Universal Journal of Educational Research 10(5): 356-367, 2022 http://www.hrpub.org
DOI: 10.13189/ujer.2022.100505

Students' Abductive Reasoning according to Scientific and Historical Knowledge

Jooyoung Jeon*, Donghee Shin

College of Education, Ewha Womans University, South Korea

Received January 16, 2022; Revised May 7, 2022; Accepted May 23, 2022

Cite This Paper in the following Citation Styles

***(a):** [1] Jooyoung Jeon, Donghee Shin , "Students' Abductive Reasoning according to Scientific and Historical Knowledge," Universal Journal of Educational Research, Vol. 10, No. 5, pp. 356 - 367, 2022. DOI: 10.13189/ujer.2022.100505.*

***(b):** Jooyoung Jeon, Donghee Shin (2022). Students' Abductive Reasoning according to Scientific and Historical Knowledge. Universal Journal of Educational Research, 10(5), 356 - 367. DOI: 10.13189/ujer.2022.100505.*

Abstract In the modern era, knowledge is plentiful. In this context, it is important for students to understand the creative process of generating scientific knowledge. In this study, we identified how the prior knowledge of different disciplines affects each stage of induction, how each abductive reasoning stage interacts with each other, and what characteristics emerge according to their scientific and historical knowledge in the context of Deoksugung Palace. We developed and applied an abductive reasoning program that teaches scientific and historical knowledge about Deoksugung Palace and analyzed the data with qualitative methods. Students' observations were not consistent across the three activities included in this program. Their observations were categorized into two types, general and scientific. General observations are broad and shallow. Scientific observations involve a brief process of identification and selection, are made in a specific context, focus on specific data, and involve manipulative observations. We reconstructed the circular and reciprocal process of abductive reasoning. The results of this study suggest that abductive reasoning is strongly affected by prior knowledge. If a teacher wants to apply abductive reasoning, they must consider the circular process, characteristics, area of prior knowledge, and each student's abductive or convergent abilities.

Keywords Abductive Reasoning, Prior Knowledge, Inquiry

1. Introduction

At the point when individuals experience the astounding phenomenon, they normally question their current beliefs and afterward attempt to explain it with theories to clarify their encounters [1]. As indicated by Peirce [2], creating explanations is a logical procedure utilizing a type of reasoning called 'abduction'. Magnani [3] described abduction as follows: 1) abduction creates plausible hypotheses, and 2) abduction infers the best explanation (inference to the best explanation; IBE) by assessing hypotheses. Harman [4] described IBE as an inference from the premise that a given hypothesis would provide a 'better' explanation for the evidence than any other hypothesis, to the conclusion that the given hypothesis is true. To summarize, abductive reasoning is reasoning from observation to its possible explanation (hyphothesis) by using situation experienced and prior knowledge [5].

Abductive reasoning is frequently used in earth science. Problems in earth science are often explanatory, postdictive, and predictive [6]. Problematic areas of earth science, such as studies of distant stars or the Earth's core, generally involve environments that are impossible to reach and impossible to recreate experimentally. Therefore, earth scientists use facts, principles, laws, and experiences as rules to estimate or predict causes, formation processes, or future states from results recorded in the global environment using abductive reasoning [7]. Many other areas of knowledge incorporate abductive reasoning. Archeologists use visual abductive reasoning to generate hypotheses [8]. According to Flach and KaKas [9], abduction is actively used in artificial intelligence (AI), in contexts such as diagnosis, planning, natural language processing, motivation analysis, and logic programming. Problems such as racial and sexual discrimination are encountered in AI. AI is a knowledge-based system that reflects the state of prior knowledge at the time. Abductive reasoning also happens in daily life as well as scientific settings [10].

Abductive reasoning is also linked to the nature of science (NOS). Understanding NOS means having faith in what science is and its value, understanding the process of scientific knowledge formation and the nature of science, in the ability to acquire knowledge, and recognizing the value of science as its consequences. Understanding the values and beliefs reflected in the process of forming and developing scientific knowledge is also necessary for understanding NOS [11]. Therefore, applying abductive reasoning to science education can help students understand NOS by informing students about what scientists do and how scientists generate knowledge.

Since abductive reasoning is essential for constructing scientific knowledge, researchers tried to identify the process. According to Kwon et al. [12], the process of creating a hypothesis involves developing a question and constructing sub-characteristics that make up the current questioning situation. Secondly, inferring the current questioning situation and the past experienced situation, and thirdly, because that explains the experienced situation. It consists of finding out the explicans, and fourthly, selecting and combining hypothetical explicans that are considered to best explain the questioning situation among these causal explicans.

Oh and Kim [13] proposed another abductive inquiry model (AIM) composed of 4 steps: exploration, examination, selection and explanation. Exploration is about Exploring or observing phenomena and identifying a problem to be explained. Examination is searching for rules to explain the data produced. Selection is evaluating and selecting the best rules to explain the phenomena given. Finally, explanation is explaining the phenomena using the rules selected.

Oh [14] explained the process of abductive reasoning using the terms “resource” and “model” and referred to rules that can be used to explain phenomena observed in abductive reasoning. These rules are resources. Magnani [15] suggested that the abductive reasoning process is model-based. Following Magnani, Oh [14] defined objects, phenomena, and ideas that better emerge in non-verbal representations as models and suggested a process of model-based abductive reasoning.

Model-based abductive reasoning shows the relationships between evidence (E), resource model (RM), explanatory model (EM), scientifically sound explanatory model (SSEM), critical resource model (CRM), and critical evidence (CE). An investigator who recognizes observational evidence as a problematic phenomenon will automatically recall or deliberately search for RMs that can be used to explain it. At this time, multiple RM rather than only one, and various evidence may be used to identify RMs. Usually, the contents of various RMs are combined differently depending on the situation to form an EM, so more than one EM can be assumed by a reasoner. Finally, the pieces of evidence that initially became the problem are explained by the EM proposed by the investigator. That is, in the process of solving the problem, EM plays the role of explaining E, not RM, and RM mediates the process from E to EM. However, the EM formed through the inference process may be scientifically invalid. This schematic shows that for SSEM to be proposed, CRM must provide elements of EM and CE that activate CRM.

Besides the process, Eco and Sebeok [16] introduced four types of abduction: (i) in overcoded abduction the rule that would provide a result that is a case of that rule is given automatically or semi-automatically; (ii) in undercoded abduction the rule is selected from a set of rules available in one’s thoughts; (iii) in creative abduction the law must be invented anew; and (iv) meta-abduction is abduction about first-level abductions.

Multiple scholars [1-10] described how prior knowledge is quintessential to abductive reasoning. Among the abductive reasoning process, prior knowledge’s effect on observation is quite well known, though not in the context of abduction. Since Descartes, the core of the scientific approach has been based on the synthesis of sensorial experiences (acquired with the aid of observation and experiment) and an intuitional and deductional (acquired by intelligence and thought) approach [17]. Haury [18] stated that observation is influenced by the assumptions and knowledge of the observer. Despite the fact that observations can be unreliable due to restricted human senses, it remains at the center of science, and is the very last arbiter in building and checking out scientific ideas. Observation is used in any level of scientific inquiry: as a stimulus for elevating questions, in linking earlier experience to new encounters, amassing knowledge, and locating patterns and relationships between events and objects. Consequently, observation is not an act of ‘looking’ an image but dependent on the observer’s perception, experiences, and conceptual knowledge, which serve as a guide in the choice and interpretation of the observation made.

The theoretical background or prior knowledge influences their observations. In other phrases, present cognitive understanding and beliefs held by an observing student influence both the character and interpretation of their observation [19, 20]. Smith and Reiser [21] stated that even the scientists’ observations are directed via their domain-particular knowledge.

Whereas many studies have focused on theoretical, philosophical, and psychological aspects of abductive reasoning, several scholars have tried to apply the concept of abductive reasoning to educational contexts. Shim et al. [22] presented a task to generate hypotheses explaining water vapor condensation to elementary school students and verified that not only the students’ prior knowledge, but also their abductive reasoning ability significantly affected their performance. Additionally, most students had similar experiences (experienced situations) and failed to link them to hypothetical explicans. Similarly, Kwon et al. [23] studied the roles of prior belief and abductive reasoning skills by administering a test about pendulum motion to 5th grade students. Their results suggested that failure to generate hypotheses was related to abductive reasoning ability, rather than simple lack of prior belief. Oh [24] described the features of abductive reasoning activities in the domain of earth science in a sample of undergraduate junior and senior students by analyzing activities step by step according to the AIM and strategies. Jeong et al. [25] analyzed abductive reasoning among elementary students and found that abductive reasoning could be characterized into five types: complex abduction, analogical abduction, observation-based abduction, logic-based abduction, and selective abduction. The abductive sub-reasoning process of gifted students differed in some ways from that of scientists. Jung [26] constructed a theory about the process and results of abduction in the context of a middle school geological fieldwork program.

Many studies [22-26] have focused on the presence or absence of abduction, the suitability of the generated hypotheses, or changes in grades in abductive reasoning-based classes. Nonetheless, how the presence or type of prior knowledge affects the overall process of abductive reasoning is little known. Additionally, albeit the studies about observation [19-21] stated the effect of prior knowledge on observation, there is a lack of research on how it interacts with the post-observation stage in abduction.

In this paper, we analyze characteristics of abductive reasoning among students learning about historical Korean architecture according to their prior scientific and historical knowledge. The research goal is to find out how the prior knowledge of different disciplines affects each stage of induction, how each abductive reasoning stage interacts with each other, and what characteristics emerge.

2. Research Procedure

This study was conducted as a process of analyzing results after developing and applying an abductive reasoning program that utilizes scientific-history prior knowledge in Deoksugung Palace. We developed and applied an abductive reasoning program that utilizes scientific and historical knowledge to teach students about Deoksugung Palace.

To develop the scientific and historic abductive reasoning program, we first examined the characteristics of abductive reasoning and scientific and historical knowledge. To operate a program that involves both scientific and historical contexts, traditional Korean palaces are considered as a location candidate. There are reasons that Deoksugung Palace was selected among other traditional places. First, the researcher and students had to visit the place at least three times, so it must be close to the university. Second, Deoksugung Palace is where familiarity and unfamiliarity coexist. It is the only traditional Korean palace where Hanok (traditional Korean building) and Yanggwan (Western-style building) exist together. To students, or any other Korean, Hanok is relatively uncommon compared to Yanggwan. Deoksugung's Yanggwan doesn't look like typical western-style buildings, nonetheless, they have many traits that students can feel familiar with, such as drainpipe, cement, stone, glass, and lanterns. These kinds of characteristics can help students to easily adapt to the place, but to find novel objects. Finally, Deoksugung Palace contains more than 500 years of history and the science of Hanok and Yanggwan. For these reasons, Deoksugung Palace was selected as an activity site. After more research about Deoksugung Palace, 4 buildings were selected as activity sites: two Hanoks (Junghwajeon, Seogeodang), and two Yanggwans (Jeonggwanheon, Seokjojeon) (Table 1).

Additionally, according to Orion [27], for students to perceive the impact of prior knowledge and experience in science fieldwork, the novelty space must be reduced to achieve effective learning. The novelty space can be reduced by prior knowledge. Therefore, field experiential learning should be conducted in stages: a preparatory unit, field trip, and summary unit. So, the researcher put preliminary activity and post activity in every activity.

Table 1. Four buildings in Deoksugung Palace

Name	Picture
Junghwajeon	
Seogeodang	
Jeonggwanheon	
Seokjojeon	

Table 2. The Activity and the Concept from Each Class

Period	Activity & Concepts
1st class	Introduction, Build rapport, Abductive reasoning practice, Discover participants' background knowledge
2nd class *1st Activity	Abductive reasoning program at Deoksugung Palace
3rd class	Wrap up the program, Provide Scientific knowledge (Density, Strength of an object, Porosity, Types of rocks, Reflectivity, Thermal conductivity, Cycloid curve, Relationship between Sun's median altitude and angle of Hanok's eave, Combustion, Bernoulli's Law, Convection)
4th class *2nd Activity	Abductive reasoning program at Deoksugung Palace
5th class	Wrap up the program, Provide scientific & historical knowledge (Truss structure, Historical knowledge about Deoksugung Palace, Joseon's situation in 18th century, The founding and intention of Daehan Empire, Various interpretation of Gojong)
6th class *3rd Activity	Abductive reasoning program at Deoksugung Palace
7th class	Finish program, Group interview

The research took place at an off-school science education program organized by the Seoul-based university. The program was launched with six first graders of middle school who chose the program as their first or second. The program allowed the researcher to observe the students' characteristics and abduction processes as the researcher and students worked together for half a year. Students' interest in science and history, experience on outdoor science activity and Deoksugung Palace, and prior knowledge were examined during the preliminary investigation. During the program, students practiced, operated abductive reasoning without and with scientific or historical knowledge provided (Table 2).

The entire analytical process was reviewed in consultation with an expert in science education. In this study, we considered the following stages of abductive reasoning based on our inquiries on previous studies [12-15]: observation, identification, selection, and explanation (Figure 1). During observation and identification stage, students examine their surroundings and identify whether they can generate questions out of the interesting phenomenon. Then students select the prior knowledge and observed data to create an explanation for that question. The model based abduction and four types of abduction were included in the analysis [14, 16].

First, we reviewed and analyzed data including preliminary investigations, observations, activity sheets, post survey, and interview data. All data collected were transcribed. The first thing we performed was open coding. We repeatedly reviewed the data and identified parts that were related to previous studies or had important meanings. Then the data were simplified and reduced by identifying the data that needed to be analyzed. The first open coding session focused on discovering the characteristics of each abductive reasoning stage. Through open coding, we decided to combine observation and identification, and also selection and explanation, because it was hard to divide these processes. Themes like observation method, intervention of prior knowledge, simple abductive reasoning, relativity to place, and strategy of abductive reasoning were derived from open coding. Afterward, selective coding was conducted based on open-coded materials and student interviews. In addition to extracting detailed characteristics for each stage, we tried to understand how each theme and stage were connected.

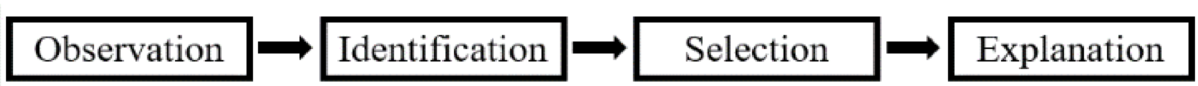

Figure 1. Stages of abductive reasoning

3. Findings

3.1. Student Characteristics in Abductive Reasoning

Abductive reasoning involves four distinct stages. During the observation stage, students examine their surroundings and collect data. The identification stage is when students evaluate whether the observed data elicit a scientific question. The selection stage is when students recall prior knowledge that is relevant to explaining the question. Finally, during the explanation stage students combine or analyze their observed data and prior knowledge to formulate a final explanation. Each student showed unique characteristics in this abductive reasoning program. Among these characteristics, several common criteria were extracted. Student characteristics and how they relate to prior knowledge are discussed in this section.

MJ's characteristics. During the observation and identification stages, MJ spent a similar amount of time in both activities. MJ spent a great deal of time on her first activity because she did not know what to observe and so observed as many things as possible. However, in the third activity, she tried to observe more details in narrower areas. For instance, in the first activity, she noted the shape of Junghwajeon window frames. In the third activity, MJ noticed that the frames had triangular bumpy holes. She investigated further based on her prior knowledge, diffused reflection, and the observed truss structure.

Another noteworthy finding is the correlation between observation and question identification stages. During observation in the first abductive reasoning activity, MJ did not acknowledge the material used in the Korean traditional building (Hanok). Yet during the identification stage, MJ formed a question about the elements of Hanok, which is made of wood. She did not consider the question during the observation stage, so she had to check again while formulating questions. However, during the third activity she did not have to go back from the identification stage to the observation stage because she immediately evaluated whether the data she observed could be used to form a question and explanation.

Additionally, both of MJ's explanations ("Yanggwan has a drainpipe, and Hanok does not have a drainpipe. Hanok would have raised the edge of the eave instead of making the drainage so that the rainwater could escape quickly," and "The shape carved on Junghwajeon's door is uneven to disperse light. It would have been necessary to disperse the light because the eyes of the King and his servants should not be dazzled") were relatable to the places under discussion. At Deoksugung Palace, Hanok and Yanggwan coexist in one place. MJ was able to contrast two types of buildings, which can only be done at Deoksugung Palace. Her third explanation was about Junghwajeon and was highly place related.

Characteristics of SW. SW was able to finish the first program on time, but he made the mistake of overgeneralization. Overgeneralization commonly happens in science and is an effect of external similarity [28]. SW's overgeneralization is shown in the following statements: "Yanggwan's yard consists of grass" and "Yanggwan is made of stone." These are false observations because the yard of Jeonggwanheon is sand and Jeonggwanheon also contains wood. Overgeneralization did not occur during the second and third abductive reasoning tasks.

We noted a relationship between observation and question identification. In the second and third activities, every question was related to observed knowledge. When observing, SW instantly determined whether what he observed could be used to formulate questions and explanations. This process did not appear during the first activity. At that time, SW had to return to the observation stage when he was forming questions. SW, however, gradually became accustomed to thinking about questions and explanations at the same time when observing, and said the knowledge provided by the researcher was very helpful.

Very simple abductive reasoning appears in his observations. "The location of the roof and the lower pillars are the same, so rainwater flows through the stone pillars. It seems like the building's inside will get wet" and "Stone will not burn easily, so the buildings are quite safe from fire" are the product of both observed data and prior knowledge.

SW's first explanation ("Stone gets wet like wood, because the stone has small pores") was not newly discovered knowledge. He already knew the explanation because he had read it in a book. Observed knowledge was therefore not used in the first activity and caused the first question and explanation to be disconnected from place. SW had no choice but to propose that question because he had the most confidence in the question and the answer and wanted to be precise. He formed a question about stone because he already had knowledge about the material's absorptivity, and this previous knowledge overshadowed observed knowledge. In addition, he was in a hurry, so he had to go back from the selection stage to the identification stage, not the observation stage.

Characteristics of SJ. SJ's observations developed after she learned about Deoksugung Palace. SJ's second observation was mainly about the eaves, drainpipe, and pillar. SJ had previously learned about eave angles and the drainage system, and how pillar shape disperses pressure. She therefore narrowed her observations to these factors. Her observation notes indicate how thoroughly she observed the four buildings. Use of the sense of touch in the third activity ("The wood frame is rough; porcelain tile is cold ") is quite noticeable, but the most distinguishable part is her construction and manipulation of the iconic model. Iconic models involve objects or processes that function to promote our understanding through real or virtual models, expressed mainly in the form of picture or drawing [29]. When SJ was observing Junghwajeon in the second activity, she observed Junghwajeon's eaves from various angles. As a result, when she looked up at the eaves from beneath them, she noticed that the centers of the eaves were slightly concave, and when viewed from the side, the eaves were raised. SJ observed the eaves from multiple angles, and drew them in detail in her notes, therefore constructing an iconic model. SJ developed abductive reasoning using this model because she felt more comfortable sketching than writing.

SJ's first question ("Why do materials like grass and wood easily catch fire, when stone doesn't?") was not seen in the observation and selection stage. She wanted to form the best explanation and thought her previous questions were not good enough, because she did not have related knowledge. SJ tried to make a new question, but she did not have time for new observations. While reviewing the observation questions, SJ recalled knowledge about the material's burning rates based on her real-life experience, which is a case-based analogy. She was certain that she could reach the best explanation with her knowledge and therefore concluded her first explanation ("Grass or wood is easily damaged. However, the stone is damaged unless pressure is applied strongly. Wood and grass that are damaged by small pressure are well lit, and stones that are not easily damaged don't burn"). A similar process happened during SJ's third activity.

SJ's second activity was different from the first and third activities. She made an iconic model of eaves after examining them from many perspectives. She constructed and manipulated the iconic model and was able to link it to knowledge she had. Her second explanation ("The more the eaves look like Hanok, the more rainwater gathers in the middle without the help of drain pipes. Jeonggwanheon and Seokjojeon, where eaves do not look like Hanok or have no eaves at all, drain the water from the top through a drainpipe") was a combination of observed knowledge ("shape of eaves and existence of drainpipe") and a concept she had previously learned ("cycloid curve"). SJ inferred scientific concepts from the model she made, and this corresponds to an image-based analogy. She explained her answer to the question using cause and effect. Her strategies in the second activity were causal combination, conceptual combination, and chained abduction. SJ's second explanation is related to Deoksugung Palace.

Characteristics of DW. DW documented more data in the first activity than the second and third activities. He tried to examine many data points to formulate questions. When other students tried to observe as many things as possible in the first activity, they disregarded future steps. They usually went back from a later stage to the observation stage to observe new things and to find new questions. On the other hand, DW considered making questions during the first observation so his observed data would be smoothly connected to his questions.

DW also used simple abductive reasoning in his first observation. He thought, "Holes in the wall are for ventilation." When he saw holes in the wall, he wondered about their purpose. He remembered that his mother always told him to open the window to refresh the air in his room. He drew out the scientific concept of ventilation from his own experience and applied it to holes in the wall at Junghwajeon. His simple abductive reasoning, which involves experience-based abduction, remained in the observation stage because DW assumed his ideas were too simple to be the final explanation.

In his second observation, quantitative observation appears. DW stated that the angle of the eaves at Jeonggwanheon was close to zero degrees. He was the only student who measured angles that precisely. DW was interested in math and science, so he may have believed that accurate measurements were important. Additionally, DW also applied the iconic model in his second abductive reasoning task. DW not only sketched observed data, but also manipulated it through future stages.

DW's first and third explanations ("People would have planted grass in the yard of Seokjojeon to make the stone less hot" and "It depends on the presence of ondol. Historically, Korea used wood that was easy to process, and foreign countries used more sturdy stones") look similar. Both are focused on the floor, material, and heating capacity. Still, DW did not acknowledge that fact in his third activity. He focused on the lower parts of buildings because he focused on the roof, which is the upper part of the building, in the second activity. He used the concept of heat capacity because it was familiar to him. DW did not use historical knowledge given by the researcher but rather prior knowledge. DW was unaware, but naturally used knowledge familiar to him.

Characteristics of EJ. In the first program, EJ, who was interested in history and science, already had prior knowledge obtained from books and movies. She revealed her prior knowledge during the observation stage (definitions of floor stone and rank stone). Based on her knowledge, EJ had already performed abductive reasoning at the observation stage. For instance, "Junghwajeon is the place where the king meets the officials because rank stones exist" and "the hole under Jeonggwanheon is not for ondol smoke." However, it was not an explanation of the degree that EJ wanted and was too simple to use as a final explanation.

EJ had a strong desire to observe new things, and unique things that other students did not notice. Since Jeonggwanjeon is distant from the other buildings, most students examined mainly Junghwajeon, Seokjojeon, and Seogeodang. After acknowledging this, EJ deliberately went to Jeonggwanheon during the first observation activity hoping to find something special. To find something different in the second activity, EJ put a pencil on the floor of Jeonggwanheon and checked to see whether the pencil would roll to observe the slope. She did not just observe, but also conducted simple experiments. Her eagerness to observe something special led her to more detailed observation.

However, EJ formed questions based on her background knowledge, not what she observed. She wanted to form the most complete and correct explanations, but to do so, she had to have knowledge she already had and felt was verified. In the second activity, she also used a book to form the explanation. Using only background knowledge in selecting or making questions was common in the second of third activities among all students. However, EJ showed this process during the first activity because she already had plenty of relevant knowledge.

During the selection stage in both the first and second activities, EJ went back to the observation stage to acquire extra knowledge. During the first selecting process, she required more knowledge about the direction the building faced in order to assist in developing the principle of floor stones. EJ examined the sun's location and the shadow of Junghwajeon to define the direction. Thus, she realized that Junghwajeon faces south and the sunlight directly reaches there. Meanwhile, in the second selection stage, EJ wanted to determine why the truss structure was used in the building. After she inspected Junghwajeon, she found that Junghwajeon's roof is particularly large and heavy compared to those of other buildings. Hence, EJ guessed that the lower part of the building was designed to properly support the heavy upper part.

Characteristics of HH. HH's degrees of observation and observation methods remained the same in the first and second activities. After he obtained scientific and historical knowledge, his observations became more detailed. For instance, HH constantly monitored Junghwajeon's foundation throughout the whole activity. His impression of the foundation was expressed as "the foundation exists" or "the foundation is high." In the third observation, HH noted the differences between stones that are in the foundation and linked these observations directly to his question. HH's questions about the foundation changed from questions about the existence of the foundation to questions about differences in color. MJ also showed similar development. MJ's observations about Junghwajeon's windows had changed from "The window is rectangular" to "The holes in the window are triangular and a little bumpy." HH's logic circuit was also comparable. HH thought he could form new questions because he had learned more things. When he acknowledged the fact that some stones were different, he recalled that Junghwajeon had burned down during the Japanese occupation of Korea and realized that this was an interesting question, so he observed the buildings more closely and tried to make new explanations.

HH committed similar mistakes of overgeneralization like the other students. In the first observation, he generalized Hanok and Yanggwan by stating that "Hanok has various colors" and "Yanggwan's color is monotonous." In the third observation, HH corrected the error by noting that "Junghwajeon is much more colorful than Seogeodang." One of his statements was, "Yanggwan has multiple layers, but most Hanoks have a single layer" He did not observe this in the observation stage, so he had to return to form a question. This also demonstrates the tendency of overgeneralization. HH characterized Junghwajeon and Seokjojeon and made a sweeping assumption about Hanok and Yanggwan because HH did not follow any standards of observation during the first activity and had to go back and inspect too many things. As a result, he did not have time to accurately observe enough about Seogeodang and Jeonggwanheon.

HH also conducted simple abduction in the first observation. HH thought, "The high stone foundation under Junghwajeon is to prevent the building from getting wet." HH left the statement in the observation because he considered it unimportant. Many students, including HH, believed that the final explanation should be complicated and important. Eco & Sebeok [16] identifies four kinds of abduction. Among them, the reasoner may be aware of only one general rule from which that case is expected to follow. This is overcoded abductive reasoning. HH and other students believed that overcoded abduction was not sufficient because it involves less prior knowledge. Students may naturally be prone to undercoded abduction in scientific or historical activities.

3.2. Criteria for Abductive Reasoning by Students

3.2.1. Observations

Every student conducted observations in their own way. Nonetheless, student observations were not consistent during the three activities, and changed over time. Students' observations can be categorized into two types, general and scientific. The distinction between types is based on the depth, area, and methods of observation.

General observation is a type of observation in which students try to observe everything they can see, but in a shallow way. Students often notice mere existence, or simply become impressed. They tend to observe sporadically over a broad area. Many students failed to observe Jeonggwanheon because the building is located far from the others. They did not manipulate objects and only used the sense of sight for observations, thereby making only simple observations [30]. Students ignored whether observed data could be used in future steps or not. Naturally, knowledge acquired by general observation is rarely used in the identification or selection stage. In many cases, students had to return to the observation stage because they could not use their observations. Overgeneralization seldom occurred because students did not have enough time to check facts, but typically appeared when students had little prior knowledge related to Deoksugung Palace.

Scientific observation involves a brief process of identification and selection. The characteristics of scientific observations are as follows: made in the context of scientific observation, specific data, and manipulative observation. Students often examined fewer items within a limited area in detail rather than making general observations. They used multiple senses and even simple experiments. Scientific observation takes time, so students tend to choose their subjects carefully, usually related to their prior knowledge. Scientific observation started with general observations. When students thought observed data were linked to their prior knowledge, they examined more closely because they believed their observations could be used to form scientific questions. In other words, they justified their observations. Students conducted manipulative observations either before or after they decided to investigate further. Data gained through scientific observation were mostly developed into scientific questions. Scientific observations included general observations but included more of a selective and circulative process that was deeply related to prior knowledge. This type of observation appeared most often in the second or third activity, after students had gained knowledge about Deoksugung Palace. According to model-based abduction, scientific observation indicates that students can evaluate the importance of evidence.

The distinctions are evident because observation is shaped by observer's prior knowledge and belief [19-21]. According to Lund [31], Hanson outlined the aspects of scientific observation as follows: "Scientific observation is a part of the whole investigation, not a process to be carried out in isolation." In this view, the prior knowledge can affect the whole abductive reasoning process in collective way. Plus, this means that scientific observation, which is connected to other inquiry processes, is closer to being an appropriate observation type since it leads to a further stage (Table 3).

Table 3. Distinctions between general and scientific observation

General Observation
Make many observations in a broad context
Simple observation
Ignores future stages Seldom used in following stages Often requires return to observation
Examples: The building is made of wood. The window is rectangular. The stone foundation is high.

Scientific Observation
Make a few observations in a narrow context
Manipulative observation
Considers future stages Influenced by prior knowledge
Examples: The wood used for the building is soft. The holes in the window frame are triangular and bumpy. The stones underneath the Hanok are unnatural to each other. For example, some stones are bright, and some stones are dark.

3.2.2. Forms of Abductive Reasoning

Eco & Sebeok [16] introduced four types of abduction: overcoded, undercoded, creative and meta-abduction. In our abductive reasoning program, not all students achieved creative abduction or meta-abduction. Because they were not familiar with the science or history of Deoksugung Palace, students remained limited to overcoded or undercoded abduction.

The students mostly engaged in undercoded abductive reasoning. They tried to identify observed and prior knowledge they could use to justify their explanations. Overcoded abduction appeared in students' activities, although many students left them in the observation stage. SW's first explanation ("Stone gets wet like wood because the stone has small pores") and SJ's third explanation ("Korean traditional paper has excellent dehumidifying effect, good ventilation, and prevents microorganisms from propagating, which is good for the preservation of Hanok") showed overcoded abduction. Neither of these two explanations was directly related to Deoksugung Palace. In the selection stage students sometimes acknowledge that they do not have enough knowledge to formulate an explanation. They then returned to the observation stage to observe new objects and form new questions. However, SW and SJ did not have enough time for additional observations and could not think of more scientific questions involving the observed data. Consequently, they chose to form questions based on their prior knowledge. Because they ignored the observed data, their explanations spontaneously became disconnected from place.

3.2.3. Unused Explanatory Models

Oh [14] described Explanatory Models (EM) to explain problem phenomena through an abductive thinking process. A few of our students used simple abductive reasoning but left it in the observation stage. Some students, like DW and HH, used overcoded abduction, which requires only one general rule, and was too simple to be the final explanation. Therefore, they formulated EMs but did not use them and tried to observe new things. In the context of model-based abduction, students were able to identify EM and Scientifically Sound Explanatory Models (SSEM). For instance, EJ performed simple abduction about slope, the purpose of the place, and purposes of the holes, but incorporated them in EM because she thought this explanation was too simple (e.g., there are several square holes drilled under Junghhwanheon, and none are used to vent ondol smoke). Furthermore, unused EM indicates that students can distinguish Critical Evidence (CE) and the Critical Resource Model (CRM).

3.3. Circular Process of Abductive Reasoning

Abductive reasoning is a straightforward form of reasoning that follows a sequence of observation, identification, selection, and explanation in a large frame. Yet, through the research, we were able to identify that the actual process is rather circular and reciprocal. Some routes are described by Kim [32], which indicated that the selection process occurs during the interpretation (identification) process (Figure 2).

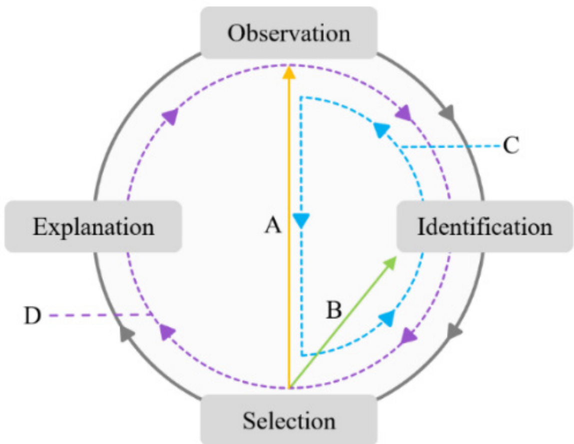

Figure 2. Circular process of abductive reasoning

A is the process of general observation. When students make general observations, they follow linear stages one by one. When they reach the selection stage, they try to identify adequate prior knowledge. Still, in many cases, they do not have enough prior knowledge to answer the identified question. Then they will decide to make more observations to form new questions. Process A often happens when students have little or no prior knowledge. Even when students have less knowledge, they constantly attempt process A until they identify any knowledge they previously had.

Process B happens when students attempt to gain new knowledge but fail because of time or other limitations, so they return to the identification stage and immediately form scientific questions. These newly derived questions often ignored observed data and were not related to Deoksugung Palace.

Process C corresponds to scientific observation. First, students observed things. When they realized that the objects they observed were related to their prior knowledge (selection), they assumed that this knowledge could be used to form a scientific question (identification). If the student elects to use the knowledge, he/she then tries to observe the object in detail. Detailed observations can happen both when the student evaluates knowledge and after the student chooses to investigate further. C often occurs when students already have plenty of scientific or historical knowledge.

Process D is about unused EMs. Students performed the whole abductive reasoning process with observed data and prior knowledge. However, if it is overcoded or too simple, they leave the EM and try to identify fresh evidence to form a new EM.

3.4. Effect of Prior Knowledge

To understand the effect of prior knowledge, student characteristics were organized and analyzed. Figure 3 is a graph with three axes (view of observation, form of observation, and unused EM). Students are differentiated by colored dots, which are indicated at the bottom-right of Figure 3. In the first and second activity, EJ is an outlier. EJ performed scientific observations in the first activity because of her prior knowledge, making her first abductive reasoning attempts similar to the second or third activities of other students. HH and EJ both used scientific and historical knowledge in the first activity, but HH had only general knowledge, like knowing that ondols are found in Hanok. EJ had more specific knowledge, such as Bakseok's mechanism. Additionally, EJ knew that she had prior knowledge, and therefore ignored knowledge given by the teacher.

A noticeable difference occurred in the transition from general observation to scientific observation. When they had no prior knowledge, five students stayed in general observation mode, except EJ. After they received knowledge from the teacher, most moved to general observation. In the final activity, everyone performed scientific observations. In other words, when students received prior knowledge, their observation became very selective. Scientific observation requires prior knowledge. Smith & Reiser [21] stated that scientists' observations are directed by their domain-specific knowledge. This statement also applies to normal students who are not experts. There was not much difference between the second and third activities in this respect. Every student except SJ engaged in scientific observation and undercoded abduction. More knowledge, in diverse areas, can encourage students to do more scientific observations and more creative abduction.

Nonetheless, in the third activity, SJ failed to mix scientific and historical knowledge and showed overcoded abduction, which did not appear in the first and second abductive reasoning tasks.

SJ's behavior can be explained by scaffolding. Scaffolding is a concept drawn from Vygotsky's sociocultural theory and his ideas about the zone of proximal development (ZPD).

"The zone of proximal development is the distance between what children can do by themselves and the next learning that they can be helped to achieve with competent assistance." [33]. Vygotsky defined scaffolding instruction as the "role of authors and others in supporting the learner's development and providing support structures to get to that next stage or level" [39]. In this program, we provided scientific and historical knowledge to the students as a scaffolding. Newly given knowledge led many students to the next level, which was scientific and creative. However, for SJ, this scaffolding worked as a challenge, and she failed to solve it. Maybe she could not achieve convergence thinking and needed that kind of scaffolding.

In any case, SJ's actions show that even when knowledge is provided to help the students, it can be counterproductive.

Finally, the students seemed unable to distinguish EM and SSEM, but this is not true. Rather, their capability to distinguish EM and SSEM either stayed the same or increased. This result is related to scientific observation. As students' observations became more selective and detailed, they eliminated simple abduction from their observation notes, because they knew that it could not yield scientific questions or explanations.

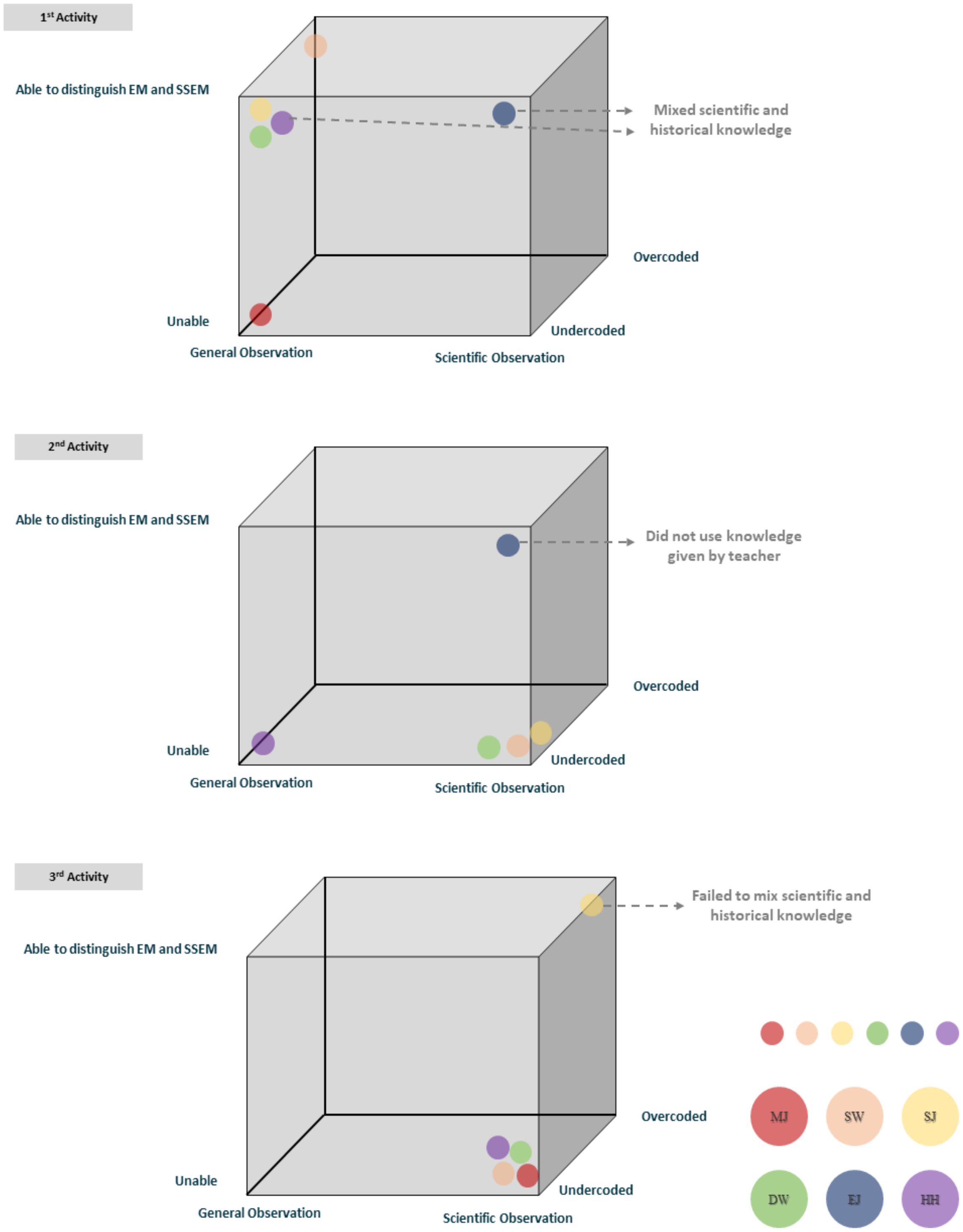

Figure 3. Effect of prior knowledge on abductive reasoning

Moreover, although not mentioned in our study criteria, the majority of students engaged in analogical abductive reasoning, which includes case-based or concept-based analogies. In addition, re-enactments, or empathetic ability, which is important in history education, did not appear at all. Even though Deoksugung Palace is a historically important place and we provided historical knowledge, students used it as additional knowledge to support scientific explanations, and none engaged in re-enactment.

4. Conclusion

In this study, we identified how the prior knowledge of different disciplines affects each stage of induction, how each abductive reasoning stage interacts with each other, and what characteristics emerge according to their scientific and historical knowledge in the context of Deoksugung Palace and used our findings to draw educational implications. We developed and applied an abductive program that provides scientific and historical knowledge about Deoksugung Palace to elementary school students. To develop the science-history abductive reasoning program at Deoksugung Palace, we examined the nature of abductive reasoning, studied the scientific and historical background of Deoksugung Palace, and established the content of the program.

Abductive reasoning is routinely used in daily life as well as in scientific contexts, but it is still hard to identify instructors who incorporate abductive reasoning in their teaching. Science learning takes place in the context of culture. We hope that this research, illustrating the circular process of abductive reasoning and the effects of prior knowledge in traditional and cultural places, can inspire and help teachers. Teachers can decide which areas of knowledge they should provide to students according to their intended results.

The results of this study can be summarized as follows. First, the relationship between prior knowledge and abductive reasoning should be more closely analyzed in science learning in historically important contexts. Follow-up studies should comprehensively or quantitatively analyze how prior knowledge affects students during each abductive reasoning stage. It is also necessary to analyze the educational effects of convergence from various angles and to develop convergence-themed programs in schools. Because there are many places with excellent scientific properties that have cultural and historical significance, it is also necessary to develop educational programs that are suitable for teaching about those places and to analyze the educational effectiveness of these programs closely.

REFERENCES

[1] D. Cunningham, “Cognition as Semiosis: The Role of Inference”, Theory & Psychology, vol. 8, no. 6, pp. 827-840, 1998.

[2] C. Peirce, “Collected Papers of Charles Sanders Peirce”, Harvard University Press, 1960.

[3] L. Magnani, “Abduction and Chance Discovery in Science”, International Journal of Knowledge-based and Intelligent Engineering Systems, vol. 11, no. 5, pp. 273-279, 2007.

[4] G. Harman, “The Inference to the Best Explanation”, The Philosophical Review, vol. 74, no. 1, pp. 88-95, 1965.

[5] Y. Kwon, J. Jeong, M. Kang, Y. Kim, “A Grounded Theory on the Process of Generating Hypothesis-knowledge about Scientific Episodes”, Journal of the Korean Association for Science Education, vol. 23, no. 5, pp. 458-469, 2003.

[6] S. Schumm, S. Schumm, “To Interpret the Earth: Ten Ways to be Wrong”, Cambridge University Press, 1998.

[7] C. Kim, “Inferences Frequently Used in Earth Science”, Journal of the Korean Earth Science Society, vol. 23, no. 2, pp. 188-193, 2002.

[8] C. Shelley, “Visual Abductive Reasoning in Archaeology”, Philosophy of Science, vol. 63, no. 2, pp. 278-301, 2016.

[9] P. Flach, A. Kakas, “Abductive and Inductive Reasoning: Background and Issues”, Springer, 2000.

[10] J. Josephson, S. Josephson, “Abductive Inference: Computation, Philosophy, Technology”, Cambridge University Press, 1996.

[11] F. Abd - El - Khalick, M. Waters, A. Le, “Representations of Nature of Science in High School Chemistry Textbooks Over the Past Four Decades”, Journal of Research in Science Teaching, vol. 45, no. 7, pp. 835-855, 2008.

[12] Y. Kwon, J. Jeong, Y. Park, M. Kang, “A Philosophical Study on the Generating Process of Declarative Scientific Knowledge-focused on Inductive, Abductive, and Deductive Process”, Journal of the Korean Association for Science Education, vol. 23, no. 3, pp. 215-228, 2003.

[13] P. Oh, C. J. Kim, “A Theoretical Study on Abduction as an Inquiry Method in Earth Science”, Journal of The Korean Association For Science Education, vol. 25, no. 5, pp. 610-623, 2005.

[14] P. Oh, “Roles of Models in Abductive Reasoning: A Schematization Through Theoretical and Empirical Studies”, Journal of the Korean Association for Science Education, vol. 36, no. 4, pp. 551-561, 2016.

[15] L. Magnani, “Model-Based and Manipulative Abduction in Science”, Foundations of Science, vol. 9, no. 3, pp. 219-247, 2004.

[16] U. Eco, T. Sebeok, “The Sign of Three: Dupin, Holmes, Peirce”, Indiana University Press, 1988.

[17] S. Hartmann, “Review of J. Cushing: Philosophical Concepts in Physics”, Erkenntnis, vol. 52, pp. 133-137, 2000.

[18] D. Haury, “Fundamental Skills in Science: Observation. Eric digest”, Eric Clearinghouse for Science Mathematics

and Environmental Education, 2002.

[19] R. Driver, B. Bell, "Students' Thinking and the Learning of Science: A Constructivist View", School Science Review, vol. 67, no. 240, pp. 443-456, 1986

[20] R. Gunstone, "Observation in Science Class: Students' Beliefs about Its Nature and Purpose", National Association for Research in Science Teaching, St. Loius, USA, April, 1996,

[21] B. Smith, B. Reiser, "Explaining Behavior Through Observational Investigation and Theory Articulation", The Journal of the Learning Sciences, vol. 14, no. 3, pp. 315-360, 2005.

[22] H. Shim, J. Jeong, K. Park, Y. Kwon, "Role and Process of Abduction in Elementary School Students' Generation of Hypotheses Concerning Vapor Condensation", Journal of the Korean Earth Science Society, vol. 24, no. 4, pp. 250-257, 2003.

[23] Y. Kwon, J. Jeong, Y. Park, "Roles of Abductive Reasoning and Prior Belief in Children's Generation of Hypotheses about Pendulum Motion", Science & Education, vol. 15, no. 6, pp. 643-656, 2006.

[24] P. Oh, "How Can Teachers Help Students Formulate Scientific Hypotheses? Some Strategies Found in Abductive Inquiry Activities of Earth Science", International Journal of Science Education, vol. 32, no. 4, pp. 541-560, 2010.

[25] S. Jeong, H. Choi, I. Yang, "An Analysis of Abductive Reasoning on the Inquiry of Scientists and Elementary School Gifted Children in Science", Journal of the Korean Association for Science Education, vol. 31, no. 6, pp. 901-919, 2011.

[26] C. Jung, "Development of Process Theory and Outcome Theory for Junior High School Students' Outdoor Fieldwork Education Focusing on Abductive Inquiry", Ewha Womans University: Ph. D. Thesis, 2018.

[27] N. Orion, "Development of a High-school Geology Course Based on Field Trips", Journal of Geological Education, vol. 31, no. 1, pp. 13-17, 1989.

[28] D. Tirosh, R. Stavy, "Students' Ability to Confine Their Application of Knowledge: The Case of Mathematics and Science", School Science and Mathematics, vol. 92, pp. 353-353, 1992.

[29] R. Harre. "The Philosophies of Science", Oxford University Press, 1972.

[30] D. Shin, J. Shin, Y. Kwon, "An Analysis on the Processes of Observation Teaching and the Types of Observation in Elementary Life Science Classes", Journal of Korean Elementary Science Education, vol. 25, no. 4, pp. 339-351, 2006.

[31] M. Lund, N. Hanson, "Observation, Discovery, and Scientific Change", Humanity Books, 2010.

[32] J. Kim, "Abductive Reasoning and Interpretations of Conceptual Combinations", Indiana University: Ph. D. Thesis, 2001.

[33] R. Van Der Stuyf, "Scaffolding as a Teaching Strategy", Adolescent Learning and Development, vol. 52, no.3, pp. 5-18, 2002.