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Using observation and measurement data in the constructing scientific explanations among elementary pre-service teachers

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Abstract
Observing phenomena and constructing scientific explanations is an essential for a student, as well as for a teacher. This case study was conducted through one-on-one interviews to gain the process of constructing a scientific explanation, an in-depth understanding of the impact of observation and measurement data. The participants of this study were four elementary pre-service teachers who non-science majored. The participants observed footage of the burning process of a candle in an airtight glass container and constructed scientific explanations in the process of verifying the measurement data. The measurement data used in this study were obtained through measurement experiments with Arduino and sensors, which measured changes in temperature, humidity, pressure, oxygen, and carbon dioxide concentrations during the burning of candles. Participants described their thought processes aloud in the process of checking observation and measurement data. Each participant performed the same protocol procedure. Along the way, we were able to identify patterns in the use of observational and measurement data on how scientific explanations are constructed. Through the case analysis of this study, we suggested a model for the construction of scientific explanations in the process of using observational data.

Keywords: constructing scientific explanation model, elementary pre-service teacher, measurement data, scientific explanation

INTRODUCTION

The ability to observe scientific phenomena and construct evidence-backed scientific explanations is essential for scientific inquiry (Duschl & Osborne, 2002; McCain, 2015; National Research Council [NRC], 2012). Recent science education perspectives emphasize science practices through the integration of scientific inquiry and scientific knowledge. The production of scientific explanations is crucial to building scientific knowledge for students (McNeill et al., 2006; Sandoval & Reiser, 2004; Zangori & Forbes, 2013, 2014).

A scientific explanation consists of what, how, and why (Chin & Brown, 2000; McNeill et al., 2006; Osborne & Patterson, 2011). Therefore, many studies have been conducted on analyzing the explanation objects, its causes, and the reasoning that connected them (Cooper, 2015). Further, extensive research has been performed on how to construct scientific explanations, including describing phenomena in more detail, using data and evidence such as scientific knowledge, interpreting the data generated, and writing scientific explanations (NRC, 2012). These studies disclosed that students have difficulty observing phenomena and constructing scientific explanations for them (McNeill & Krajcik, 2008; Osborne & Patterson, 2011). Various scaffolding attempts have been devoted to increasing this awareness for constructing scientific explanations. Several approaches have been developed to help students explain scientific concepts, including online programs and writing frameworks (Lucas et al., 2022; Masters & Docktor, 2022; McNeill et al., 2006; Sandoval & Reiser, 2004; Wang, 2015).

A recent study revealed that the explanations teachers provide in science classrooms directly affect students' understanding and conceptual knowledge

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Contribution to the literature

- In this study, we provide a detailed analysis of how observation and measurement data were used to construct scientific explanations.
- To accomplish our goal, we have developed and implemented data collection protocols for the application of case studies.
- We developed a model for the construction of scientific explanations based on observation and measurement data by discussing the results of the study.

formation. Their findings indicate that students and teachers need help with scientific explanations and that teachers in science classrooms usually explain topics using textbooks or by referring to relevant knowledge (Crawford, 2000; Lizotte et al., 2004; Masters & Rogers, 2018). Because elementary school teachers teach multiple subjects, it is crucial to explore their characteristics of constructing scientific explanations in a science context.

The purpose of scientific explanation is to make sense of natural phenomena that can be observed scientific explanations of natural phenomena are based on observation (McNeill & Krajcik, 2008) and to understand and explain phenomena through the five senses, one must understand microscopic phenomena (De Andrade et al., 2020; Cooper, 2015; Taber, 2013). Microscopic conceptualization is commonly used to explain scientific phenomena. According to the observer's prior knowledge and the methods of reasoning, scientific explanations are constructed differently. To encourage student participation in science practices, NGSS Lead States (2013) recently selected and presented phenomena that can be used as strategies such as candle trick. Because chemical and physical phenomena are involved, it can be explained in various ways.

Although numerous studies support scientific explanations, microscopic phenomena remain difficult to be explained scientifically. Therefore, we have taken note of recent trends such as the use of digital devices and various changes in the educational field. Approaches to scientific measurement methods can be made using open-source tools such as Arduino and low-cost sensors (Grinias et al., 2016; Papadimitropoulos et al., 2021). In other words, science, especially chemistry education, is associated with microscopic phenomena (Taber, 2013), which means that measurement data can also influence scientific explanations. Thus, we could rethink scientific explanations that have already been developed.

Data visualized by measuring microscopic phenomena can shed new light on scientific explanations constructed on the basis of existing observations and interpretation of accumulated knowledge. For example, the burning of candles involves temperature changes and flame extinguishing. Previous research has often been based on asking students to construct an explanation by presenting them with questions about phenomena (Lee & She, 2010; Prieto et al., 1992; Watson et al., 1997). Focus of these studies was for students to observe, deduce, and explain the phenomenon of combustion. But it can be assumed that by visualizing and measuring changes in invisible phenomena, students can give a richer explanation in addition to observing the phenomenon. In other words, when measuring chemicals, changes in concentration can be used for scientific explanations. It is important to analyze how measurement data affects scientific explanations, because the ways in which measurement data affect scientific explanations can differ from the ways in which scientific explanations rely solely on observation.

In this study, observation and measurement data regarding candle burning are presented to elementary pre-service teachers (PSTs) who did not major in science for an in-depth understanding of the construction of scientific explanations using observation and measurement data using Yin's (2009) case study approach. Yin's (2009) qualitative analysis clarifies the nature of the case and guides systematic analysis. We, therefore, did not focus on evaluating scientific explanations or analyzing who gave the highest-quality explanations. The central questions of this study are: First, when and how do participants use observation and measurement data in the process of constructing their descriptions? Second, how are the explanations that participants construct in the process of checking their observation and measurement data reflected in the scientific explanation?

Theoretical Framework

Scientific explanation

Scientific explanations can be divided into three categories: ontological, causal, and epistemological (Osborne & Patterson, 2011). The hypothesis-deductive examination of science education includes both epistemological and causal questions because science explanations derived deductively from laws, theories, or hypotheses include causal questions. Using data and evidence to form claims about any phenomenon is vital in this method. A scientific explanation is based on causal relationships to phenomena and revolves around the cause and effect of a phenomenon (Yao et al., 2016). Consequently, the study of how we know it and explanations of why it happened dominates the analysis of how and why (Cooper, 2015).

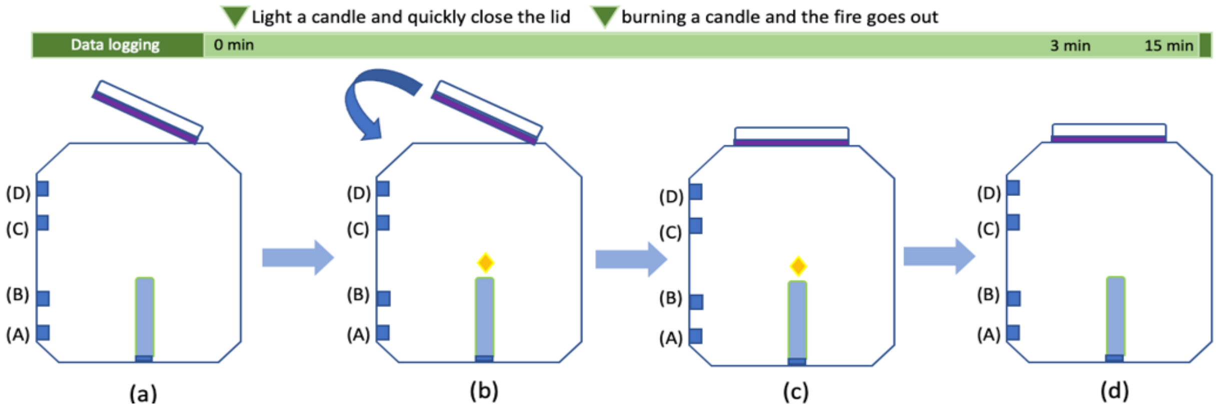

Figure 1. Experimental process for data logging ([a] before burning [b] turn on light, & lid on [approximately four seconds] [c] burning a candle [approximately 100 seconds] [d] after burning) (Baek, 2021)

To construct scientific explanations based on observing phenomena, microscopic phenomena must be understood; thus, studying the reasoning process is essential. Consequently, studies have focused on analyzing the reasoning process based on changes in concepts and evidence, evaluating how evidence influences scientific explanations, and coordinates with theory (Zangori & Forbes, 2013). A similar context exists in this study. This work, however, differs in that it provides PSTs with a concrete and empirical example of constructing prior knowledge, observation data, measurement data, and explanations.

Combustion of a candle

Several factors that contribute to the scientific explanation of candle combustion. In chemical terms, the reaction has the following formula.

$$C_nH_{2n+2}(s) + xO_2(g) \rightarrow yCO_2(g) + zH_2O(l) \quad (1)$$

That is, to burn a candle in the solid state (C_nH_{2n+2}), oxygen in the gaseous state is required. In the gaseous O_2 state, carbon dioxide and water vapor are generated from this reaction. The generated water vapor generated at this time changes into liquid water due to temperature and water vapor pressure. As a result, the combustion process of candles in a sealed glass container can be described from chemical and physical perspectives (Prieto et al., 1992). From a chemical point of view, candles burn by consuming oxygen (the reactant), generating carbon dioxide and water (the products) (Johnson, 2010). However, since candle combustion generates heat, physical explanations can also be offered for how heat enters and exits. These explanations include air expansion and contraction caused by temperature changes during candle combustion. However, this explanation relies solely on observations (Massalha, 2016; Prieto et al., 1992). Therefore, in this study, we analyzed how the scientific explanations are constructed based on measurement data, including changes in oxygen and carbon dioxide concentrations, humidity, temperature, and pressure, during the combustion process of candles.

MATERIALS AND METHODS

Research Materials

Experimental setting

The experimental apparatus and observation and measurement data collection process are shown in **Figure 1**. Experiments were conducted in an airtight glass container with a lid of 5,000 mL (Bormioli Rocco Fido purchased just before the investigation) and a white cylindrical candle with a diameter of 1.2 cm and a length of 10 cm placed in the middle of the bottom of the container. On the inner wall of the glass container, sensors were attached to four positions (A)-(D). Three types of sensors were used in this study: an environmental sensor (BME 280, environmental sensor), an oxygen concentration sensor (grove-oxygen sensor), and a carbon dioxide concentration sensor (DFROBOT CO_2 sensor) that simultaneously monitors temperature, humidity, and air pressure. Sensors were connected to Arduino Uno boards for real-time data recording. Changes in measurement parameters were recorded at least 20 times. Repeated measurements confirmed the simultaneous measurement of the oxygen concentration and environmental sensors. Therefore, an environmental sensor and an oxygen concentration sensor were used to measure the heights of the experimental subjects in this study. Additionally, carbon dioxide concentrations were measured. During each measurement, a candle was lit, capped, and burned until it was extinguished by itself, which took approximately 100 sec. In total, measurements were collected for 15 min, including the time after the candle was extinguished.

Observation data and measurement data

Observation data: Only the sensor position was displayed as observation data, while the candle-burning phenomenon occurred in the experimental device without the sensor for over 15 min. To address the same phenomenon, measurement and observation data were collected. Measurement data for this study include video

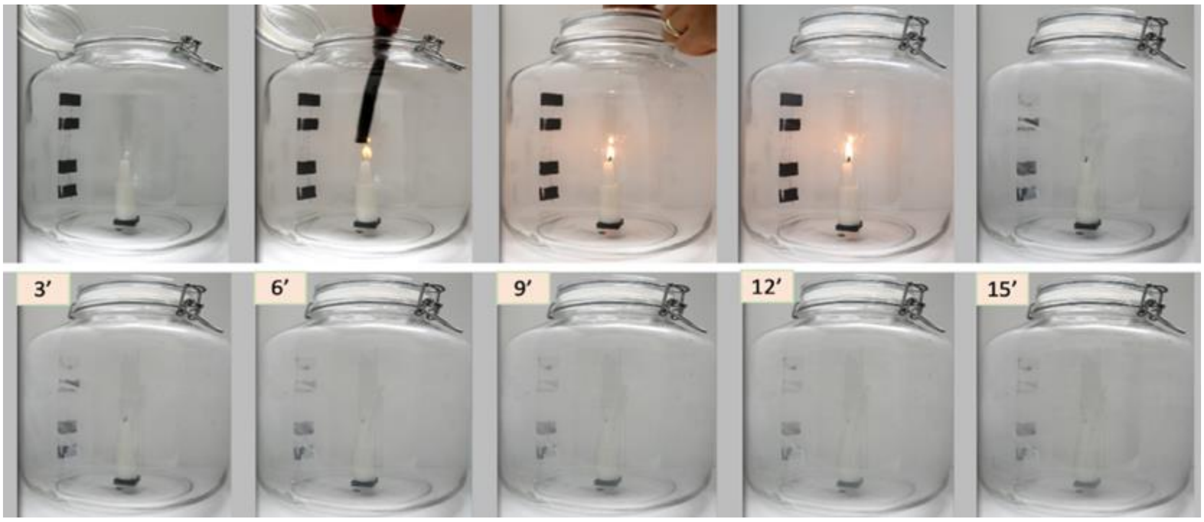

Figure 2. Observation data (above row provided VOD also) (Source: Authors' own elaboration)

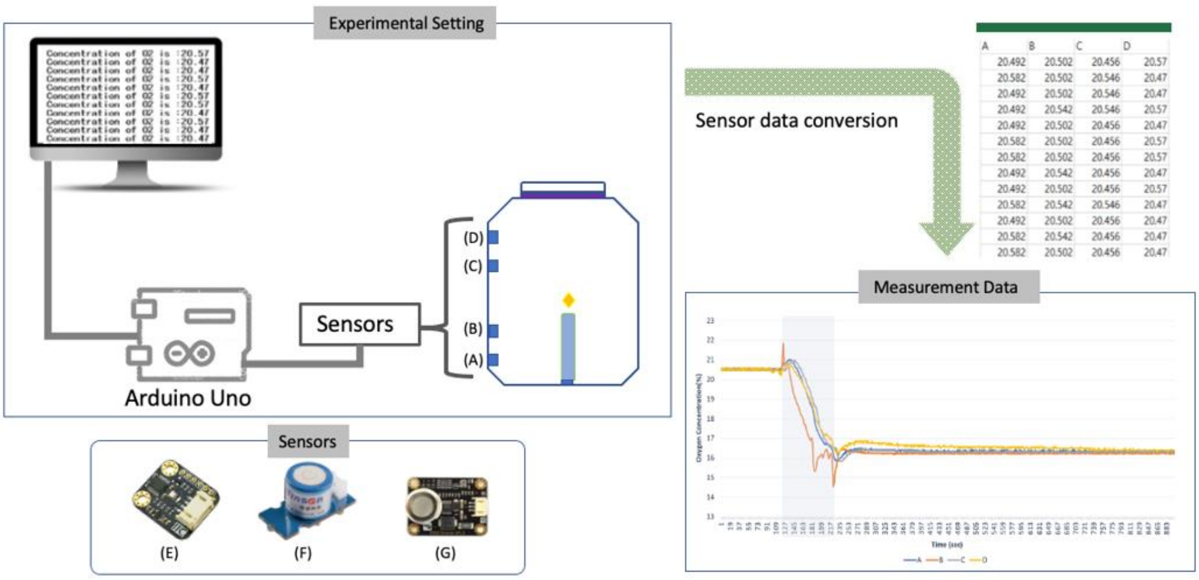

Figure 3. Measurement experiments & measurement data ([A]-[D] position of sensor, [E] temperature, humidity &, barometric pressure measurement sensor, [F] oxygen concentration measurement sensor, & [G] carbon dioxide concentration measurement sensor) (Source: [E] https://www.dfrobot.com/product-1606.html, [F] https://wiki.seeedstudio.com/Grove-Gas_Sensor-O2/, [G] https://www.dfrobot.com/product-1023.html)

recordings and photographs. The first three minutes of the video recording feature the candle-burning process. We captured the burning process from three to 15 minutes at three-minute intervals (**Figure 2**).

The top row in **Figure 2** displays the preparation of the device in the video. It also shows the lighting of the candle, the closing of the lid, and the candle burning and extinguishing, presenting the main scenes of the experiments. The bottom row shows the changes in the following three-minute intervals.

Measurement data: As shown in **Figure 3**, the measurement values for approximately 15 minutes of the candle's burning process were converted into a graph. This was called the measurement data in this study, which included temperature, humidity, air pressure, and oxygen and carbon dioxide concentration. In **Appendix A**, these measurement data are presented.

Research Methods

Participants

Four elementary PSTs who did not study intensive math and science in high school or scientific fields at the university participated in the study. The students were first-year students at college of education in South Korea's central region and had completed a semester course in department of elementary education. We used the online platform since classes at the university were online. Additionally, upon thorough examination of the provided materials, the participants demonstrated no impediments in articulating their ideas. Furthermore, it was evident that they were well-accustomed to exchanging their thoughts through the transmission of word files.

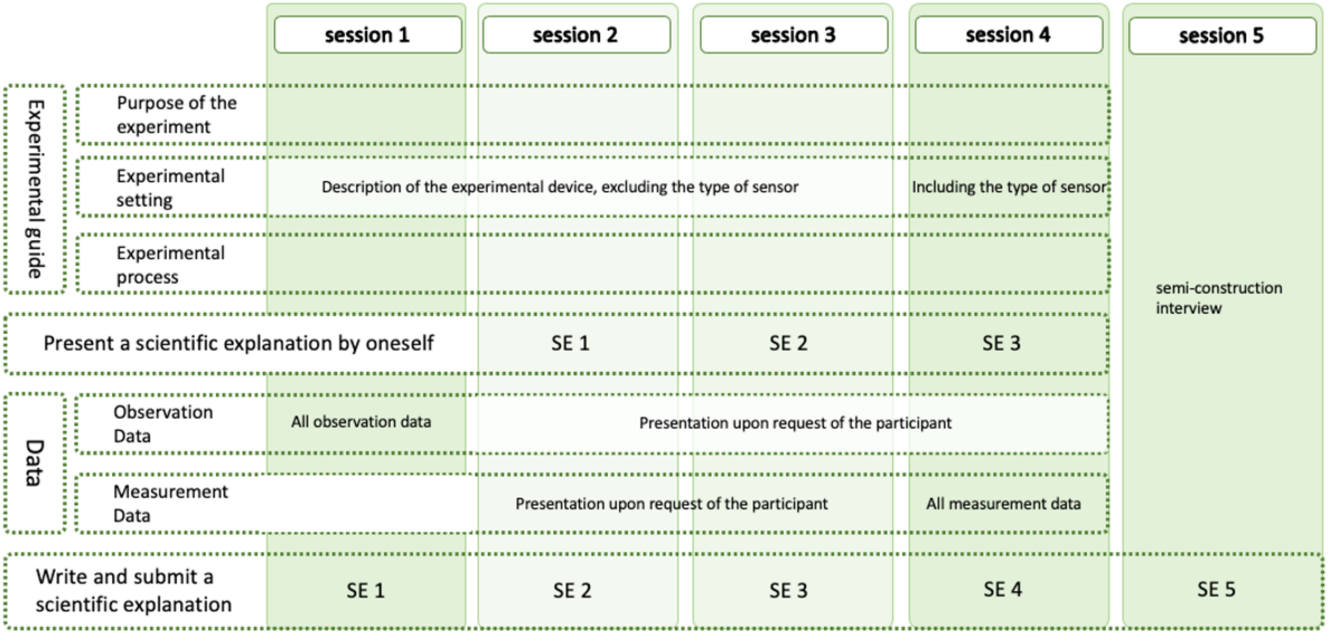

Figure 4. Session proceedings for research protocol (Source: Authors' own elaboration)

Research protocol

Data were collected based on a data collection protocol, as shown in **Figure 4**, in order to gain an in-depth understanding of how non-science elementary PSTs construct scientific explanations. Participants were interviewed one-to-one online using Zoom (https://zoom.us) over a period of three hours with their consent.

The clinical interview for participants was conducted, as follows: First, the study was preceded by preliminary research, including explanations for study subjects, the preparation of consent forms, a prior orientation, guidance on the study's progression, and participants' details. The researcher created a natural atmosphere for speaking by pre-orienting participants and rehearsing their expressions in words immediately. Finally, at the beginning of the clinical interview, we briefly outlined the progression of sessions 1-5. The explanation of the progress from session 1 to session 5 is provided below.

Session 1: A researcher guided the experiment and presented observation data. Once all observation data were probed, each participant wrote a scientific explanation in document form, as **Appendix B**. In this study, this document was referred to as SE1.

Session 2: Following the guided experiment, the researcher presented the SE1 to the monitor for the participant to request measurement data independently. The materials requested by the participants were presented. Furthermore, participants could request additional data individually while checking their desired measurement data. After identifying all the materials that participants wanted, they filled out SE2 on the same scientific explanation form they used in SE1.

Session 3: Session 3 (SE3) proceeded similarly to SE2, except that SE2 was presented.

Session 4: This session involved the description of the type. The participants reviewed all the measurement data collected by the researcher in session 4 (SE4) after checking SE3. The data was suspended, and SE4 was created.

Session 5: Researchers conducted a semi-structured interview with each participant, including questions regarding candle burning, measurement data, description composition, and additional research questions. Then, the participants completed and submitted a final scientific explanation, SE5, which describes the burning process of candles.

The researcher did not intervene in the participants' utterances during SE1-SE4. Additionally, the researcher kept field notes throughout the four sessions and used them for SE5.

Data analysis

We have transcribed all recorded sessions to analyze the collected data. An in-depth qualitative study was conducted to understand how elementary PSTs without science majors construct scientific explanations. Consequently, based on the factors reflected in the participants' scientific explanations, **Table 1** was constructed. This study's scientific explanation framework is based on three factors: knowledge, data, and explanation. Subcategories were then created. Prior knowledge includes scientific ideas, theories, laws, etc., that participants already know, as well as alternative ideas, such as misconceptions. This study used observational and measurement data. The explanations can also be divided into three subcategories: partially,

Table 1. A scientific explanation analysis framework

Class	Subclass	Criteria	Code
Knowledge	Prior knowledge	Prior knowledge that participants already have - Scientific concepts, theories, laws, etc. - Including alternative concepts	PK
Data	Observation data	Recording data during combustion for observation - A video & photos of experiment presented - Used in SE1 - Used in SE2-SE4 if participant's asking for	OD
	Measurement data	Sensor data of changes in temperature, humidity, air pressure, oxygen concentration, & carbon dioxide concentration during combustion - Graphs presented - Used in SE2-SE4	MD
Explanation	Partially explanation	Description in process of checking measurement data "- Include one source - Description with only one element	PE
	Integrative explanation	In process of checking measurement data, description described through combination of explanations, extensions, etc. - Connection, integration, etc. of partial descriptions & other element(s), etc. - Connection, integration of prior knowledge, & other element(s), etc. - Linkage, application, etc. of measurement data & observation data, etc.	IE
	Scientific explanation	At the end of each session, participants wrote and submitted a description of the burning process of candles	SE

Table 2. Coding of participant Cho's utterances in SE1

	Part of transcription in SE1	PK	OD	PE	IE
1	It took 100 seconds to ignite and burn.		V		
2	After the fire went out, the bottle was filled with smoke-like steam.		V		
3	Since then, it has become more and more cloudy.		V		
4	More smoke was coming out.			V	
5	No, it was foggy, as if more smoke was coming out.		V		
6	In the photo, the wick was less visible at 15 min than at three minutes.			V	
7	In the photo, the wick was not visible better at 15 min than at three minutes.		V		
8	As time passed, the sensor became more obscured.		V		
9	It was further obscured owing to the smoke.			V	
10	Smoke may be particles of carbon dioxide and water.	V			
11	They had to stay because they could not get out of the bottle, which made them blurry.			V	

integrative, and scientific. When checking the data, partially explanations are only one part of the participant's statement. Integrative descriptions, on the other hand, combine or extend explanations that connect or integrate two or more elements. The scientific explanations submitted after the sessions describes the burning process of a candle.

To analyze the data, each corresponding element was displayed in the full copy of SE1 through SE5. An example is shown in **Table 2**. A series of description construction processes resulted in prior knowledge, observation data, and measurement data. Participant checks ranged from verification to writing a coded scientific explanation. In addition to understanding the relationships between each element and its use, we wanted to understand how they were connected.

Figure 5 illustrates how this pattern analysis process works. In **Figure 5**, each element was arranged, as shown in (a), and the elements were listed sequentially and visualized as shown in (b). Whenever only one appearance occurred, an arrow indicated the direction of the connection, and the thickness of the line stated the frequency of occurrence. A circle was used to express if the same element was repeated.

RESULTS

Construction of Scientific Explanations

Pattern of each session

In this section, we examined the processes of identifying participants' data and analyzing explanations. Consequently, the speech patterns of the participants in SE1 to SE4 were analyzed. In SE1, participants checked the observation data, and in SE2 and SE3, the researcher verified that the required measurement data. In SE4, the participants inspected the data presented by the researchers. During SE2 and SE3, most participants verified the data, and the number of utterances increased.

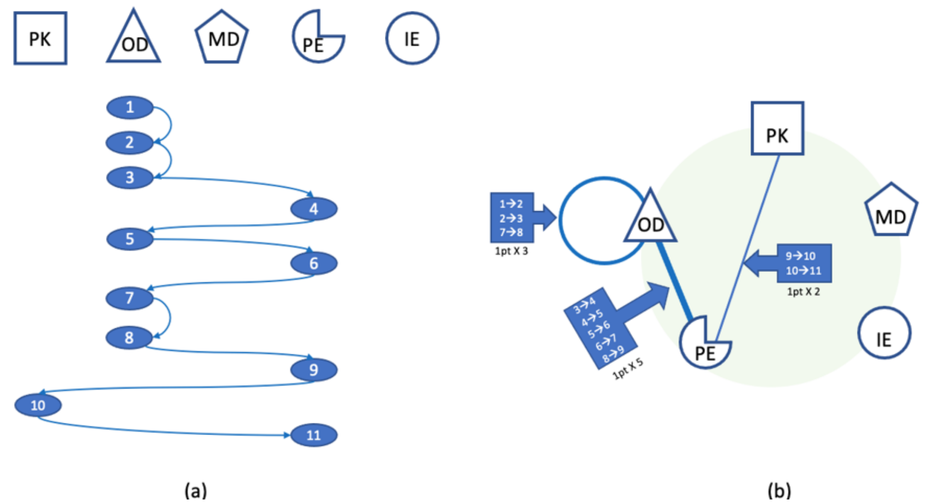

Figure 5. Analyzing participants' process of constructing (Source: Authors' own elaboration)

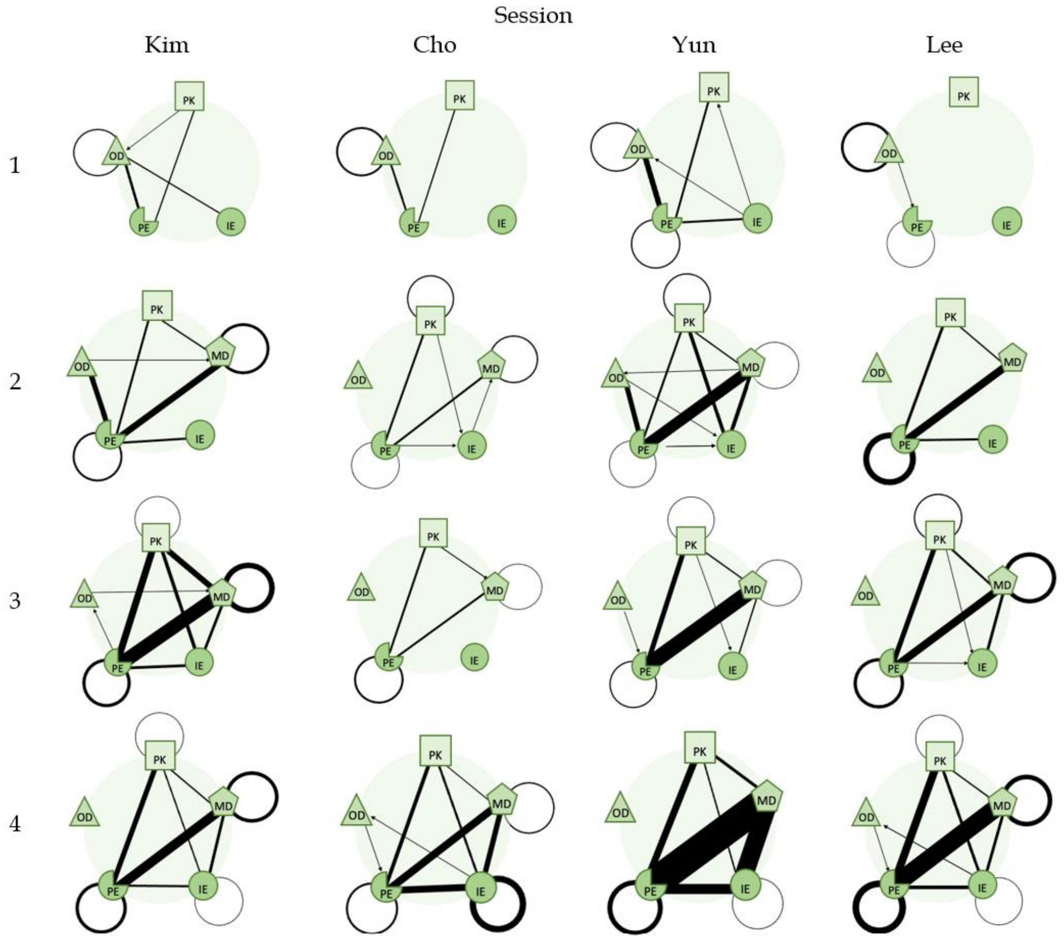

Figure 6. Speech patterns of participants in SE1-SE4 (Source: Authors' own elaboration)

The pattern analysis results are shown in **Figure 6** for SE1-SE4, indicating the connection and frequency of the elements in each participant's utterances.

As part of SE1, Kim and Yun presented observational data, prior knowledge, and partially and integrative explanations, whereas Cho presented prior knowledge and partially explanations. For Lee, observations and partially explanations were all he had to offer. Kim and Yun used prior knowledge to link specific aspects of their observations with explanations of why they happened. These are some specific examples of their expressions.

Kim's case:

PK *-In process of combustion, products were generated.*

OD *-I could observe the fogging inside the glass bottle.*

PE *-This is because water was produced during the combustion process.*

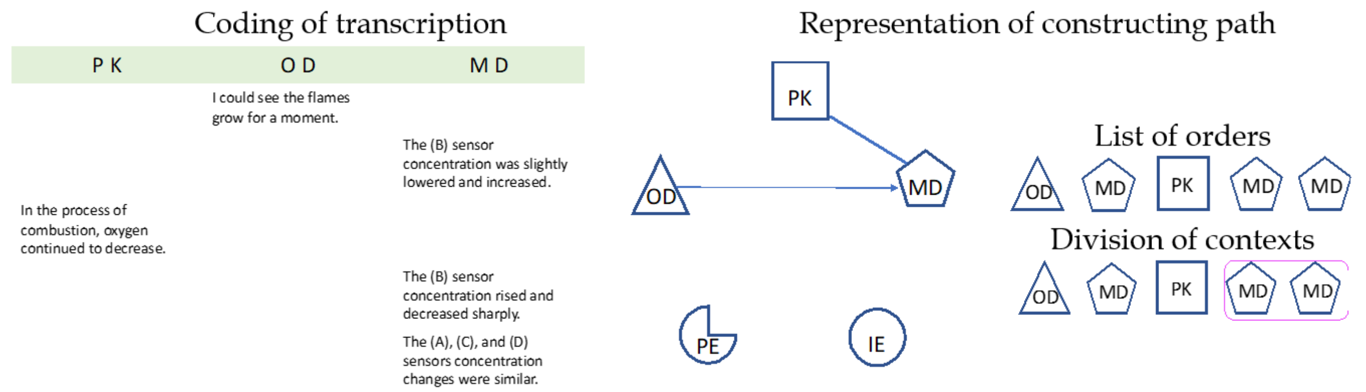

Figure 7. Analyzing participant's constructing path (in SE2) (Source: Authors' own elaboration)

[Omitted]

OD *-After combustion, you can see that the water vapor becomes thicker.*

IE *-This is because it has gradually evaporated under elevated temperatures.*

Yun's case:

OD *-Two or three times I could see the flame grow and then shrink again, and the candle went out.*

PE *-This is because of oxygen.*

[Omitted]

IE *-Because carbon dioxide was on top, the candle burned down and became larger when it comes to the part, where there was oxygen.*

[Omitted]

PK *-Three conditions for combustion are oxygen, dematerialization, and temperature above the ignition point.*

OD *-I could observe that inside of glass bottle was foggy.*

PE *-This is due to carbon dioxide or by burning candles and materials …*

In Lee's case, on the other hand, the list of observations centered on it.

Lee 's case:

OD *-After lighting and closing the lid.*

OD *-It rode well until 1:16, then suddenly faded and then came up again little by little.*

OD *-Smoke billowed.*

OD *-And the glass bottle grew foggy.*

PE *-The smoke was trapped and foggy.*

OD *-Smoke was generated until fire was completely extinguished.*

During SE2-SE4, participants requested measurement data based on their scientific explanations. When he tried to confirm it, he realized that he was linking the partially explanation with the integrative explanation. The measurement data helped coordinate the connections between the requested data and the integrative explanation. There are differences in these characteristics based on the order of sessions, such as SE2 for Yun, SE3 for Kim, and SE4 for Cho and Lee. Regardless, all participants had prior knowledge, which facilitates the emergence of observation data, measurement data, and partially and integrative explanations. When analyzing the changes over time, the growing connection between measurement data and partially explanations was evident. Furthermore, in SE3, where almost all of the measurement data were confirmed, there was little connection between the observation data and the integrative explanation. As the sessions progressed, participants were more likely to rely on measurement data to construct explanations. Observational data and measurement data patterns indicate this interpretation.

Use of observation data and measurement data

We needed to distinguish between participants' prior knowledge, observation data, measurement data, partially explanations, and integrative explanations during the data verification process based on the context associated with the participants' speech focus to examine how these factors interacted. We distinguished the confirmation of data in the same way as in **Figure 7** and examined the data based on the context of participants' utterances. Using elements in context was analyzed by grouping and listing elements that pair with each other.

As shown in **Figure 7** during SE2, construction explanations were explained in a step-by-step manner. In SE2, the participants checked the oxygen concentration measurement data. In addition to recalling observation data and linking them with measurement data, participants demonstrated characteristics validating prior knowledge. In the next step, the measurement data were categorized based on the sensor's attachment location. Because the measurement

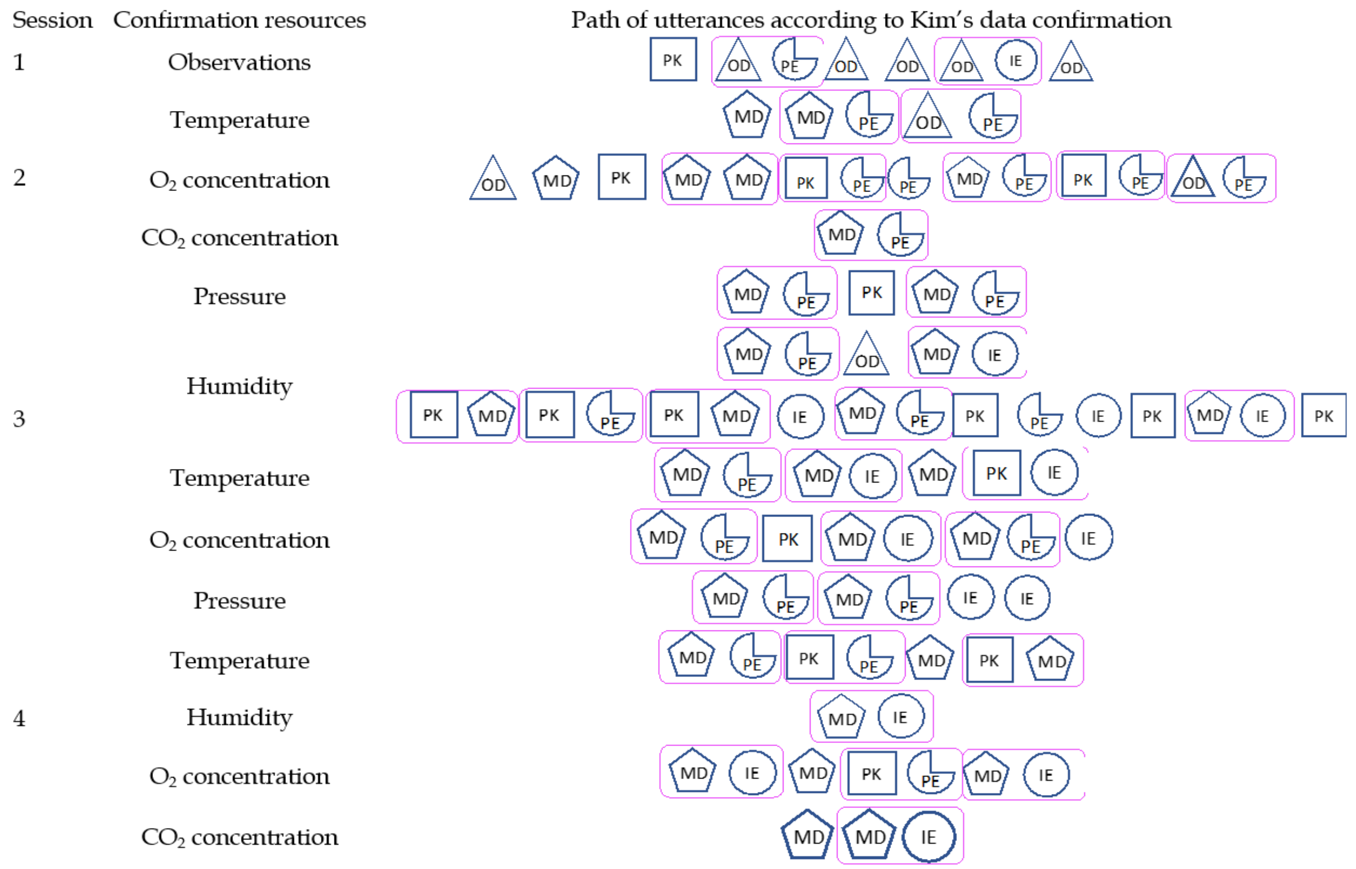

Figure 8. Kim's path to data verification in SE1-SE4 (Source: Authors' own elaboration)

data here demonstrate the same trend, it is possible to group the [MD-MD] together. Kim's utterances, including a variety of patterns, are covered in this section.

Figure 8 shows Kim's speech patterns based on his confirmation data from SE1 through SE4. Kim constructed explanations based on the data he examined. Partially explanations were developed in response to observation and measurement data, with prior knowledge and integrative explanations used separately. Accordingly, Kim did not only list his interpretations of the material but also combined them into a single description. Thus, Kim partially explained what can be derived from the data. After that, he repeatedly recalled prior knowledge, existing explanations, and the previously identified observation and measurement data. This element represents the characteristics of explaining things. In between sessions and during them, these characteristics were noted.

Observation data revealed connections between Kim's sessions (**Figure 9**). In SE1, Kim noted that the second sensor was gradually whitewashed. Then, he requested and confirmed the temperature measurement data in SE2. He explained that increasing water vapor could explain the increasingly obscured sensor position. At SE3, Kim asked for humidity measurement data and linked them to partially explanations. As a result, the description of the temperature measurement data was integrated with the explanation of the (C) sensor-obscured phenomenon.

On the other hand, we found characteristics identifying the context of a session, even within a single session. Kim found a part of his explanation, where he could differentiate between contexts while checking the data and constructing the explanation. In this context, several characteristic utterances function as links in referring to several elements. Scientific explanations consist of many components, rather than forming a monotonous. Instead, the participant formed connections with previous explanations. Creating questions, evaluating explanations, verifying explanations, directing explanations, and constructing explanations characterized these connections. Examples of such utterances are provided as follows:

Interrogative generation:

By some factor … Why?

(C) and (B) are similar distances to flames, so I wonder why (B) sensors look different.

I wonder if it is due to a reaction with some other substance.

Measurement data verification:

The pattern is different and inconsistent with conventional scientific knowledge.

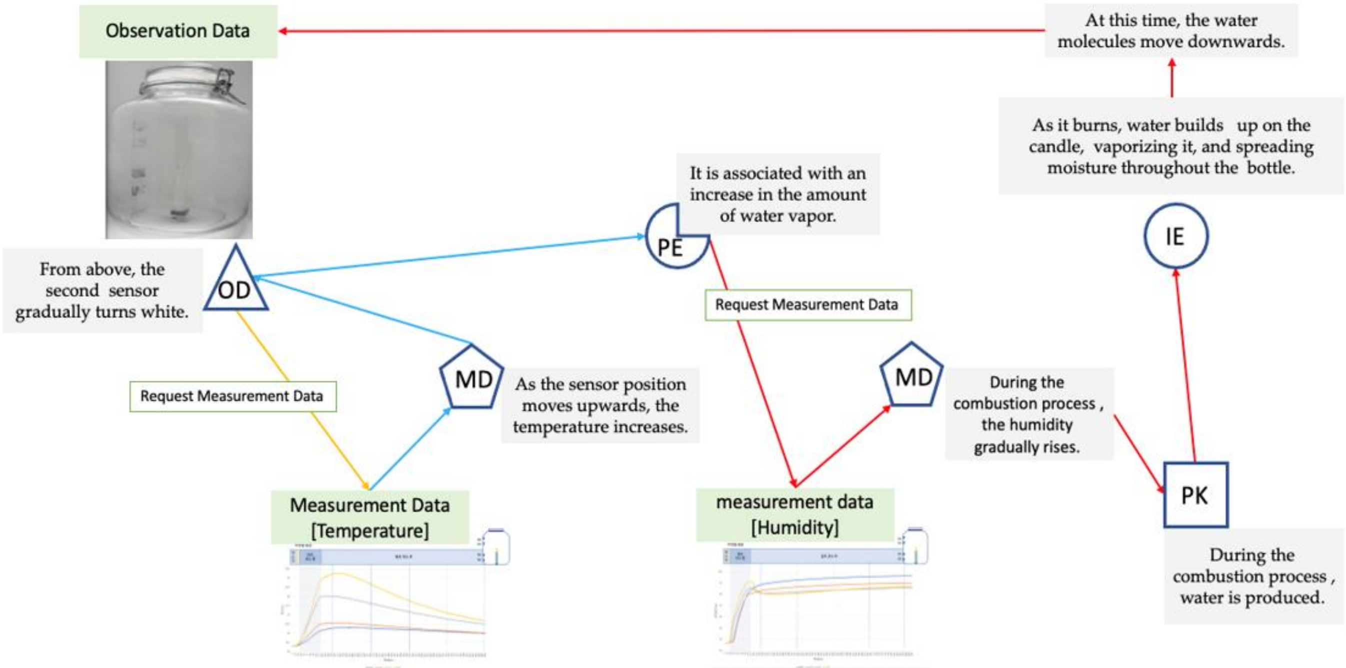

Figure 9. Kim's usage of observation & measurement data (Source: Authors' own elaboration)

> It is inconsistent with the existing knowledge of the expansion of gases.
>
> This is something I had not discovered before.

Evaluation of explanations:

> It can be seen that the previous prediction has explanatory power.
>
> The isolation of CO_2 was a misrepresentation.
>
> There was a misunderstanding about the direction of movement of water vapor.

Verification of explanations:

> The position in which the temperature change should be based is not where the flame starts.

Direction of explanations:

> So, how do we explain (A)?
>
> An explanation of the process that leads to stabilization is needed.
>
> The direction in which water vapor travels must be reconsidered.
>
> I am curious about the role of location in (B) and the relationship between (B) and (C).

Difficulty in constructing explanations:

> It is difficult to understand the connection between pollination.
>
> I'm not sure why.
>
> I do not know much about science, so it's difficult to explain further.

Even though the utterances that serve as these links were not included in the elements that make up the scientific explanation, participants used them to differentiate contexts, check partially explanations, and provide integrative explanations by verifying and connecting various aspects. The composition's characteristics were evident. In addition to considering the limitations of his explanations, he demonstrated metacognitive thinking, which involves thinking about his thinking process.

Changes in Scientific Explanations

In this study, the scientific explanations were written about the same question, candle burning process. Most participants described the burning process of a candle as a sequential or orderly identification of the data. Thus, the characteristics of the data were interpreted while highlighting the features of the combustion process, before, during, and after extinguishment. While checking observation and measurement data, no additional questions were raised whenever the integrative explanations were reflected in scientific explanations. The scientific explanations became increasingly elaborate as the sessions progressed. The explanation included only a portion of the material identified in the session, or he had questions besides the explanation that he initially wrote. In addition, the explanation became cohesive.

The participants wrote scientific explanations with the following characteristics: First, the scientific explanation (SE1) written at the end of SE1 referred to combustion conditions as the starting point for the explanation.

> Combustion requires oxygen.

Participants prepared scientific explanations based on observation of flames, smoke generation, changes in glass bottles, and combustion products.

> Just before the candle went out, the flame grew slightly smaller.
>
> As the candle burned out, white smoke rose from the lid.
>
> It became foggy inside the glass bottle.
>
> As a result of combustion, carbon dioxide is produced.
>
> The combustion process produces water molecules and carbon dioxide.

The candles written by the participants were extinguished because of the following reasons:

> The candle burned out because the oxygen in the container had been exhausted during the combustion process.
>
> During this process, the carbon dioxide produced under the glass bottle prevented oxygen supply, thus extinguishing the candle.

Participants revised their scientific explanations from SE2 to SE4. An elaboration of scientific explanations was observed. Seeing these changes as new or additions to something that had never existed was quite difficult because the scientific explanation (SE 1) that was written initially has been maintained but expanded upon. Using measurement data, the part mentioned in SE1 was refined or reinforced, while the previous description was modified. The most notable one was the change in oxygen content in the most of explanations of the participants. Oxygen in combustion conditions was elaborated as "oxygen over a certain level" while previously referred to as "oxygen."

Furthermore, no oxygen could be supplied to the candle; thus, it was extinguished. If a candle is extinguished for some reason, such as "when the oxygen concentration reaches a certain level, it cannot burn." According to the measurement conditions, the explanation was elaborated. Participants were able to modify their alternative explanations using measurement data.

However, in some cases, the previous explanation was maintained. Throughout SE1, Yun focused on the carbon dioxide concentration as the basis for the combustion process. The measurement data were reviewed to support the explanation. He stated that the produced carbon dioxide increased to the top of the bottle. When the amount of carbon dioxide (CO_2) substantially increased, the candle shrank initially and grew slightly over time.

While retaining the original scientific explanation, changes in temperature, oxygen concentration, and humidity were added to the movement of carbon dioxide during combustion. It was clear that these elaborations and reinforcements of scientific explanations showed similar characteristics from SE1 to SE4.

Participants submitted SE5 at the end but tended to write it differently than those in the previous sessions. Most participant explanations showed the characteristics of a holistic narrative, including a description of the process of constructing a scientific explanation. This included what they could or could not explain while synthesizing previous scientific explanations. For instance, Kim's SE5 involved the following:

> Before I started, I knew nothing other than that combustion is a combination of oxygen and matter and that carbon dioxide is produced.
>
> [omitted]
>
> The temperature gradually increased during combustion. It was confirmed that the temperature was not determined by proximity to the flame because it was higher toward the top. This is expected to be more related to the movement of the material produced during combustion and the air inside the bottle than to the flame's heat.
>
> The humidity gradually increased as the temperature increased, and the humidity was the highest at the top. It was confirmed that water vapor rises when it vaporizes. This may result from water vapor agglomerating on the upper surface of the sealed container.
>
> During combustion, the temperature and humidity increased while the oxygen concentration continued to decrease. This is because oxygen is continuously consumed during the combustion process. However, the fact that the oxygen concentration value near the B sensor in oxygen rises immediately after the end of combustion; thus, additional explanations are required for the consumption of oxygen during combustion. At the same time, as the oxygen concentration decreased, the concentration of carbon dioxide increased.

Table 3. Classification of scientific explanations

Scientific explanations from participants		SE
SE1	Scientific explanations written by participants after verifying observation data Scientific explanations that participants already had - Submit at the end of SE1	SE-A
SE2-SE4	Scientific explanations made by participants in process of verifying observations & measurement data Scientific explanations as participants' construction - Submit at the end of SE2 to SE4	SE-CV
SE5	Scientific description submitted by participant at the end of the interview Scientific description finally written by participants - Submit at the end of SE5	SE-F

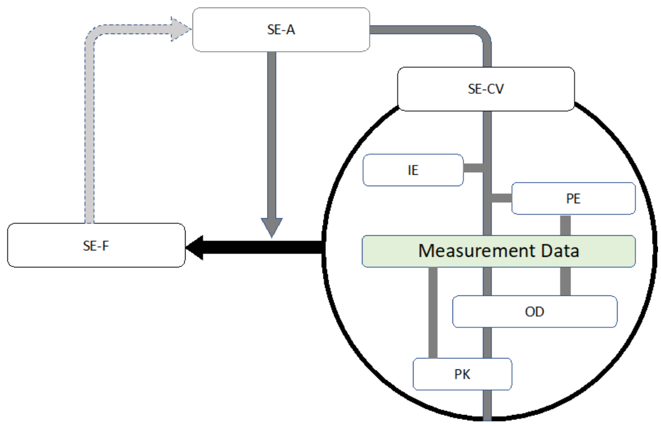

Figure 10. Process of constructing scientific explanations (PK: Prior knowledge; OD: Observation data; PE: Partially explanation; IE: Integrative explanation; SE-A: Scientific explanations that participants already had [SE1]; SE-CV: Scientific explanations as participants' construction [SE2-4]; & SE-F: Scientific explanations finally written by participants [SE5]) (Source: Authors' own elaboration)

> Taken together, above results show that oxygen is a necessary for combustion. However, a lack of oxygen is not necessarily required if combustion does not start or end. That is, presence of oxygen is not sufficient for combustion, and adequate humidity is required as an environmental condition for combustion to proceed.
>
> [omitted]

DISCUSSION

Construction of Scientific Explanations

The scientific explanations were renamed in **Table 3** to examine how they were constructed. The scientific explanations began with the observations in SE1. They include the explanations that participants already had (SE-A). Participants observed and wrote about the phenomena using the same process and data. As a result, these methods were used as a starting point for observing phenomena and developing scientific explanations without interventions from measurement data. In most cases, they reflected ideas that participants already had.

During SE2-SE4, the participants evaluated the measurement data considering their existing explanations (SE-CV, which stands for scientific explanations based on constructing and reshaping), and in the final step, they wrote their final explanations (SE-F). We verified the data by classifying scientific explanations and analyzed the relationship among them.

The scientific explanations constructed by participants have the following characteristics: First, the initial scientific explanations (SE-A) prepared following observational data were greatly influenced by the participants' prior knowledge. Prior knowledge was used to describe combustion conditions and products. Second, the participants' initial scientific explanations (SE-A) during the data verification process strongly influenced the partially and integrative explanations they provided after the measurement data were presented. The initial scientific explanations (SE-A) served as the foundation for the construction of the scientific explanations (SE-CV) as the central aspect of the measurement data verification process. Based on measurement data, self-evaluation and data verification, including the assurance, addition, and inspection of prior knowledge and observation data, were implemented. Throughout the development of partially and integrative explanations, a variety of elements were included. An integrative explanation was derived from the measurement data, which correlated directly with the final scientific explanation. In addition, the final scientific explanation (SE-F) indicated that the participants previously provided scientific explanations (SE-A) were retained and that the scientific explanations (SE-CV) developed during the verification of the measurement data were reflected separately. **Figure 10** shows the construction of scientific explanations. During the verification of the measurement data, the adjustment process was conducted by verifying, confirming, and correcting the participants' explanations and interpretations. A constructed scientific explanation comprises partial and integrative explanations derived from this process. In the process of constructing scientific explanations, several factors are involved, including the initial scientific explanations, which must be connected to the final explanation. As the first step, verification was necessary to evaluate the validity of explanations.

Observation and Measurement Data-Based Construction Process

Based on the process of requesting and confirming observation data and measurement data, the contents included in the elementary PSTs' scientific explanations were revised and reorganized. Based on the characteristics of the participants, the data were used in various ways. Nevertheless, the scientific knowledge used in the scientific description and the elements included in the final constructed scientific explanations (SE-F) followed similar patterns. The explanation of why the flame went out was based on this feature. Therefore, during the process of checking the oxygen concentration measurement data, it was determined that the candle in the sealed container had gone out due to the exhaustion of oxygen, and the reason for the candle's extinguishment had been changed to consider factors, such as oxygen blocking carbon dioxide and humidity. These results differ from those reported by Chinn and Malhotra (2002), who found that the data-driven discussion in the teaching and learning of anomalous cases did not change scientific concepts. There is a difference between using observational data alone and using observational data combined with the measurement data of the process in which the phenomenon occurred. The measurement data might be inconsistent with the participant's prior knowledge. The participants requested the measurement data as part of the verification process.

> Why this point in the measurements?

> Why do the measurements indicate this trend?

Partially explanations were constructed using these questions as a starting point while examining the various measurement data. The partial descriptions constructed at this time indicate the characteristics of the hypothesis.

> If the micro-combustion process takes place.

Assumptions were constructed such as

> As carbon dioxide is heavier, it will tend to be located at the bottom; however, at higher temperatures, it will be distributed more widely at the top.

In addition, the participants applied the partially explanations to other measurements.

> Here, I'd say that the previous explanations are right.

> As a matter of fact, it is not true that carbon dioxide was separated into carbon and oxygen.

As a result, they evaluated their explanations. Their observations constituted the basis of these characteristics, which have the same context as the process of knowledge generation centered on inductive thinking (Yao et al., 2016). As a result of this case study, the participants themselves made use of metacognition. Alternatively, verifying one's own explanation can be understood as a metacognitive process involving the use of one's own cognition to analyze and rethink previous explanations. Based on our results, the measurement data that provided the basis for verification in this metacognitive process.

Participants indicated that they needed to become more familiar with science, that the subject matter of this study was difficult to understand, and that a lack of prior knowledge would significantly affect their explanation construction process. Nevertheless, the measurement data were used in a way that was generally agreed upon. Several individual characteristics affected in the process of constructing scientific explanations, including the level of prior knowledge possessed by the participant. However, this can also be used as a teaching strategy, such as scaffolding, since it evokes scientific knowledge that was not previously considered or makes us realize the need for scientific knowledge. This results like one used an evidence-based scientific explanation online program that utilized a scaffolding setting (Kyza & Edelson, 2005).

From an epistemological perspective, Sandoval and Reiser (2004) emphasized the importance of clarifying coherent causal explanations and utilizing data to support causal claims as critical elements of explanations through explanation-based inquiry. A key feature of scientific explanations is that they adjust causal relationships and data patterns and that concepts and epistemological scaffolding play an important role in this process. In connection with these characteristics, our results have implications on the use of data as they show the effect of measurement and observational data on the process of constructing scientific explanations, which will directly impact the teaching and learning of scientific phenomena (Masters & Docktor, 2022; Yao & Guo, 2018).

Moreover, our results indicate that the scientific explanations of elementary PSTs can be used the model the construction of a scientific explanation. The reflection of the initial scientific explanatory model proposed by Clement (2008) and the process of evaluating and revising the reconstructed model. Based on the thought process in the model construction and the repetition of this process, it appears that the reflection of the initial scientific explanation (SE-A) is similar to the construction process of the measurement data-based scientific explanation (SE-CV) and the final constructed scientific explanation (SE-F). However, although the logical though process is central to building connections between models, as suggested by Clement (2008), our work shows that measurement data play a crucial role in connecting the phenomenon of candle burning with a scientific explanation model. Real-time measurement data play a vital role in the scientific explanation of processes, including causal relationships underlying microscopic phenomena. Therefore, we should focus on how the measurement data may be used in scientific explanation construction.

Observation and Measurement Data Reflected in Scientific Explanation

The elementary PSTs who participated in this study showed that the measurement data were used in the construction of scientific explanations through coordination and application. In addition, the use of the measurement data differed from that of the observation data.

First, the use of the measurement data in explanatory construction through intraindividual evidence and the reconciliation of theories were achieved. Kuhn (1989) argued that new knowledge is constructed through discerning differences between evidence and theory and coordinating between them, which is the core of scientific thinking. When the measurement data were presented, participants judged whether they matched the measurement data based on their own experience, prior knowledge, and expectations of what the measurement data would be. If they matched, they reinforced the partially explanations, and if there was a discrepancy, they did not include it in their explanations and withheld it temporarily. In the case of the measurement data that did not match the participants' prior knowledge or existing explanations, attempts were made to construct explanations by restructuring or modifying prior knowledge through building connection with other measurement data and introducing new explanations that had not been thought. This process is characterized by the similarity of scientific explanations to the process of argumentation, the participants repeatedly used local verification, such as "because, therefore, what is (what it will be)," including the rationale for why the measurement data exhibit such a tendency. However, the purpose of this process was not to convince others but to construct a plausible causal process of why a phenomenon occurs. In the end, arguments are made in the form of conclusions through the process of justification through evidence in the course of scientific explanation construction. This structure was consistent with the structure of the scientific explanation of the 'CER framework proposed by NRC (2012) as a strategy for constructing students' scientific explanations.

However, the results of this study provide another implication for research (Novak et al., 2009) to help students construct scientific explanations by presenting claim-evidence-reasoning structures to help students construct scientific explanations by applying this framework of scientific explanations. In this study, if the participants' prior knowledge and the observation data and measurement data presented to the participants are called evidence, and the partially and integrative explanations constructed by the participants involved 'evidence-claim-evidence-reasoning-argument ... For example, when the participants constructed a scientific explanation of burning candles in an airtight container and the phenomenon of candle extinguishing, they described claims based on prior knowledge. Then, they presented observation data or measurement data as evidence to connect the data to the relationship. There was also a tendency to use measurement data as evidence to form another argument and repeat this process. In other words, the arguments in scientific explanations were constructed inductively and were not completed at once but were precisely adjusted, transformed, and modified through the verification of measurement data. In the repetitive process, the participants withheld judgment about their reasoning, where self-examination, called metacognition, was used to link the inferences.

The participants in this study highlighted two aspects of the use of measurement data to construct the scientific explanations of candle combustion: coordination and application. This differs from previous research (Prieto et al., 1992), where students presented a superficial list of observations and connections between them. Additionally, the measurement data provided a different perspective from the observation data. The specifics were, as follows.

First, the use of measurement data was used to construct explanations through intraindividual evidence, and the reconciliation of theories was achieved. The basis of scientific thinking is the ability to discern differences between evidence and theory and to coordinate them, as Kuhn (1989) argued. As the measurement data were presented, participants judged whether they correlated with the data based on their experiences, prior knowledge, and expectations of what the data would show. When they matched, they reinforced the partially explanation; if there was a discrepancy, they did not include it in their scientific explanation. When the measurement data did not match prior knowledge or existing explanations, new explanations were introduced by restructuring or modifying prior knowledge connected with other measurement data. There is a similarity between scientific explanations and argumentation, as well as the repetition of the process. In evaluating the measurement data and developing an explanation, the participants repeatedly appeared in the process of logically verifying "because, therefore, what is (what will be)," including the rationale for why the measurement data exhibits such a tendency. The purpose of this process was not to persuade others but to construct and accept one's own explanation for why a phenomenon occurred. Ultimately, this structure of scientific explanation represents the structure of scientific explanation in which arguments are made in the form of conclusions based on evidence. This structure was consistent with the structure of the scientific explanation of the 'CER framework' proposed by NRC (2012) as a strategy for developing students' scientific explanations.

A further indication for future research can be found in the results of this study. To help students construct scientific explanations, Novak et al. (2009) proposed claim-evidence-reasoning structures to assist students with applying the framework for scientific explanations. This study has shown that if participants' prior knowledge, observation and measurement data presented to them constitute evidence, and partially and integrative explanations used to verify measurement data include inferences, then the scientific explanation constructed by participants can be viewed as evidence-claim-evidence-reasoning … argument. For instance, the participants frequently described claims based on prior knowledge for the scientific explanations of burning and extinguishing candles in an airtight container. After that, the observation and measurement data were presented as evidence to demonstrate the connection between the data and the relationship.

As a result of using measurement data as evidence, another argument was expected to be formed, and the process would be repeated. As a result, scientific explanations are constructed inductively, and arguments are not created at once, but are adjusted, transformed, and modified through the verification of measurement data. By refraining from judging their reasoning during this repetitive process, participants were able to link between their conclusions through self-examination, also known as metacognition.

Based on the findings of this study, using observation data in conjunction with measurement data can provide a metacognitive awakening when reconciling evidence and theory to construct a scientific explanation. When used in scientific explanations, measurement data can contribute positively to prior knowledge and interpretation. Thus, measurement data can be used to develop educational strategies. In addition, the results of this study differ from those reported by Chinn and Malhotra (2002), who claimed that scientific inquiry involves a sequential process of hypothesis formulation, experimentation, results analysis, and conclusion development. Therefore, students do not undergo a more complex process of reconciling theory with evidence but instead connect conclusions to straightforward learning objectives. In addition, a scientific explanation component was included in the inquiry. Participants, however, constructed explanations on their observations. This study can be considered a circular inquiry as it combines scientific explanations with measurement data by revising and reconstructing previously constructed scientific explanations and verifying that measurement data contained in the explanations were repeated and regressive.

Further, the measurement data were applied to explanations they either already had or just constructed to influence the verification process. During the verification of the measurement data, the explanations constructed by the participants were revised or confirmed because they confirmed the explanations while checking other measurement data and reflecting on the previous explanations. In that time, measurement data served as a criterion for judging the explanations. The participants tended to place measured data rather than prior knowledge at the center of their judgments. In addition, the construction of an explanation tended to be completed when the measurement data were linked to the observation data. This result contradicts the conventional notion (Yao & Guo, 2018) that secondary teachers use evidence based on their knowledge of scientific concepts, principles, and laws to interpret the results of a given inquiry rather than using the results of their inquiry. Furthermore, studies have shown that limitations of scientific explanations, such as the reliance on observational data, are influential as evidence to aid in the construction of scientific explanations.

Through the repetition of this measurement data-based explanation and the confirmation process, a complete explanation based on the measurement data was reflected in the scientific explanation. It is possible to interpret this characteristic as a process of adjusting evidence and theory in which participants can distinguish their cognitive thought processes by relying on the prior knowledge and explanatory structures they already had when constructing explanations using prior knowledge, observation data, measurement data, and their explanations. To begin with, the explanation of observation data was top-down process based on existing knowledge or scientific explanations. In contrast, the scientific explanation that occurs when constructing an explanation based on measurement data was a bottom-up process that connected prior knowledge with partially explanations. As such, it differs from the reflection on the scientific explanations (SE-A) made by the participants prior to receiving the measurement data. It is related to the findings of this study since the scientific explanations developed during the verification of measurement data (SE-CV) was incorporated into the final scientific explanation (SE-F). In addition, a top-down process is central to the cognitive process in which evidence is used. In the context of the verification process, top-down processes are at the heart of the metacognitive process, which is the global metaprocess for rethinking the cognitive place from the bottom up simultaneously. Thus, measurement data may be used as scaffolding to integrate cognitive and metacognitive strategies. As Wang (2015) explained, scaffolding is essential for the promotion of metacognition because incorrect explanations result from faulty cognitive reasoning, making scaffolding a vital tool to promote metacognition.

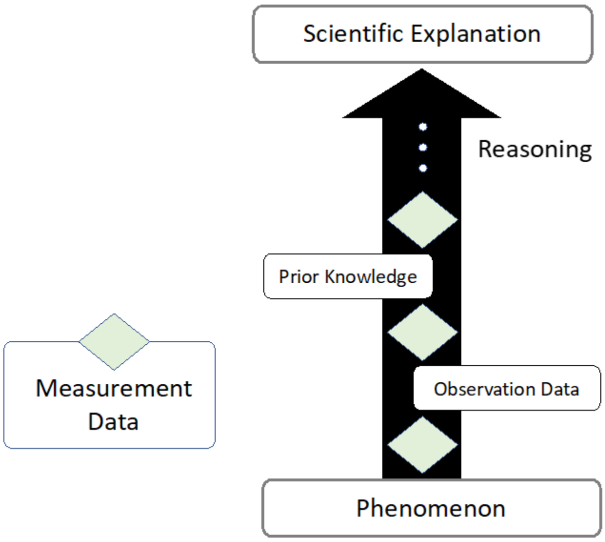

Figure 11. A model of scientific explanatory construction (Source: Authors' own elaboration)

A central element of the verification process was using the measurement data to construct scientific explanations. In addition, it served as a criterion for evaluating and reconstructing scientific explanations. As a result, the measurement data have become central to the construction of scientific explanations, consistent with the acceptance of the opinions of scientists. Therefore, the participants appeared to be more confident when they assessed their experiences and prior knowledge rather than judging based on the uncertainty of their own experience or prior knowledge. This is even though the researchers stated in each session that they had measured the data. The participants appeared to be more confident about their measurements. Based on this, the participants consolidated and reorganized their explanations. As a result, when they applied their explanations to a variety of measurement data, they created scientific explanations that were clear and noncontradictory as much as possible.

The final analysis involved participants applying their integrative explanations to construct scientific explanations (SE-CV). Hence, if the explanation, based on prior knowledge and measurement data, was accurate, this phenomenon would be observed. The final scientific explanation (SE-F) differed from the scientific explanation (SE-A) formulated by the participants using only observational data. That is, the process by which the phenomenon occurs was described logically, and the observational data were reflected in the scientific explanation only as a result. However, when measurement data were presented along with observational data, the participants' logical thought processes were verified and modified based on the measurement data. The measurement data were essential for explaining how the phenomena appeared in this context. Consequently, the observational data were used to verify the results of the explanation construction process centered around the measurement data. The measurement data were used as the basis for cognitive reasoning to construct the explanations. These results might be attributed to the fact that observational data are not directly related to scientific knowledge, but they were rather linked through explanations. On the other hand, measurement data are intimately related to observations, prior knowledge, measurement data, and scientific explanations. Further, the process of constructing explanations through measurement data (SE-CV) was reflected by the scientific explanation (SE-F), a single explanation developed as a result of checking each observation data, and the process by which the explanations were maintained until the end became linked and integrated with other data was reflected in the scientific explanation (SE-F). Measurement data play an important role in microscopic phenomena that cannot be observed directly through the five senses.

CONCLUSIONS

In constructing scientific explanations, the measurement data of microscopic phenomena can provide connections among prior knowledge, observations, and partially explanations. The elementary PSTs who participated in this study underwent a process of self-examination using measurement data. Their scientific explanations were reformulated through evaluation, correction, and holding. Moreover, their scientific explanations reflected the initial scientific explanations of the participants based on prior knowledge (SE-A), besides those drive from the measurement data (SE-CV). Therefore, scientific explanations formed during the verification of measurement data may play a significant role in the construction of the final scientific explanations (SE-F). Using measurement data can overcome shortcomings due to limited prior knowledge and observation data.

In summary, we investigated the scientific explanations constructed by elementary PSTs who did not major in science while observing candle burning and comparing observation data with measurement data. Therefore, observing the phenomenon and comparing the measurement data with prior knowledge can lead to a scientific explanation. In conclusion, we describe the process of scientific explanation as shown in **Figure 11**.

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Ethical statement: Authors stated that the study was approved by the Institutional Review Board (IRB) of Korea National University of Education, approval date: 28 July 2020, document number for the ethics committee approval: KNUE-2020-H-00198-1. Authors further stated that participants' personal information contained in the collected research and analysis data was changed to a pseudonym. And the researcher complied with the guidelines of the Institutional Review Board (IRB) of Korea National University of Education.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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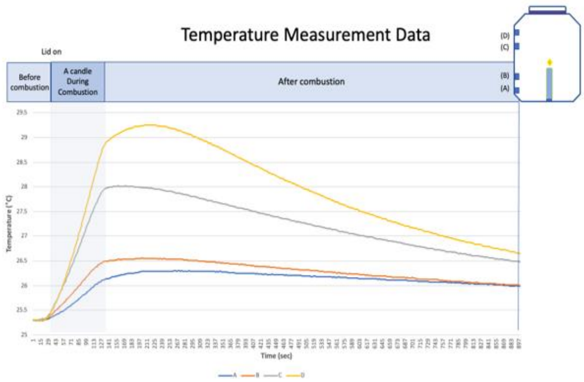
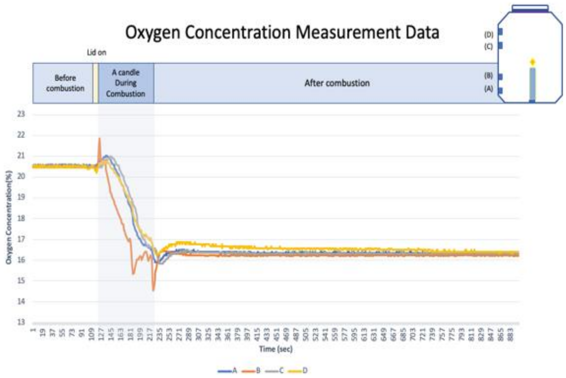
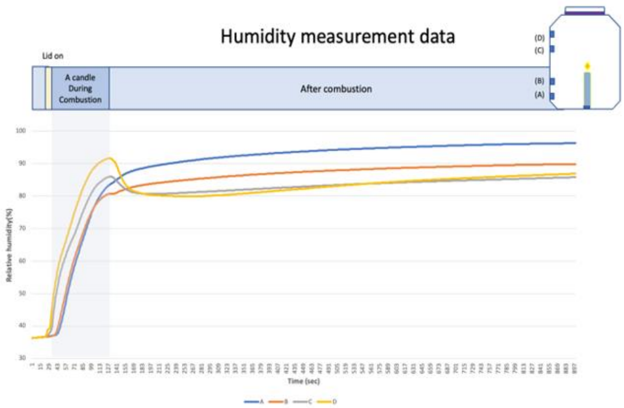
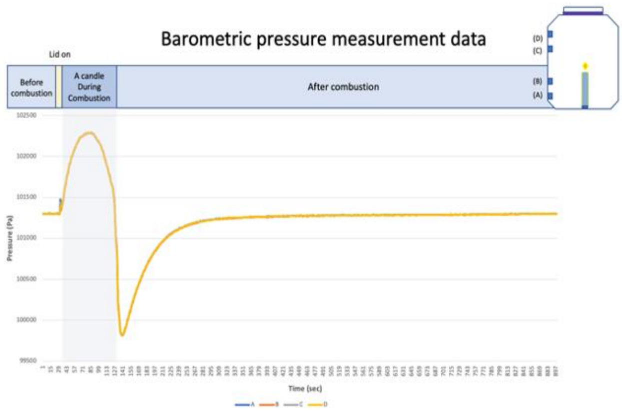
APPENDIX A: MEASUREMENT DATA





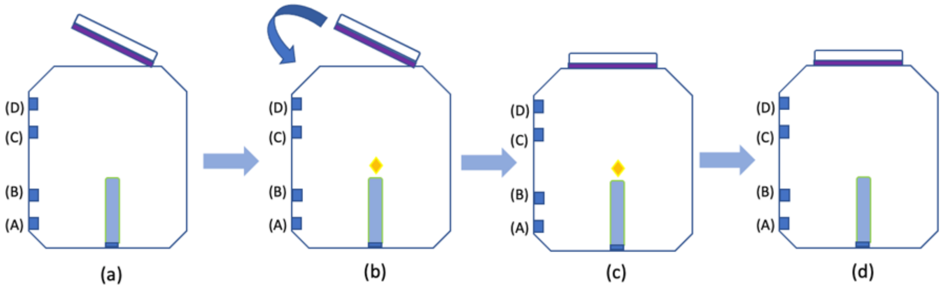




(Source: Authors' own elaboration)

APPENDIX B: SCIENTIFIC EXPLANATION WRITING

The figure below is a **schematic diagram showing the combustion process of candles. Explain the burning process of** a candle, **including why** the **candle** in **an airtight container goes out.**



(Source: Authors' own elaboration)