the planets.* • *The law of conservation of mass has been refined as our understanding that mass can turn into energy has improved.* *These responses would not receive credit:* • *The law of gravity was formed after scientists made many observations.* (This statement could be made concerning any law and does not illustrate the stage of *observation* specific to the law of gravity.) • *It was a long process to form the law of conservation of energy.* (This statement is too vague to be meaningful.) *Student does not have to provide the standard scientific name of the law if the law can be inferred from the student's response.*	Student provides an example of <u>one or more</u> stages of how a particular scientific *[theory/law]* has been or could be developed. *Student does not have to provide the standard scientific name of the [theory/law] if the [theory/law] can be inferred from the student's response.*	1 pt.
Student provides an example of <u>two or more</u> stages of how a particular scientific law has been or could be developed. *Student may use the same or a different example of a scientific law to describe a second characteristic; the second characteristic described must be unique to receive credit.*	Student provides an example of <u>two or more</u> stages of how a particular scientific *[theory/law]*] has been or could be developed. *Student may use the same or a different example of a scientific [theory/law] to describe a second characteristic; the second characteristic described must be unique to receive credit.*	1 pt.

Scoring Plan for Parallel Tasks (continued)

Misconception Rectification

Student explains that scientific laws can never be proven. Examples: *These responses would receive credit:* • *A law can be further supported over time as new data were gathered, but science can never prove something.* • *For a law to be "proven," it implies that no discovery could ever be found that disproves the law, and science has to always remain open to that possibility.* *These responses would not receive credit:* • *A law cannot be proven.* (This information is already given to the student and adds no new information.) • *A law will require more evidence for it to be proven.* (Science cannot prove laws. It can only produce evidence.) *Student does not have to provide the standard scientific name of the law if the law can be inferred from the student's response.* *Point is awarded if student rectifies the misconception but does not specifically reference the misconception or a particular scientific law.*	Student explains that scientific *[theories/laws] [state correction of the misconception]*. *Student does not have to provide the standard scientific name of the [theory/law] if the [theory/law] can be inferred from the student's response.* *Point is awarded if student rectifies the misconception but does not specifically reference the misconception or a particular scientific [theory/law].*	2 pts.