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THE NATURE OF SCIENTIFIC EVIDENCE AND ITS IMPLICATIONS FOR TEACHING SCIENCE

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Abstract. *Scientific evidence-based reasoning has been recognized as a form of reasoning that characterizes scientific thinking. This study questioned what scientific evidence means in the various types of scientific activities; that is, this study explored the nature of scientific evidence (NOSE). To do this, previous studies were examined to understand how scientific evidence was analyzed, evaluated, and utilized during the scientific activities of scientists or students in scientific or everyday situations. Through this process, seven statements were identified to describe the NOSE. This study explains these seven NOSE statements, constructs a process of scientific evidence-based reasoning as a structured form by reflecting these seven statements comprehensively, and discusses the practical implications for teaching science in schools. Finally, the limitations of this study are discussed, and possible directions for future studies are suggested. It is believed that the list of NOSE characteristics can provide a starting point for further elucidation and discussion of scientific evidence and helping students' science learning in more authentic ways.*

Keywords: *evidence evaluation, evidence-based reasoning, evidence-based response, idea-based response, scientific evidence*

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Introduction

When scientists support or oppose scientific claims, they put substantial efforts into analyzing, criticizing, and evaluating evidence. Therefore, understanding the nature of scientific evidence—which is closely related to the nature of science—and the rational use of it represents one of the most important aspects of the scientific enterprise (Sampson et al., 2013). Science educators have also emphasized that it is important for students to properly understand the characteristics of scientific evidence, have the ability to carry out scientific reasoning using evidence, and make efforts to develop their scientific inquiry and problem-solving abilities by practicing evidence-based reasoning (Bricker & Bell, 2008; Brown et al., 2010; Driver et al., 2000; Jimenez-Aleixandre & Erduran, 2007; Osborne et al., 2004; Piekny & Maehler, 2013; Roberts & Gott, 2010). Therefore, the use and development of evidence-based reasoning is included as one of the main objectives of scientific learning. For example, the Next Generation Science Standards (NGSS) includes 'Engaging in argument from evidence' in the science and engineering practices of the NGSS (NGSS Lead States, 2013), while the 2015 revised national science curriculum of Korea also includes 'discussions and arguments based on evidence' as one of the main scientific skills (Ministry of Education, 2015).

This study begins with the following questions: "How can we describe the nature of scientific evidence?" and "What needs to be considered to help students use scientific evidence properly?".

To begin answering the questions, it is critical to look into what role scientific evidence plays in scientific activities. At first, scientific evidence plays an important role in the context of scientific discovery; that is, collected scientific data serves as evidence for deriving new scientific knowledge. In this case, the process of discovering new laws from experimental data is sometimes seen as a content-independent, logical, and mechanical process (Langley et al., 1987). For example, when original data that Max

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Planck used to discover a new formula describing the black body radiation phenomenon were presented to eight mathematicians and scientists without background knowledge or a contextual description related to the data, five of them were able to derive the same formula as Planck within a few minutes, with three of them using the same process used by Planck (Langley et al., 1987, p. 53). In another example, a computer was able to derive Kepler's law after data were input and the discovery logic was programmed (Qin & Simon 1990).

However, in many other cases, the actual discovery process from evidence to claims is not so simple. For example, if the actual scientists' discovery is scrutinized in further detail, we can find that new scientific laws are discovered through the selection or transformation of data, rather than using the data as it is. For example, Robert Millikan obtained the value of the elementary electric charge using only 58 of the 175 points of data measured from an oil drop experiment (Franklin, 1997). This may be because that the data set often involves some data that conflict with certain scientific claims as well as supporting data (Zimmerman, 2000), and different claims can often be made from the same evidence (Gould, 1989, p. 67). As a result, it is difficult to simply the process from evidence to claims in the context of discovery as a mechanical process.

Scientific evidence also plays an important role in the context of the justification of a proposed scientific claim or hypothesis. According to Klahr and Dunbar (1988), a claim proposed in a theoretical space is evaluated as to whether it is consistent with the evidence collected from the experimental space; if a claim is supported by evidence, then that claim can represent new scientific knowledge. However, according to deductive process of hypothesis testing, even if a claim is supported by scientific evidence, the claim cannot be concluded as a correct claim (Popper, 1968; Park et al., 2001). Therefore, the process of confirming a claim based on the supporting evidence is neither simple nor linear.

Of course, if evidence is inconsistent with a claim, then that claim should be logically rejected (Popper, 1968); the disputed claim can be replaced by a new claim that can explain the conflicting evidence (Kuhn, 2011, p. 498). However, in many cases involving conflicting evidence, the existing claims may persist for a variety of reasons (Chin & Brewer, 1998). Therefore, Kuhn (1970, p. 77) noted that "no process yet disclosed by the historical study of scientific development at all resembles the methodological stereotype of falsification". Further, conflicting evidence may serve to modify and refine existing claims rather than discard them, thus enabling these claims to be developed into more articulate and elaborate claims (Lakatos, 1994; Park, 2002).

In school science education, the importance of evidence is emphasized in various contexts such as actual experiments, thought experiments, and argumentation activities. In these situations, science educators have reported that there are various characteristics involved in the process of interpreting or evaluating scientific evidence. For example, Kim et al. (2018) and Koslowski et al. (1989) observed that, in the process of eliciting claims from experimental data, student reasoning was influenced by their background knowledge or epistemological beliefs. Sandoval and Millwood (2005) observed that students sometimes failed to make sufficient use of evidence when making claims, or they failed to elaborate upon the relationship between the evidence and their claims.

In thought experiments, even though empirical data are not collected, valuable results can be obtained through logical thinking; these can then serve as evidence from which to draw new claims and be used to justify or disprove existing claims (Park et al., 2001). This process can also help strengthen students' evidence-based scientific reasoning.

In argumentation activities, which represent an important scientific practice in schools (Driver et al., 2000; Duschl & Osborne, 2002; Erduran et al., 2004; Jimenez-Aleixandre et al., 2000), student understanding of the relevant evidence and their ability to make persuasive claims were emphasized (Toulmin, 1958/2003). That is, scientific evidence is not only used to generate claims, but it is also used to persuade others through justification (Jimenez-Aleixandre & Erduran, 2007). It has often been observed that the process and results of scientific argumentation can be judged and accepted differently by the different participants in the discourse (Belland et al., 2008), because the background knowledge and beliefs of the discourse partner(s) can influence their argumentation.

As such, scientific evidence plays a major role in discovering new scientific claims, justifying existing claims, and persuading others of the claims, or disproving and refuting existing claims, not only in actual experimental research, but also in thought experiments and argumentation activities. However, the roles and characteristics of evidence have been differentially defined depending on the background and field of study (Fox, 2011, p. 157). Therefore, this study strives to outline the nature of scientific evidence in a more comprehensive way, and to discuss its implications for teaching scientific activities to develop students' evidence-based reasoning.

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Research Purposes

The first research purpose is to extract and identify various aspects of the nature of scientific evidence (NOSE) in diverse studies by examining how data, evidence, and claims were related and processed by scientists or students in scientific or everyday contexts. The second purpose is to organize various aspects of NOSE into a structured framework and to discuss the implications of this framework for science teaching.

Research Methodology

General Background

To elucidate the NOSE, this study reviewed articles and books explaining how scientists or students explore, interpret, and utilize scientific evidence in the context of scientific research or science learning. In the case of systematic literature reviews, researchers select literature related to their specific research questions, then analyze, evaluate, and synthesize the literature in systematic and rigorous ways to find answers to the research questions (Davies et al., 2013; Okoli & Schabram, 2010). In this approach, researchers select all studies related to the research questions, analyze them comprehensively through a quantitative meta-analysis, and identify the general trend of the studies with the purpose of suggesting new directions of research.

On the other hand, some researchers utilize a semi-systematic review approach with the intention to identify new research themes or generate new research questions that emerge from the qualitative interpretive method (Snyder, 2019). In this process, rather than reviewing all studies related to the research question, researchers determine the scope and criteria of literature and develop codes or categories to represent the major characteristics of the reviewed literature within the determined scope and criteria. This study used the semi-systematic review approach to elucidate the characteristics of scientific evidence.

Selection Process of Literature

For the semi-systematic review, as there are different ways that studies can be selected from the existing literature, it is important for researchers to clearly establish the selection criteria according to their particular research problems and intentions (Davis et al., 2006). In this study, three contexts were focused for literature selection: research by scientists in scientific contexts, inquiry activities by students in scientific contexts and inquiry activities by students in everyday contexts. To understand the NOSE, this study began with several articles and books which explicitly demonstrated how scientists and students used evidence in the above three contexts. Table 1 lists some of the initially selected studies. The scope of the literature review was extended by exploring the references cited in the reviewed literature, as well as by searching for more studies in the three contexts using search engines such as 'Academic Search Complete' and 'Google Scholar' with specific keywords such as 'evidence-based thinking', 'roles of evidence', 'claim and evidence', etc.

Table 1
Examples of Initial Literature Selected to Examine the Characteristics of Scientific Evidence

Context		Examples of selected literature
Scientist	Scientific context	- Lakatos (1994): described the process by which Bohr's initial incomplete atomic model was developed through articulation and refinement based on conflicting evidence. - Franklin (1997): looked into how data was selected, transformed, and interpreted in Millikan's experiment. - Park et al. (2001): based on the history of physics, explained roles of logical results (as evidence) obtained through thought experiments in suggesting new ideas, rejecting old ideas, suggesting dilemmas, etc.

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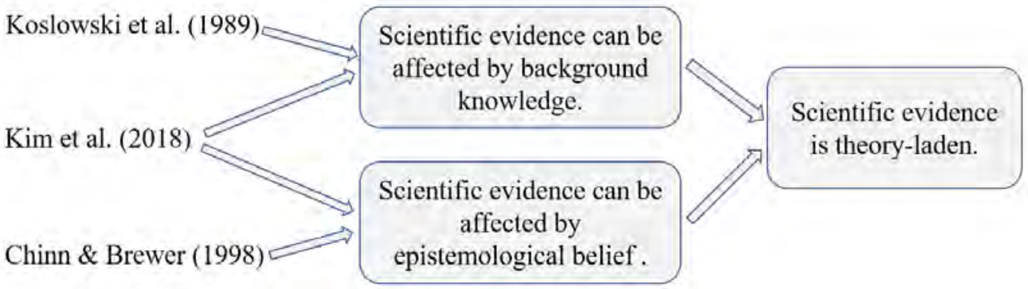
Context		Examples of selected literature
Student	Scientific context	- Achinstein (1978): suggested three types of evidence to determine whether jaundice could be evidence of cirrhosis of the liver. - Kim et al. (2018): using Boyle's actual data, examined whether students' background knowledge and epistemological belief could affect their use of evidence. - Park et al. (2001): analyzed students' various responses when they were provided with supporting or conflicting evidence.
	Everyday context	- D. Kuhn et al. (1988): in the situation where children ate certain foods and caught a cold, questioned whether students drew claims based on evidence or their background knowledge. - Koslowski et al. (1989): in various situations, such as the relationship between gasoline additives and fuel efficiency, analyzed various factors that could affect the use of evidence.

The Process of Identifying the NOSE

Articles and books were selected based on the three contexts to analyze and discuss the role and use of scientific evidence. From this process, the major characteristics of NOSE were extracted from the selected literature. For example, from Franklin's paper (Franklin, 1997) which examined the process of Millikan's experiment, the following statement was extracted: "scientific evidence and the data are not the same because scientific evidence is made after the data is selected or transformed." Through this process, multiple characteristics of NOSE were identified from a single paper or book, and similar characteristics from different studies were combined into a single characteristic. This process was repeatedly carried out to finalize the characteristics that represented the NOSE. These final statements of the characteristics of NOSE were again categorized into common properties and re-represented as single representative statements, as presented in Figure 1.

Figure 1
Example Statements Describing the NOSE from the Literature



After determining the NOSE into seven statements, an additional literature search was conducted to verify the statements of the characteristics of NOSE. In this process, it was examined whether the characteristics of scientific evidence in the new literature could be explained by the seven NOSE statements extracted through the previous process. In this process, some statements of NOSE were modified with new ideas, but there were no major changes. That is, the seven statements of NOSE could explain the context, roles, and characteristics of the evidence in other science studies.

Then, the seven NOSEs were combined into a single diagram in a structured form to comprehensively depict the process of scientific evidence-based reasoning. Based on this structured form of the NOSE statements, educational implications of the NOSE were discussed for teaching science in schools.

Research Results

Based on the literature review, seven statements were developed to describe the Nature Of Scientific Evidence (NOSE). This section explains each NOSE statement.

NOSE 1: Scientific Evidence is Distinct from Explanatory Theory

Kuhn et al. (1988) stressed that the core of scientific thinking was coordination between evidence and theory (or idea), and that it was critical in scientific reasoning to distinguish evidence and theory. In their study, theory included the ideas, beliefs, background knowledge, and experiences of the scientific inquirer(s). To understand the relationship between evidence and theory, they conducted a study on how students used and interpreted data as evidence to make claims. To this end, researchers used various picture cards showing certain foods children had eaten and indicating whether or not they had caught a cold. Researchers then asked students to analyze the picture cards and make claims about the relationship between the food type and catching a cold.

In this study, Kuhn et al. (1988) classified students' claims into two categories: the evidence-based response and the idea-based response (or the theory-based response). The 'evidence-based response' occurred when students used the information on the picture cards to make a claim, while the 'idea (or theory)-based response' occurred when students used their own daily experience or background knowledge that had not been presented on the picture cards. The researchers observed that some young students showed the idea-based response, and they explained that this response was because young students failed to distinguish ideas from evidence (Kuhn et al., 1988).

In the case of idea-based response, students focus on their own theories or claims to explain phenomena rather than evidence. For example, in the study by Kuhn et al. (1988), after viewing picture cards showing that children who ate oranges with other food did not catch a cold, students made an idea-based response that 'children did not catch a cold because oranges have vitamin C which was good for preventing a cold'. In this case, students did not analyze the information on the picture cards in detail, instead they explained their own ideas by using their background knowledge of oranges as sources of vitamin C, which helped prevent colds. However, based on the available evidence, this claim may not be correct, because according to the picture cards, the children who did not catch a cold also ate other foods in addition to oranges. That is, based solely on the picture cards, it was not clear if the children did not catch a cold because of eating oranges or because of eating the other foods. Therefore, before making their claims, these students needed to examine the data provided on the picture cards as evidence in further detail.

Such biased responses based on ideas can be found in other studies. Yang (2004) explored high school students' claims of whether the use of underground water affected ground subsidence, and they found that some students did not express the need for evidence and only explained their claim based on their background knowledge; Klaczynski (2000) called this 'theory-motivated' reasoning.

If someone makes only an idea (or theory)-based response without making an evidence-based response, they may miss the opportunity to recognize that the initial claim could be wrong (Kuhn & Pearsall, 2000). For example, Park et al. (1993) used evidence about whether the shadow of an object was affected by the shape of the light source or the shape of the object. Before observing the evidence, some middle students predicted that the shape of the shadow was determined by the shape of an object; however, some of the evidence indicated that the shape of the light source affected the shape of the shadow. When observing the evidence, some students who gave solely idea-based responses did not change their claims, as they failed to recognize the conflicting evidence. Therefore, Klaczynski (2000) also noted that when 'theory-motivated' reasoning was made, conflicting evidence was likely ignored or refuted, and the existing claims could be sustained.

The fact that evidence is critical to making claims in scientific reasoning does not mean that idea-based responses are not important. 'Idea-based response' takes an explanatory role in making claims by describing the causal relationship between the evidence and the claim. To emphasize the explanatory role of idea-based response, this study adopts the term, 'explanatory theory', instead of 'idea' or 'theory', as shown in Figure 2:

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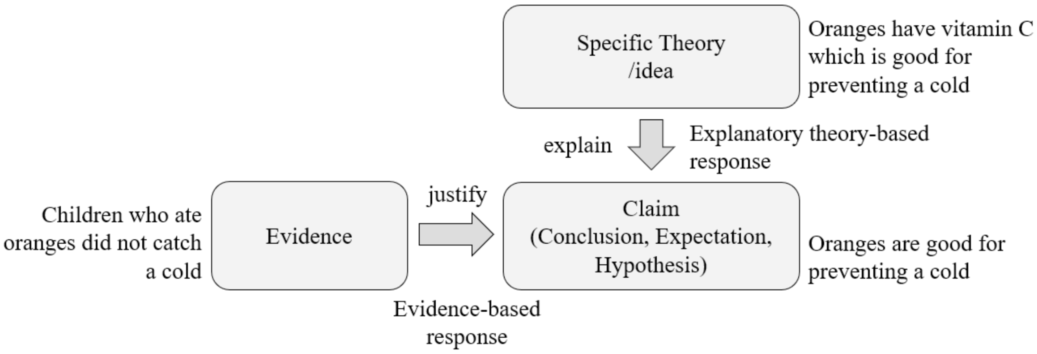
Figure 2

Evidence-Based and Explanatory Theory-Based Responses



The explanatory theory serves to explain why an event has happened. For instance, if students had only used the information on the pictures to make a claim that the oranges could prevent cold, without providing any explanation for the causal relationship between them, then the claim could not be sufficiently justified. Conversely, as mentioned earlier, if the students responded based solely on explanatory theory without mentioning evidence, then their claim was also hard to justify. Therefore, for effective evidence-based reasoning, explanatory theory-based and evidence-based responses are necessarily complementary (Figure 2). Here, evidence-based 'reasoning' and evidence-based 'response' are used with different meanings. Specifically, evidence-based reasoning includes the explanatory theory-based response as well as the evidence-based response.

The importance of explanatory theory in evidence-based reasoning is well illustrated in Achinstein (1978). In a discussion of whether jaundice could be evidence of cirrhosis, Achinstein (1978) explained that jaundice could be evidence of cirrhosis based on his previously knowledge that 35 % of cirrhosis patients had shown jaundice. However, in this case, the evidence was only 'potential' evidence. By additionally providing an explanatory theory to explain the causal relationship between jaundice and cirrhosis, the potential evidence could be considered 'veridical' evidence.

The need for explanatory theory in evidence-based reasoning can also be seen in Toulmin's argumentation model (Toulmin, 1958/2003). According to Toulmin, when deriving a claim from data, 'warrant' and 'backing' serve as explanatory theories, while 'data' serves as evidence. If Toulmin's model is applied to the previous case about the relationship between oranges and colds, the claim that 'oranges are good for preventing a cold' can be made from data that 'children who ate oranges did not catch a cold', based on the background information that 'oranges have vitamin C' (warrant) and 'vitamin C is known to prevent catching a cold' (backing).

NOSE 2: Logically Driven Results can also be Scientific Evidence

In addition to observation or measurement data obtained from actual experiments, logically driven results in unrealistic situations, such as those obtained through thought experiments, can also be used as scientific evidence. For example, in Galileo's thought experiments about the speed of falling objects, he created a situation in which two objects ($W_A > W_B$) were tied together with a massless string and allowed to fall. (Figure 3). In this situation, based on Aristotle' assumption that the heavy object falls faster than the light object, he came up with two contradictory logical results: a) the tied object ($W_A + W_B$) would fall faster than W_A because of the increase of overall weight, and b) the tied object would fall faster than W_B but slower than W_A because of a retarding effect created by W_B, which would cause it to fall slower. Galileo used these two possible but contradictory results to reject Aristotle's claim (Park et al., 2000).

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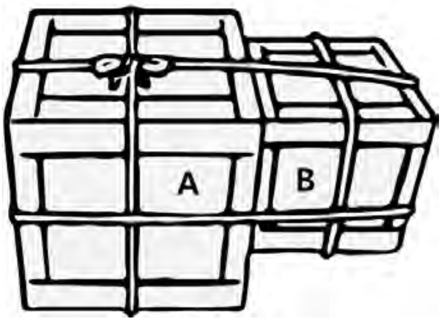
Figure 3
Galileo's Thought Experiment



Logical results obtained from thought experiments have long been used as evidence because there are and have been many scientific situations in which actual data cannot be experimentally obtained. For example, in Figure 3, Galileo could not make a vacuum state to observe falling objects without air resistance, nor could he exactly measure the falling time. Even in modern times, it is difficult to create many ideal conditions, such as infinite distance, zero size, and constant, uniform, or ignored volume, in the real world (Song et al., 2000).

In other study, Park and Han (2002) adopted logical results obtained by deductive thinking as evidence. They presented a deductive logic task to middle school students who had the misconception that 'when the ball thrown vertically upward is moving upward, there is an upward force acting on that ball' (Figure 4) and examined whether the logical result of the deductive task served as evidence to change the students' misconception. As a result, the students, who were able to derive the logical result that force acts on a ball in the downward direction when it moves vertically upward in Figure 4, corrected their misconception.

Figure 4
Logical Deductive Task (Park & Han, 2002; Lee & Park, 2013)

Premise 1: If an object is moving more and more slowly, then the net force acts on that object in the opposite direction to that of its motion.

Premise 2: A ball that is thrown vertically upward is moving upward more and more slowly.

NOSE 3: Scientific Evidence is often Different from Raw Data.

Data and evidence are often discussed without a clear distinction, but strictly speaking, evidence and data are different (Brown et al., 2010; Sampson et al., 2013). That is, scientific data is often used as evidence after being selected, transformed, and analyzed.

Franklin (1987) analyzed Millikan's oil drop experiments and found that not all measured data were used as evidence: In Millikan's work published in 1923, he only used 58 data to support his claim from the 175 data measured since 1911. Among the data that he did not use, two were discarded because the device used to obtain the data was not appropriate, twelve were discarded because theoretical corrections were necessary to accept these data, six were discarded because they differed from his expectation, twenty-two were discarded without even being calculated for their charges, and five were discarded simply for being considered in some way insufficient (Franklin, 1987).

Some evidence can be presented after the initial data are transformed. In Millikan's oil drop experiment, he measured the time and distance of oil drop when they fell; the measured data were calculated to obtain the value of the electrical charge, and the calculated values were used as evidence to claim that the electric charge had a minimum value.

In some cases, evidence is obtained by interpreting data using inquiry skills, such as controlling variables. For example, when only Table 3[a] is given to students, some students tend to conclude that 'variable A2 affects

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variable B'. However, this conclusion is premature, because in the absence of variable A1, variable A2 may not affect variable B. For example, if data such as that in Table 3[b] is additionally presented, then the above conclusion cannot be correct.

Table 3

Relational Data between Independent and Dependent Variables

[a]

Independent Variable A		Dependent variable B
Variable A1	Variable A2	
Exists	Exists	Changes
Exists	None	Does not change

[b]

Independent Variable A		Dependent variable B
Variable A1	Variable A2	
None	Exists	Does not change
None	None	Does not change

Statistical analysis is often required in the process of using data as evidence. For example, when a treatment is administered to an experimental group, to claim that the treatment really works compared to the control group, researchers must carefully compare the standard deviation and standard error values as well as the mean values of the two groups. This is a to prevent accidental differences from being misunderstood as important differences.

NOSE 4: Scientific Evidence is Theory-Laden

In the process of drawing claims from evidence, scientific evidence is influenced by the individual's background knowledge, expectation of the experimental results, experience, epistemological beliefs, etc. For example, Koslowski et al. (1989) used data including information that gasoline additives had nothing to do with car fuel efficiency. When, together with the evidence, they provided students with additional information (background knowledge) stating that 'gasoline additives could contain impurities that could completely interfere with combustion', they observed that an increasing number of grade nine and college students made claims that gasoline additives affected fuel efficiency. This result showed that background knowledge influenced the interpretation of evidence.

Kim et al. (2018) used data from Boyle's experiments (Langley et al. 1987, p. 82) showing that air pressure and volume were not exactly inversely proportional. They then presented these data to two groups of student teachers, groups A and B. However, the information that the data were about air pressure and volume was provided only to group A. The research findings showed that group A was more inclined to claim that the two variables were inversely proportional, even though the data did not exactly show this trend. Regarding this phenomenon, Fox (2011, p. 154) said that "evidence is frequently identified and interpreted through the lens of a particular theory".

Belief also affects the use and evaluation of evidence. Achinstein (1978) observed that although there were data showing probabilistic relationships between jaundice and cirrhosis as well as theories explaining the possibilities of a causal relationship between them, if the researcher as a decision maker did not believe these data and theories as evidence, then the symptoms of jaundice might not be taken as evidence for the diagnosis of cirrhosis.

The effect of belief is often observed in school science when evidence is inconsistent with the student's idea. For example, Chinn and Brewer (1998) found that some students did not believe conflicting evidence for various reasons, such as attributing it to methodological error, lack of sufficient data, or inaccurate measurement. In addition to these factors, there was also a belief that 'science can always be wrong'.

A similar example can be seen in learning relativity theory: Students might not accept the logical results of length contraction or time dilation obtained through thought experiments as evidence due to their commitment to a mechanistic worldview (Dimitriadi & Halkia 2012). According to Kim et al. (2018), when Boyle's actual data showing that air volume was not exactly inversely proportional to air pressure were presented, students who believed that 'science should be exact to understand nature' drew a complex formula (e.g., $y=26.35x^{-0.915}$) for the two variables. However, other students who believed that 'scientists need to find out simple regularity' suggested simple formulae (e.g., $y \propto 1/x$) based on the given data. In other words, students' different epistemological beliefs influenced how they analyzed and transformed the data as evidence, and these variations resulted in different claims.

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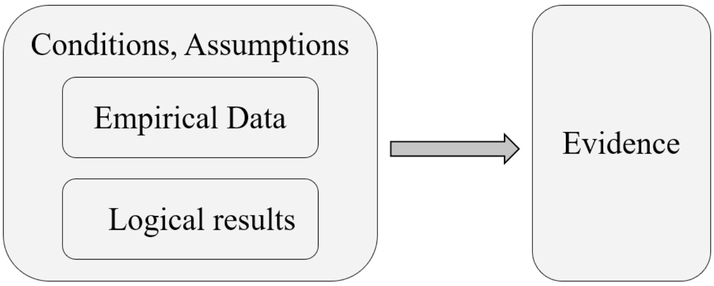
NOSE 5: Scientific Evidence is Context-Laden.

Scientific evidence is also affected by the context in which the data was obtained. That is, scientific evidence is influenced by the assumptions, conditions, and situations included in the experimental context. For example, data on the relationship between the electric current and voltage on a resistor can be used as evidence for the claim that 'the electric current is proportional to the voltage'. However, this claim is only correct when the following condition is satisfied: 'No heat is generated on the resistor, so the value of resistance does not change during the experiment'. In addition, to use the measurement results of incident angles and refraction angles to obtain the refractive index value of the material, the value of the wavelength of light should be identified. This is because, even if the incident angle is the same, the angle of refraction of the material varies with the wavelength of light.

According to the research program by Lakatos (1994), scientific knowledge includes not only the core of theories, but also a protective belt consisting of assumptions, auxiliary hypotheses, and the situation and conditions related to the core of the theories. Similarly, when data is used as evidence, it is necessary to clarify the context and process in which the data was obtained.

Logical results as evidence are also processed along with assumptions or certain conditions that act as contexts of logical thinking (Figure 5). For example, in Galileo's thought experiment in Figure 3, 'the heavy object falls faster than the light object' and 'the two bodies are tied with weightless strings' are background assumptions or conditions:

Figure 5
Evidence with Conditions and Assumptions



Clarifying the contexts in which data is collected can guarantee the validity or reliability of the scientific evidence. Nicolaidou et al. (2011) noted that the reliability of evidence could be determined by the sources of the evidence as well as the data collection methods used. The reliability of the sources of evidence can be obtained by questioning those who collected the data and determining whether a peer evaluation was conducted or whether any bias was involved. The reliability of how evidence has been obtained can also be assured by assessing whether the data can be replicated, whether the variables have been correctly controlled, or whether data for counterclaims have been compared. All these conditions are critical to examine and use scientific evidence, because 'scientific evidence is context-laden'.

NOSE 6: Evidence that Supports a Claim cannot Guarantee the Truth of the Claim

When evidence supports a claim, it is often concluded that the claim is true. However, confirming a claim is not logically warranted because this process corresponds to the 'affirmation of the consequent' in the syllogism of deductive logic. In other words, as shown in Figure 6, even though the two premises given in the syllogism are true, we cannot logically conclude that 'This is A'. Likewise, in Figure 6, we cannot conclude that 'hypothesis H is correct' despite the presence of supporting experimental result R (Park et al., 2001).

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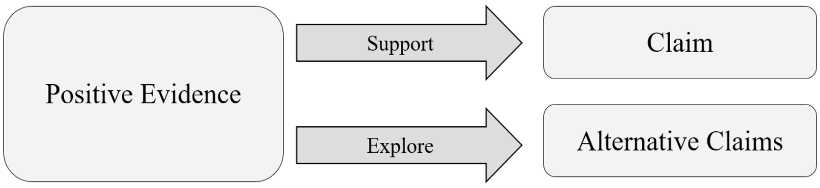
Figure 6
The Syllogistic Structure of 'Affirmation of the Consequent' and Confirming Hypothesis

[Syllogism]
Premise 1: If A, then B
Premise 2: This is B

[Confirming Hypothesis]
Premise 1: If scientific hypothesis 'H' is correct, then experimental result 'R' is expected.
Premise 2: In this experiment, 'R' is observed.

The reason why a claim cannot be guaranteed to be true even if evidence supports it is because some evidence can be used to support other claims (Lawson, 1995, p. 361). For example, observational evidence that the sun rises in the east in the morning may be used as evidence to support the heliocentric model, but it may also be used as evidence to support the geocentric model. Therefore, even when supporting evidence is obtained, researchers need to explore other possible claims that can be supported by the same evidence (Figure 7).

Figure 7
Positive Evidence Can Support a Claim and Can Also Draw an Alternative Claim

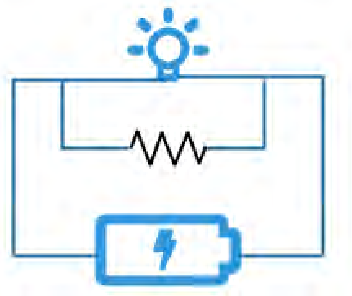


Regarding NOSE 6, Popper (1968, p. 19) noted that, "My proposal is based upon an asymmetry between verifiability and falsifiability; … For these are never derivable from singular statements [that is, verification cannot be possible], but can be contradicted by singular statements [that is, falsification is logically possible]".

Nevertheless, when students obtain scientific evidence that supports a claim, they often make the 'error of affirmation of the consequent'; that is, they draw the erroneous conclusion that 'the claim is correct' (Park et al., 2001). This logical error is also observed in the case of scientists. For example, Kern et al. (1983) found that when they presented a syllogism task to 72 psychologists, biologists, and physicists, about 30% of the subjects made the 'error of affirmation of the consequent'.

It is interesting to note that some evidence can support students' misconceptions, such as in the case of the heliocentric hypothesis described above. In Figure 8, students often demonstrate the misconception that if they increase the resistance in the circuit, then the bulb will become brighter because the current flowing through the resistor will be reduced, thus allowing more current to flow to the bulb (Park & Kim, 1998).

Figure 8
A Simple Electric Circuit



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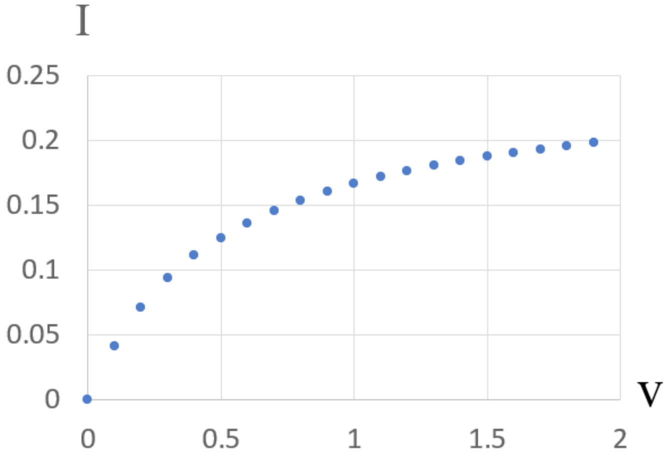
In fact, if students connect the bulb and the resistance to the actual battery and increase the resistance, they will see the bulb become brighter. However, this is not simply because 'the current previously flowing through the resistor flows to the bulb', but because of the following complex process: resistance increases → total resistance increases → total current decreases → the voltage drop by the internal resistance inside the battery decreases → the terminal voltage of the battery increases → the voltage applied to the bulb increases → the bulb gets brighter. Therefore, it is very important in the scientific reasoning process to explore the possibility of alternative claims, rather than simply concluding that a claim is correct immediately when supporting evidence is obtained (Lawson, 1992).

NOSE 7: Conflicting Evidence Can Sometimes be Used to Modify and Articulate a Claim Rather than Rejecting the Claim.

According to Popper (1968)'s falsification, if experimental evidence is inconsistent with a claim, then the claim should be rejected by the *'modus tollens'* of deductive logic. However, this simple deductive logic does not apply to real science, because each claim includes not only a core theory, but also a protective belt that consists of the initial conditions, assumptions, or auxiliary hypotheses (Lakatos, 1994). Therefore, conflicting evidence can disprove the protective belt rather than the core theory. For example, looking at the data on the voltage and current on a small light bulb shown in Figure 9, the data do not match Ohm's law. However, this data does not disprove Ohm's law, which is the core theory, because the condition that 'the temperature of the resistance should be constant' was not satisfied.

Figure 9
Electric Current and Voltage on a Small Electric Bulb



When evidence conflicts a claim in the science process, it sometimes leads to the more articulated and sophisticated development of the claim (Park, 2002). For example, Lakatos (1994, pp. 61-64) described the process of developing Bohr's initial atomic model of 1913 into a more sophisticated and articulated model when discrepant data was generated. Specifically, the initial atomic model was a model in which the nucleus was fixed, and the electrons orbited in circular orbits with constant mass; however, when discrepant data emerged, the early model was developed into a more sophisticated model wherein the nucleus orbited around the center of mass of the nucleus and electron, the electron moved in an elliptical orbit, and the mass of electrons increased to relativistic mass.

Therefore, Dirac (1979, Location 1615) mentioned that even though there was a discrepancy between Einstein's theory and well-confirmed observations, Einstein would attempt to make some modifications to deal with these discrepancies, rather than abandoning the fundamentals of his theory.

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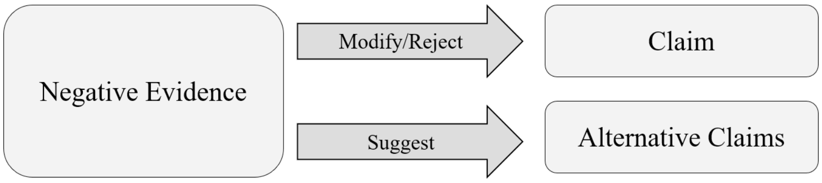
However, if a new alternative claim is invented to account for conflicting evidence, the existing claim can be discarded. Therefore, Kuhn (1970, p. 77) noted that "once it has achieved the status of paradigm, a scientific theory is declared invalid only if an alternative candidate is available to take its place". Lakatos (1994, p. 35) also stated that "[t]here is no falsification before the emergence of a better theory".

As depicted in Figure 10, scientific evidence that conflicts with a claim may help modify the existing claim, while it can also lead to the claim being discarded when new alternative claims are suggested.

Figure 10

Modification of Existing Claim or Suggestion of New Alternative Claim in Response to Conflicting Evidence



Discussion

After reviewing the examples of working with evidence in scientific activities by scientists and students, this study suggests seven characteristics describing the nature of scientific evidence (NOSE); these are listed in Table 4. In addition, Figure 11 shows the structured form obtained by integrating the seven NOSE statements. This structured form mainly consists of four types of elements - data, evidence, background theories, and claims - and represents how each element is connected, and it also indicates which NOSE is reflected at each element or connection. For example, Figure 11 indicates that background theory (background knowledge, epistemological beliefs, and experiences) affects (NOSE 4) the selection, transformation, and analysis of the data to make it into evidence (NOSE 3). In this section, how to guide students to use scientific evidence based on the 7 NOSE statements will be discussed.

Table 4

Seven Elements Describing the NOSE

Type	NOSE
NOSE 1	Scientific evidence is distinct from explanatory theory.
NOSE 2	Logically driven results can also be scientific evidence.
NOSE 3	Scientific evidence is often different from raw data.
NOSE 4	Scientific evidence is theory laden.
NOSE 5	Scientific evidence is context laden.
NOSE 6	Evidence that supports a claim cannot guarantee the truth of the claim.
NOSE 7	Conflicting evidence can sometimes be used to modify and articulate a claim rather than rejecting the claim.

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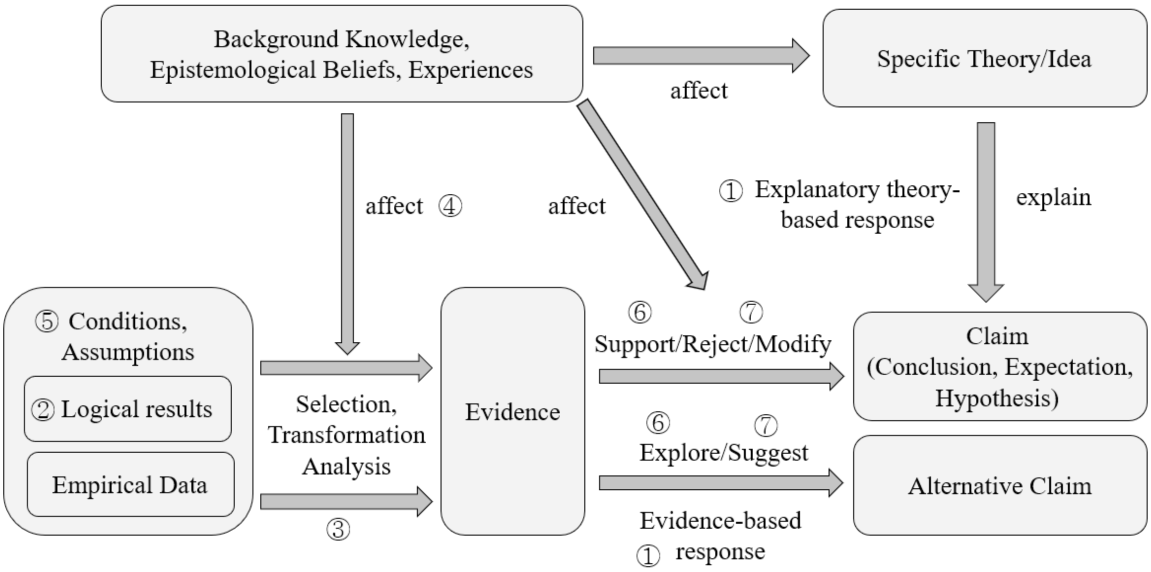
Figure 11
Structured Form of Evidence-Based Scientific Reasoning Reflecting the NOSE Statements



* Number indicates the number of the NOSE statement in Table 4.

NOSE 1 stresses that it is important to distinguish between explanatory theory and evidence. Therefore, to help students distinguish evidence from explanatory theory and respond based on evidence first, the question "How did you come to that claim?" can be more helpful than "What is your claim?" (Kuhn & Pearsall, 2000). More explicitly, the question, "How does your claim relate to the given data?" would be more helpful for the evidence-based response. Secondly, the question, "Why do you think so?" or "Explain your claim using explanation theory" can be used to draw an explanatory-theory based response. That is, these questions can make students think about the causal relationship between evidence and claim.

According to NOSE 2, logically driven results obtained through thought experiments can serve as scientific evidence. Computer simulation has recently emerged as one of the main types of scientific inquiry. For example, scientists often use simulations to explore topics for which it is difficult to conduct real experiments, such as climate change and global warming (Chinn & Malhotra, 2002). In school science, students also conduct educational simulations to explore phenomena that can occur in situations where variables cannot be actually manipulated, in dangerous or imaginary situations, or in situations that require a long time. Therefore, the ability of students to obtain, interpret, and use evidence from a simulation also needs to be considered as an important aspect of evidence-based reasoning.

NOSE 3 indicates that data become evidence after selection, analysis, or transformation; this process requires the use of various inquiry skills. Therefore, when reasoning based on scientific evidence, it is necessary to teach together various inquiry skills, such as controlling variables, constructing or interpreting tables or graphs, calculating numerically, and analyzing data statistically (Gott & Duggan, 2008). Big data has recently been emphasized as an important source of scientific evidence (Chinn & Malhotra, 2002), so a student's data processing ability to extract useful and purposeful data from big data and analyze them also needs to be addressed to develop evidence-based reasoning in school science.

According to NOSE 4, scientific evidence is influenced by various background theories, such as background knowledge, epistemological belief, or experience. Therefore, even when presenting the same evidence, science teachers need to recognize that students may draw different evidence-based claims depending on their background theories. In such cases, it is important to examine what and how student's background theories have influenced their claims. For example, in the case of data analysis related to Boyle's law (Kim et al., 2018), the question, "How can you make claims about the relationship between two variables, if you do not know that this data is about variables of air pressure and volume?" can be asked. This question can help students realize that while background theories can help claims, they can also lead to biased claims.

NOSE 5 recommends that students examine and clarify the circumstances or conditions in which the evidence has been created because the evidence depends on the context in which the data were obtained. For example, when pushing an object on a desk, it is important to check whether the friction on the desk is negligible to obtain the relationship between the pushing force and acceleration of the object. In addition, checking the context in which data have been obtained is important to ensure the reliability of any corresponding evidence. However, students often fail to check this aspect. For example, when Diezmann and Watters (1998) examined an activity in which children aged 6–7 were asked to make claims about the colonization of Mars using various related information, they observed that children lacked the ability to verify the reliability of the evidence when using various information as evidence.

Through thought experiments, logically 'valid' results can be obtained regardless of whether the conditions or assumptions are 'true' or not. That is, if there are some errors in the conditions or assumptions, logically 'valid' but not 'correct' evidence can be obtained. Therefore, when students use logical results as evidence, it is necessary to check not only the logical thinking itself, but also the conditions and assumptions behind the logical process and results.

NOSE 6 emphasizes that the truth of a claim supported by evidence cannot be guaranteed. This is because alternative claims supported by the same evidence may be possible as well. Therefore, when students obtain supporting evidence from their inquiry activities, it is necessary to encourage them to keep skeptical and critical attitudes so that they can explore whether or not alternative claims are possible. That is, rather than choosing only one 'right' claim that can be explained by evidence, it is necessary to encourage students to consider and suggest multiple possible claims. This encouragement can also help students develop creative thinking. In this process, students may choose a 'most plausible' claim by comparing different claims and criticizing the rationale for each claim.

According to NOSE 7, conflicting evidence may be used to articulate and develop a claim rather than reject it. However, if a new claim that can explain the conflicting evidence is suggested, then the existing claim can be discarded. Therefore, when students obtain conflicting evidence, it is necessary to encourage them to explore the following various activities: First, students need to examine the validity and reliability of scientific evidence, as described in NOSE 5. That is, it is necessary to begin by ensuring that the assumed conditions or assumptions are satisfied in the process of obtaining evidence, and that there are no errors in the process of obtaining evidence. In this step, if it is assured that the evidence is valid and reliable, then the evidence can be accepted.

Next, the following two efforts are required as the second step: First, rather than rejecting the existing claim by accepting conflicting evidence, it is necessary to explore whether the existing claim can be articulated and refined in such a way that can explain the contradictory evidence. For example, for the small bulb in Figure 9, the initial claim, I=V/$R_0$$I = V/R_0$, can be modified to I=V/[R_0(1+αV)] by changing the relationship such that the resistance increases with voltage.

Second, it is necessary to explore whether there are alternative claims that can explain the conflicting evidence. If there is an alternative claim that can explain the conflicting evidence, and that alternative claim is incompatible with the existing claim, then the existing claim can be discarded while accepting the alternative claim. In this process, reasonable criteria can be used to accept an alternative claim. For example, Lakatos (1994, p. 32) proposed the following criteria for selecting alternative claim: (1) T′ [alternative theory] has excess empirical content over T [existing theory], (2) T′ explains the previous success of T, and (3) Some of the excess content T′ is corroborated. However, students can also use unreasonable criteria such as 'authority' or 'approval by others' (Huber et al., 2019; Sanz-Menéndez & Cruz-Castro, 2019; Walton et al., 2008). Therefore, teachers need to recommend logical and coherent criteria for accepting or selecting alternative claims.

Conclusions and Implications

Since evidence-based scientific reasoning has been emphasized as a form of reasoning that characterizes scientific thinking, many researchers have sought to understand the evaluation process of scientific evidence and developed various strategies to help students develop their evidence-based scientific reasoning. However, it is not simple to answer questions such as, "What is scientific evidence?", and "What and how should teachers teach students for evidence-based scientific reasoning?". This is because the process of evaluating and utilizing scientific evidence differs in various situations of scientific activities, and it has many different characteristics. Therefore, it is necessary to comprehensively clarify the nature of scientific evidence (NOSE).

This study re-analyzed the research that explored the use of scientific evidence by scientists or students in science or the everyday context, and ultimately extracted seven NOSE statements from the re-analysis. The seven NOSE statements represent the main features found in the process of obtaining evidence from data, deriving claims based on evidence, supporting or discarding the existing claim or proposing alternative claims when the evidence is consistent or inconsistent with the claims.

In addition, this study drew a structured form consisting of seven NOSE statements. Based on this structured form, it further discussed teaching implications for student scientific activities. This structure helps teachers determine which parts of NOSE are well performed and which parts are not when students attempt to derive or verify claims based on evidence. Thus, this structure can also be utilized as an evaluation tool or a guiding tool for student scientific evidence-based reasoning.

However, this study has certain limitations. Even though a lot of literature was analyzed to extract the NOSE statements, no literature review can be complete, and it cannot be asserted that the seven NOSE statements extracted in this study can cover all aspects of NOSE in scientific activities. Therefore, more literature analysis is required, and it is expected that additional literature reviews can modify and refine the seven proposed NOSE statements. However, at least, the results of this study can serve as a useful starting point for further research into the nature of scientific evidence (NOSE).

Declaration of Interest

Authors declare no competing interest.

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