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EFFECTIVENESS OF GENERATING AN EXPLANATORY HYPOTHESIS FOR INCONGRUENT RESULTS IN ENHANCING SUBSEQUENT SCIENCE LEARNING

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Abstract. *While existing studies have underscored the educational benefits of generating explanatory hypotheses (EHs) in response to unexpected outcomes, empirical research on the underlying mechanisms driving their effectiveness in science learning remains limited. Thus, this study aimed to empirically examine the effectiveness of generating an EH for incongruent results in enhancing science learning. Two studies were conducted with 208 students who faced incongruent results out of 578 fifth and sixth-grade students. Study 1 revealed through hierarchical regression analysis that generating an EH predicted enhanced science learning and uncovered the highest predictive power compared to other predictors, including prior knowledge and motivating variables. Study 2 explored the contribution of generating an EH for incongruent results to comprehending scientific concepts through think-aloud protocols and retrospective interviews. The results demonstrated that, unlike students who could not generate EHs and passively acquired information from the text, students who formulated EHs more actively organized information by verifying their hypotheses and paraphrasing the scientific concepts in the text during reading the learning material after generating their hypotheses. The study findings indicate science education direction for future research and broaden the discourse surrounding effective educational practices.*

Keywords: *explanatory hypothesis, incongruent results, science learning, mixed-method approach*

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Introduction

Science is driven by curiosity and aims to understand the natural world by uncovering the unknown and addressing questions that challenge existing knowledge. It can be regarded as an enterprise wherein explorations, not invariably predicated on prior hypotheses or theories, uncover puzzling observations that require explanations (Lawson, 2010). Accordingly, the heart of scientific activities lies in evolving naïve theories into more sophisticated ones, and individuals who do science often encounter unexpected results that deviate from their initial expectations. Such encounters with unexpected results prompt individuals to inquire into their causes, encouraging the generation of predictions or alternative explanations by back-tracking the outcomes to identify the underlying reasons (Brockbank & Walker, 2022; Brod et al., 2018; Park, 2006). Merely observing unexpected results is insufficient to falsify the core of their conceptions without generating a new alternative explanatory hypothesis (EH) (Park, 2001). Therefore, even when faced with unexpected results, suggesting a tentative EH for the occurrence of the results is crucial because it stimulates further scientific inquiry (Lipton, 2004; Schulz, 2012; Zimmerman, 2000) and facilitates the change of preconceptions into scientific concepts (Park & Kim, 1998). Generating hypotheses for such unexpected results can influence subsequent scientific learning and exploration, which is essential for the advancement and progress of science (Allchin & Zemplén, 2020; Bao et al., 2022; Brod et al., 2018). Therefore, extensive research on generating EHs, which can explain inconsistent results when they occur, is essential in science education.

However, the mechanisms by which generating an EH for incongruent results may improve learning are not well known. Research on the act of generating an EH when confronting contradictory observations has primarily focused on its processes or origins (e.g., Lawson, 2004; Park, 2006), specific types or styles (e.g., Lawson, 2010; Park, 2006), and generation and testing (e.g., Hoew et al., 2000; Lawson, 2004), rather than on the learning effects of generating an EH for incongruous results. An empirical understanding of generating an EH for incongruent results in students' academic achievements is crucial, as this understanding can enlighten science educators regarding

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the importance of developing students' hypothesis-generating skills and providing them with opportunities for generating EHs. Particularly, providing students with opportunities to generate new alternative hypotheses to explain unexpected results is essential because conceptual change may not occur if students do not experience meaningful conflict, even when they make incorrect predictions (Driver, 1988; Limon, 2001; Park, 2001). Therefore, when students are provided with the opportunity to generate EHs for inconsistent outcomes, it becomes important to examine whether generating EHs for incongruent results can enhance their subsequent science learning. However, research on the effectiveness of EH generation in science learning is limited. Therefore, by focusing on the learning effect of generating an EH for unexpected outcomes, this research examined its effectiveness in enhancing subsequent science learning.

Generating an EH for Incongruent Results as an Opportunity for Subsequent Science Learning

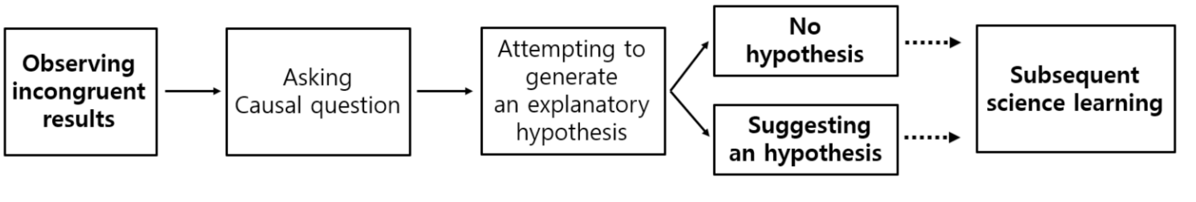
An EH is a type of hypothesis that potentially explains observed scientific phenomena (Park, 2006). Generally, it begins with observing outcomes and then surmising the reasons for these outcomes by leveraging prior knowledge and experience. EHs can address causal questions, particularly those arising from observations of phenomena and offer insights into why certain events occur or why specific patterns exist (Wenham, 1993). Therefore, generating an EH for incongruent results in this study refers to the act of formulating a tentative EH upon encountering incongruity as an attempt to explain or make sense of the inconsistency.

Science is inherent hypothetico-deductive in nature in that it emphasizes formulating descriptive and causal hypotheses based on personal experience and knowledge, testing the hypotheses, and resolving inconsistencies when observing puzzling natural phenomena in everyday life (Lawson, 2004). Therefore, generating an EH for incongruent results is a fundamental element in the nature of scientists' science and is consequently emphasized in science education (Bao et al., 2022; Park, 2006).

For effective science learning, presenting results that contradict students' preconceptions has been emphasized in previous studies (e.g., Bonawitz et al., 2012; Lee et al., 2003; Stahl & Feigenson, 2017). Students confronted with phenomena that violate their existing theories naturally further explore and sometimes generate new tentative hypotheses to account for these discrepancies. Because these tentative hypotheses can activate students' prior knowledge and encourage them to connect existing knowledge and new information, students can reconcile the differences between their initial predictions and actual results or better understand the incongruent phenomena by comparing their hypotheses with the actual results in subsequent learning (Morrison et al., 2015; Stahl & Feigenson, 2017). Falsifying the core of their conception based solely on contradictory observations without a new alternative EH is challenging (Park, 2001). Therefore, when confronting an unexpected outcome, generating an EH for discrepancies, regardless of whether the hypothesis is correct or incorrect, can serve as an opportunity to learn scientific concepts (Bonawitz et al., 2012; Brod et al., 2018).

Figure 1 presents the EH generation process when confronted with incongruent results. Students observe incongruent results and then pose a causal question regarding the reason behind the results. They then attempt to generate a hypothesis explaining the results, eventually settling on one that they find plausible, or in some cases, failing to generate a hypothesis (Lawson, 2010; Park, 2006). At this point, the hypothesis generated is typically required to be tested or verified through further inquiry (e.g., subsequent science learning), with the results supporting or refuting it (Kim et al., 2012; Lawson, 2004). Students can then evaluate and verify their EHs based on evidence, seeking new knowledge as they refine and integrate their pre-existing knowledge (Bao et al., 2022; Kuhn & Dean, 2004; Kuhn, et al., 2009). Therefore, generating an EH serves as a catalyst for reconstructing and expanding scientific knowledge.

Figure 1
EH Generation Process for Incongruent Results and Subsequent Science Learning



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Complex Factors Influencing the Generation of an EH for Incongruent Results

Although there is rich literature on studies of generating an EH when confronting contradictory results, the research community seems to have not yet reached a consensus on the factors that can affect the generation of an EH for incongruent results. According to the existing literature on generating an EH, several key factors that influence its generation are closely related or interconnected. Abundant research evidence suggests that the most prominent of these key factors is corresponding prior knowledge (Kuang et al., 2023; Schulz, 2012; Park, 2006). The corresponding prior knowledge—knowledge necessary for EH generation in a context—refers to domain-specific content knowledge about scientific concepts, including theories and laws, which enables students to understand the phenomena that science seeks to explain (Kind & Osborne, 2017). The knowledge serves as a foundation for generating hypotheses in specific contexts (Osborne, 2014).

However, prior knowledge alone is insufficient to predict the occurrence of generating an EH when confronted with incongruent outcomes. Thus, in addition to prior knowledge, two additional factors that could influence EH generation were identified: motivation to engage in EH generation and cognitive abilities. Motivation, such as curiosity or interest regarding the given content or phenomenon, is necessary to engage in subsequent exploration and generate EHs for inconsistent results in science learning (Bonawitz et al., 2012; Lee et al., 2003). This is because individuals may struggle to generate an EH when they lack interest in inconsistent results or are not curious about the result occurrence. The need for cognition is also evidenced as an intrinsic motivation to engage in effortful cognitive tasks (Cacioppo & Petty, 1982), which is crucial in prompting EH generation. Need for cognition refers to an individual's inclination to engage in and enjoy thinking (Cacioppo & Petty, 1982). Individuals with a high need for cognition enjoy solving complex problems and are more likely to engage in incongruity detection (Leding & Antonio, 2019), it pertains to their need to understand and rationalize relevant environments when their cognitive structures diverge from the experiential world (Cohen et al., 1955). Generally, proposing an EH for incongruity requires motivation to undertake the task and strive toward its solutions, particularly when they are not apparent (Mayer, 1998). This motivation may be relevant to the need for cognition associated with tasks that demand active exploration and those with non-apparent solutions (Funke, 2001; Rudolph et al., 2018). Students with a high need for cognition tend to persistently explore given problems because of their likely lower need for cognitive closure—a desired cognitive end state that can be achieved by extensive or limited processing (Fortier & Burkell, 2014; Webster & Kruglanski, 1994). They continue to seek explanations even after checking the answer to a problem (Coutinho et al., 2005). Consequently, the need for cognition is positively related to the generation of an EH for incongruent results (Fleischhauer et al., 2010; Hill et al., 2013). Additionally, certain factors, which may not be direct motivations for generating an EH, can influence an individual's motivation to generate an EH. These include students' science self-concept and perceived task difficulty. Students who possess a high academic self-concept within a particular field demonstrate confidence and a feeling of superiority in their competence within that subject area (Bong & Skaalvik, 2003; Ferla et al., 2009). Therefore, students with a higher science self-concept can engage in generating an EH with confidence, even when their expectations are incorrect. Additionally, considering that students' perceived task difficulty can influence their reasoning strategies for generating hypotheses about given tasks (Heemskerk et al., 2007) or their motivation for subsequent learning (Robinson, 2001), their motivation to engage in EH generation may vary depending on their perceived task difficulty. Thus, motivational factors are undoubtedly integral predictors of EH generation for incongruent results.

Furthermore, EH generation depends on cognitive abilities and is not limited to learners' prior knowledge or motivation. As suggested by numerous studies, cognitive abilities that can influence EH generation encompass the scientific reasoning skills necessary for scientific inquiry, including the ability to explore a problem, formulate hypotheses, manipulate variables, and evaluate outcomes, along with higher-order thinking abilities such as critical/analytical thinking and causal reasoning (Bao et al., 2022; Zimmerman, 2000). These numerous cognitive abilities intricately intertwine to influence the EH generation. Therefore, even when an individual possesses elevated levels of some of these abilities, it remains unclear whether encountering incongruent results can lead to EH generation. This uncertainty may be partially attributed to the fact that the corresponding prior knowledge or specific abilities required to generate an EH may vary with the context, and EHs may not be generated when motivation to engage in EH generation is lacking.

EH generation is a complex skill that develops relatively late (Piekny & Maehler, 2013); thus, assessing scientific reasoning skills in younger students may be inappropriate (Osterhaus & Koerber, 2023). Therefore, rather than examining all potential cognitive abilities that could influence EH generation, this study assumed that students who successfully generated an EH for incongruent results possessed higher cognitive abilities (but identifying the

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specific abilities contributing to this success is challenging). Consequently, in this study, science curiosity, interest, science self-concept, need for cognition, and prior knowledge (as measured by pre-test scores) were classified as the learner's pre-existing variables, while perceived difficulty and state curiosity were classified as the learner's experienced variables during problem-solving. This categorization aimed to control for factors such as prior knowledge and motivation that could influence EH generation and subsequent science learning.

Current Research

Although the aforementioned discussion shows that generating an EH for incongruent results can be an opportunity for subsequent science learning, the scope or pattern of EH-induced learning enhancement remains unknown. No study, to the best of our knowledge, has explored how generated hypotheses, whether correct or incorrect, relate to subsequent science learning or elucidate the reasons behind their potential positive impact on the learning of scientific concepts. Therefore, the aim was to address these gaps in literature by conducting two studies that explored the effectiveness of generating an EH in enhancing subsequent science learning after hypothesis generation, focusing on improving conceptual understanding. The first study empirically tested whether generating an EH for incongruent results can predict improvements in science learning that follows the EH generation. The second study explored how generating an EH for incongruent results could positively influence the comprehension of scientific concepts in subsequent learning after the EH generation. The aim of this research was to answer the following two research questions:

Research Question 1. Does generating an EH for incongruent results positively predict subsequent science learning outcomes? (Study 1)

Research Question 2. If so, how can generating an EH for incongruent results contribute to enhancing subsequent science learning? (Study 2)

Research Methodology

A quantitative approach is effective for analyzing trends using statistical data; however, it is limited in demonstrating the substantive relationships between various cases and experiences within the educational context (Kang & Kim, 2024). Therefore, an explanatory sequential mixed-method approach was employed, integrating quantitative statistical analyses with qualitative think-aloud protocol data, to track and elucidate the quantitative findings and obtain a comprehensive understanding of the effectiveness of generating an EH for incongruent results (see Creswell & Plano Clark, 2007).

Study 1: Does generating an EH for incongruent results positively predict subsequent science learning outcomes?

Participants

The participants comprised 578 fifth- and sixth-grade students (287 females; 236 in fifth grade) from two elementary schools—one in a large city (13 classes, 410 students) and the other in a rural area (7 classes, 168 students) in South Korea. Among the 578 students, those who responded insincerely or unclearly and those with at least one missing response, were excluded from the analysis, resulting in 492 students' responses being obtained. Among them, 269 faced results that aligned with their expectations, whereas 223 confronted results that violated their expectations. Among the students who encountered a violated result, 15 students with low confidence in their preconceptions (i.e., students with a preconception belief level of two or lower) were excluded, and a final analysis was conducted with 208 students (105 females; 88 in fifth grade).

Procedures

The procedure for Study 1 is illustrated in Figure 2. Before presenting students with one Science Question (see Figure 3), students underwent assessments of science curiosity, science self-concept, interest in thermal conductivity (as covered by the Science Question), and need for cognition measures.

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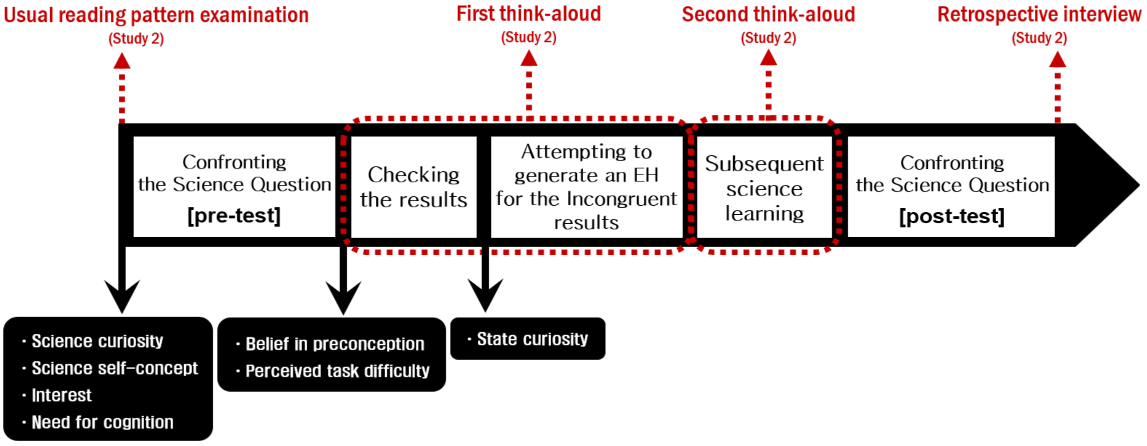
Figure 2

Overview of the Research Procedure (Parts Highlighted in Red are Introduced in Study 2)



All students were asked to answer the Science Question (pre-test) and justify their answers. Immediately after attempting to answer the Science Question, students' beliefs in preconceptions and their perceived task difficulty in answering the Science Question were measured. Following the ratings, students were shown the results (the correct answer) of the Science Question without explanation and then asked to generate an EH for the results. After providing sufficient time for them to generate an EH, their state curiosity regarding the results was measured. Subsequently, the learning material was provided to the students, which included the solution and explanations of the corresponding scientific concepts necessary to solve the Science Question (see Figure 3). After a 3-minute break, students were asked again to attempt answering the Science Question (post-test). None of the tasks were time-limited and were performed in a typical science class context.

Measures

Seven variables were assessed. For students to encounter an expectation-violating outcome, they must recognize their incorrect answer and hold some belief in their preconceptions (Lee et al., 2003); thus, beliefs in preconceptions were measured to identify students who encountered results incongruent with their preconceptions. Additionally, science curiosity, science self-concept, interest, need for cognition, perceived task difficulty, and state curiosity were included as control variables because they were expected to affect both EHs generation for incongruent results and subsequent science learning. When modifying specific measurement items, consultation was sought from five experts in the field. Furthermore, pilot testing was carried out with fifth- and sixth-grade elementary school students to ascertain any potential challenges in understanding and answering the revised items. All items in the measures for this study were structured to elicit responses on a five-point Likert scale, ranging from "not agree at all" to "strongly agree."

Control variables

Students' science curiosity was assessed using the Epistemic Curiosity Scale comprising 10 items developed by Litman and Spielberger (2003). The scale was modified by revising certain items to assess epistemic curiosity regarding science. An example of a revised item included: "When I learn new scientific contents, I would like to find out more about it." Cronbach's α was .915. Science self-concept was assessed by modifying the self-concept measurement developed by Kim (1985) to specifically evaluate self-concept within a scientific discipline (i.e., science self-concept). An example item included, "I can do better science than other students if I set my mind to it," and Cronbach's α was .944. The interest questionnaire comprised three items assessing students' level of interest in the contents of the Science Question, with the sample item being "How does heat transfer?" Cronbach's α was .882. The Need for Cognition Scale, developed by Cacioppo et al. (1984), was used to measure the need for cognition. A sample item was "I enjoy problems that require a lot of thinking," and Cronbach's α for a total of 18 items was .886. The perceived task difficulty, representing the degree to which the participants perceived the Science Question as difficult, was assessed using a single item: "I think this question is difficult." State curiosity triggered after encountering an expectation-violation

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outcome was measured using the Science State Curiosity Scale developed by Kang et al. (2020), which comprised five items designed to assess curiosity after checking the answer. Cronbach's α for the five items was .899.

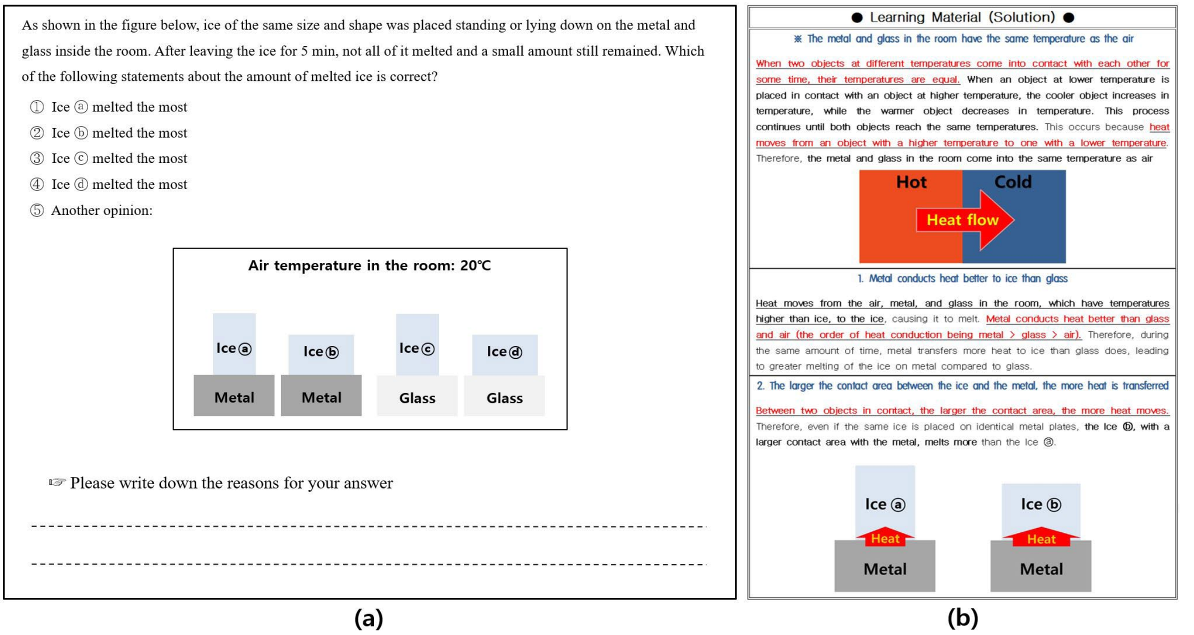
Belief in preconception

Students' belief in their preconceptions was assessed using two items measuring the confidence in their answers after solving the Science Question developed by Lee et al. (2003): "I think my choice is right" and "I have a reason for my choice." Cronbach's α for the two items was .728.

Science Question (pre- and post-tests)

Generating an EH for incongruent results is influenced by students' prior knowledge, everyday experience, and observations (Schulz, 2012). Therefore, selecting Science Question contents that are familiar to students, and falls within the scope of the regular curriculum is advisable, enabling students to formulate their hypotheses regarding the results of the question. In line with this, thermal concepts familiar to students were selected for the Science Question contents (Kang & Kim, 2024). The Science Question was designed in a descriptive question format, as depicted in Figure 3, requiring students to write down the reasons for their answers to examine their conceptions more thoroughly. For this study, the Science Question was administered as pre- and post-tests. The order of answers was rearranged in the post-test to mitigate the risk of students simply recalling correct answers without understanding the scientific concepts. This ensured that the pre- and post-tests were identical except for the sequence of answer choices, allowing for direct comparison. The Science Question was designed to measure two scientific concepts—metal has higher thermal conductivity than glass, and the extent of heat transfer increases with a larger contact area between both materials. Each concept was scored out of four points, for a total of eight points for the Science Question.[1]

Figure 3
(a) Science Question and (b) Learning Material Containing Scientific Concepts and Explanations Related to the Science Question



(a) (b)

1 In the Science Question, students' explanations regarding their responses were scored based on a four-step scoring criteria (see Authors, 2024): (1) "Is it appropriate for the question context and free of misconceptions?" (2) "Does the student state their own thoughts without explaining the conditions of the question as they are?" (3) "Is the reason for the phenomenon explained using scientific concepts?" and (4) "Are scientific terms and expressions used?" A score of 1 point was assigned for each step when satisfied, whereas students who answered with "I do not know" or "I just guessed" received 0 points, irrespective of the scoring criteria. Two science education experts determined Cohen's κ range for each target concept as 0.918–0.955. Discrepancies in the scoring were addressed through discussions until a consensus was reached.

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Analysis

Students are required to identify their incorrect answers and possess a certain degree of belief in their preconceptions to encounter a violation outcome (Lee et al., 2003). Therefore, the analysis was conducted on 208 students who gave incorrect answers to the Science Question and exhibited belief in their preconceptions at an average level or higher (i.e., students with a combined score of 3 or higher on two items measuring belief in preconception on a Likert scale ranging from 0 to 4). The 208 students were divided into two groups: 95 students capable of generating an EH for incongruent results (EH group) and 113 students unable to generate an EH for incongruent results (nEH group). The criteria and examples used to distinguish the two groups are presented in Table 1.

Table 1
Criteria and Examples for Determining Whether an EH Has Been Generated

Group	Criteria	Examples
EH	• Students can generate an EH for incongruent results (correct answers to the question).	- "Metal conducts heat better than glass" (a correct hypothesis)
	• Including EHs that are scientifically incorrect	- "Ice melts faster because metal is hotter" (an incorrect hypothesis)"
nEH	• Students cannot generate an EH for incongruent results (correct answers to the question)	- "I don't know"
	• Including a restatement of the Science Question conditions but no explanation for the results	- "Ice is lying down on the metal" (a restatement of the Science Question conditions)

Note. EH: Explanatory Hypothesis, nEH: non-Explanatory Hypothesis

Whether the post-test scores of the EH group were higher than those of the nEH group was tested. Since students in the EH group who generated an EH correctly might score higher on the post-test than those who generated an EH incorrectly, a one-way analysis of variance was conducted to determine whether the post-test scores differed among students who generated an EH correctly, those who generated an EH incorrectly, and those in the nEH group. After confirming that the post-test scores of the EH group were higher than those of the nEH group, a hierarchical regression analysis was conducted to ascertain whether generating an EH for incongruent results could significantly predict subsequent science learning, with post-test scores as the dependent variable. The first model (Model 1) included students' pre-existing variables that were expected to influence the generation of EHs or post-test scores, such as science curiosity, science self-concept, interest, need for cognition, and pre-test scores (prior knowledge). In the second model (Model 2), variables experienced during solving the question that were expected to affect post-test scores were added, such as perceived task difficulty and state curiosity. In the third model (Model 3), generating an EH was added to verify whether it could significantly predict post-test scores, even after controlling for independent variables included in Models 1 and 2. Statistical analyses were conducted using SPSS Statistics 22.

Study 2: How can generating an EH for incongruent results contribute to enhancing subsequent science learning?

Although students in the EH group in Study 1 demonstrate better subsequent science learning outcomes, there remains a lack of understanding regarding the mechanisms responsible for the positive impact of generating an EH on subsequent science learning. Thus, the second study examined how generating an EH for incongruent results contributes to the enhancement of subsequent science learning (i.e., reading the learning material), focusing on learning that occurs after hypothesis generation. This study adopts a new approach to explore students' subsequent science learning through qualitative analysis derived from think-aloud protocols and retrospective interview data.

Participants

A class was randomly selected from the 20 classes that participated in Study 1 to ensure sufficient variance in hypothesis-generating skills among participants. All the students in the selected class were invited to participate,

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of which 95.8% (23 students, 12 females) agreed to participate. The selected students were general students who had never been diagnosed with dyslexia or learning disabilities or nominated as gifted students by the Office of Education. Among them, 13 students encountered results that aligned with their expectations, while 10 encountered results that violated their expectations. All 10 students who encountered violation results believed in their preconceptions at an average level or higher. The 10 students were divided into two groups: the EH group comprising six students (including two females) and the nEH group comprising four students (including two females), depending on whether they generated EHs for incongruent results (see Table 1).

Procedures

A concurrent think-aloud protocol was adopted to capture the processes of EH generation and comprehension of the learning material by the students to examine the contribution of EH generation to subsequent science learning. 'Think-aloud' is a research technique, wherein participants verbalize their thoughts that come to mind as they go through a task or process, providing insights into their cognitive processes (Kucan & Beck, 1997). This method is advantageous in effectively identifying the real-time cognitive process or EH-generation processes when a student solves given tasks and understands written material (Ericsson & Simon, 1993). As shown in Figure 2, two think-aloud tasks were introduced during Study 2: the first one was while students checked the Science Question results and subsequently attempted to generate EHs for those results. The second task was introduced while students learned scientific concepts related to the question by reading the learning material.

One week before receiving the Science Question, students were trained to think out loud over two sessions of approximately two hours. The training, which was designed as a rehearsal for the research task, involved practice tasks similar to the actual research tasks to help students fully comprehend and familiarize themselves with the think-aloud method. During the sessions, students' usual reading patterns—the order in which they read the material (whether they read it sequentially) and the parts they focused on (whether they read the entire text or specific parts, or looked at all pictures)—were examined twice using two practice reading materials, each covering a different thermal concept. In the week following the training, the Science Question and accompanying learning material were presented to the students during their regular science classes. The students then attempted the question and learned relevant scientific concepts for approximately 10–15 min. While reading the learning material, students were instructed to underline the sentences they were currently reading, and a video captured the part being read alongside the order of reading. Students were requested to work individually, refrain from interacting with each other, and avoid copying each other's work during the assignments.

Measurements were taken five times in a classroom setting with 23 students randomly divided into five groups of four to five each to minimize background noise and prevent students from overhearing their peer's thought verbalizations. Interventions in the middle of the task were avoided to prevent disruptions to the task process. However, if the students were silent for more than approximately five seconds, they were prompted by asking "*Please speak if any thoughts come to mind*" or "*What are you thinking about right now?*" to encourage continuous thinking aloud.

Based on the transcriptions and video data, a retrospective interview was conducted individually in a classroom the following day to further probe students' EH generation and learning processes. The students were shown transcriptions of their think-aloud monologues and video recordings of their behaviors while reading to help them recall their thinking and cognitive activities while generating EH and reading. The interviews were semi-structured; thus, additional questions were posed to the students when further clarification regarding their responses was required, aiming at eliciting their thoughts. The main interview questions during the EH generation process included, "*Why did you think this way?*" and during the subsequent learning process, *"In what order/how did you read the learning material?"* Each interview lasted 10–20 min and was transcribed for analysis.

Measures

All instruments used in Study 2 were identical to those used in Study 1, except for examinations on students' usual reading patterns, two think-aloud protocols, and retrospective interviews (see Figure 2).

Analysis

The duration of the students' two think-aloud sessions ranged from 2–10 min, and the think-aloud protocols were transcribed verbatim from the audio recordings. As this study aimed to explore the differences in subsequent

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science learning (i.e., conceptual understanding) between the EH and nEH groups, the analysis focused on the second think-aloud protocol, which represented students' cognitive processes while reading the learning material (cf. the first protocol was used as a reference to aid in understanding students' cognitive and thinking processes from EH generation to subsequent learning while analyzing the second protocol).

The analysis of the second protocol aimed to track students' reading processes and identify their comprehension strategies. Initially, the learning material was directly marked to track the reading process, such as the students' reading patterns (i.e., the order of reading and parts read) and reading time (i.e., time spent reading and comprehending the learning material) by listening to the students' audio recordings. Subsequently, the transcribed think-aloud protocols were categorized based on the types of comprehension strategy used while reading the learning material (see Figure 4 and Table 2). First, verbalized responses during the think-aloud task were parsed into idea units, which generally comprised phrases containing a subject and a verb. Each idea unit was then categorized by referencing Carlson et al. (2014) and Van den Broek et al. (2001). Further, the frequencies of each strategy were scrutinized, and those strategies that occurred less than twice throughout the entire transcripts (e.g., evaluative comments about text such as "*the text is long*") and responses that did not fall into any of the strategies (e.g., responses solely comprising filler words such as "*Um...*") were excluded. As shown in Table 2, seven strategies were identified, which were categorized into those that actively organized information from the text, including association, bridging inference, paraphrase, query, and verification, and those that passively acquired information, including repetition and monitoring comprehension. Two researchers independently coded and assessed the inter-rater agreement of think-aloud coding using a randomly selected 40% of the transcripts. The average agreement was 93.9% and any disagreements were resolved by discussion.

An additional cognitive load that can arise from engaging in concurrent think-aloud tasks may cause students to be less successful in their tasks (Van den Haak et al., 2004). Therefore, independent samples t-tests were conducted to compare the pre-test scores between the group that engaged in think-aloud practice (10 students) and the group that did not (198 students), as well as the post-test scores between the two groups, to determine whether think-aloud tasks affected students' task success. In addition, the Mann–Whitney U-test was used to examine the differences in reading time, number of sentences read, and frequency of comprehension strategy types between the EH and nEH groups while reading the learning material. The collected data were analyzed using SPSS 22.0.

Figure 4

Examples of the Second Think-aloud Protocol Analysis to Track Reading Process and Identify Comprehension Strategies

Think-aloud protocols (described in order)	Source	Strategies
...	-	...
"1. Metal conducts heat better to ice than glass"	***T*** *(7th sentence)*	-
"Yeah, see, I was right."	***R***	Verification
"Metal transfers heat better than glass."	***R***	Paraphrase
"Heat moves from the air, metal, and glass in the room, which have temperatures higher than ice, to the ice, causing it to melt."	***T*** *(8th sentence)*	-
"Heat moves from the air, metal, and glass to the ice."	***T*** *(8th sentence)*	Repetition
"Ah, air also transfers heat."	***R***	Paraphrase
"Metal conducts heat better than glass and air (the order of heat conduction being metal > glass > air)."	***T*** *(9th sentence)*	-
"Therefore, during the same amount of time, metal transfers more heat to ice than glass does, leading to greater melting of the ice on metal compared to glass."	***T*** *(10th sentence)*	-
"Um... I know this."	***R***	Monitoring comprehension
...	-	...

Note. A hyphen indicates instances where comprehension strategies were not used. Refer to Table 2 for the strategies. ***T*** indicates "text" from the learning material, ***R*** indicates "responses" verbalized by the students.

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Table 2
Types of Comprehension Strategy Used during Reading the Learning Material

Strategies		Description/Definition	Examples
Actively information organization	Association	Bringing to mind relevant information or phenomena not explicitly mentioned in the text	“Then the metal will heat up faster”
	Bridging inference	Connecting contents of the current sentence with text information provided nearby or local sentences	“Oh, so this was because of that!”
	Paraphrase	Rephrasing (part of) the current sentence or their understanding with their own words	“So, like, a larger contact area results in more effective heat transfer.” “So that’s why the ice ⓑ on the metal melts quickly.”
	Query	Expressing a surprise or posing a question	“Uh? Why is this like this?” “So, which metal conducts heat the best?”
	Verification	Checking whether their prediction or explanatory hypothesis is correct	“I was right.” “It’s not that the metal is warm, but rather…” “Yeah, that is it.”
Passively information acquisition	Repetition	Restating all or a substantial proportion of the text sentence verbatim	the action of reiterating the previous or current sentence
	Monitoring comprehension	Reflecting on their own state of enlightenment or agreeing with a sentence or picture	“Aha, so that’s what it is” “I got it now” “I don’t’ quite understand.”

Research Results

Study 1: Predictiveness of generating an EH for incongruent results on subsequent science learning

Post-test scores were compared among students who generated an EH correctly, those who generated an EH incorrectly, and those who could not generate an EH. Figure 5 illustrates the post-test scores of the three groups. For the EH group, there was no significant difference in post-test scores between the 29 students who generated an EH correctly (M = 6.14, SD = 2.17) and the 66 students who generated an EH incorrectly (M = 5.77, SD = 2.38) (p = .829). However, students in the nEH group (M = 3.28, SD = 2.94) had significantly lower post-test scores than those who generated an EH correctly (p < .001) and incorrectly (p < .001). These results suggest that, regardless of whether the hypotheses generated by students were correct, those who could generate EHs had better post-learning outcomes than those who could not.

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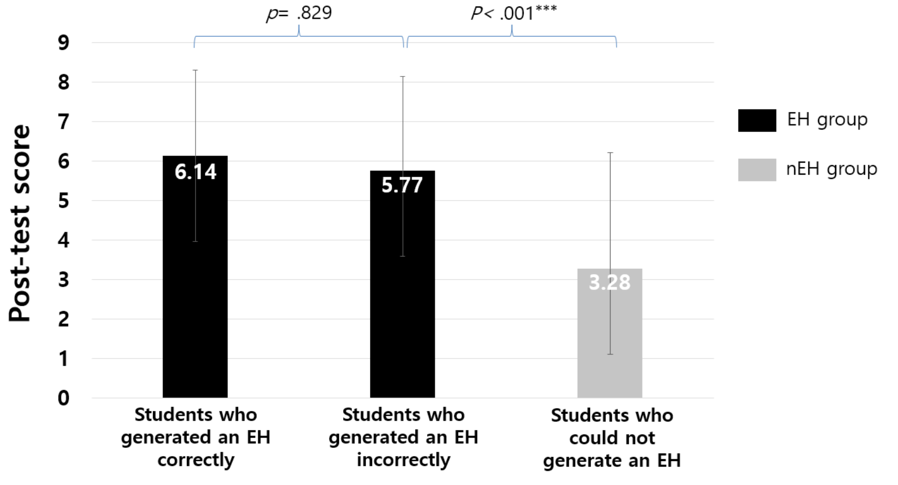
Figure 5

Comparisons of Post-test Scores among Students Who Generated an EH Correctly, Those Who Generated an EH Incorrectly, and Those Who Could not Generate an EH



Note. The error bars reflect standard errors. *** indicates $p < .001$.

The results of the hierarchical regression analysis to ascertain whether generating an EH for incongruent results predicted post-test scores are presented in Table 3. The variance inflation factors of all the independent variables were less than 3, indicating no multicollinearity among the variables. The differences in R^2 between Models 1 and 2, and those between Models 2 and 3, were statistically significant ($\triangle R^2 = .036$, $p < .05$; $\triangle R^2 = .142$, $p < .001$, respectively), indicating that in Models 2 and 3, the added variables explained the post-test score beyond those accounted for by the variables in Models 1 and 2, respectively.

In Model 3, the predictors accounted for 29.7% of the variance in the post-test scores ($F = 10.499$, $p < .001$). After controlling for other predictors in Models 1 and 2, generating an EH positively predicted post-test scores significantly ($\beta = .386$, $p < .001$). Specifically, generating an EH showed the highest predictive power for post-test scores compared to other predictor variables, including prior knowledge (as measured by pre-test scores) and motivating variables such as state curiosity. The results suggest that generating an EH for incongruent results can positively impact science learning when students encounter violation outcomes.

Table 3

Predictiveness of Variables in the Post-test Score

Predictors	Model 1			Model 2			Model 3		
	B	*S.E.*	*β*	*B*	*S.E.*	*β*	*B*	*S.E.*	*β*
Pre-existing variables									
Science curiosity	.016	.033	.048	-.006	.033	-.019	-.016	.031	-.048
Science self-concept	.013	.017	.063	.009	.017	.044	.011	.016	.055
Interest	.111	.088	.101	.008	.094	.008	.012	.086	.011
Need for cognition	.001	.026	.003	-.002	.026	-.009	-.010	.024	-.038
Pre-test score	.418	.101	.248***	.379	.100	.252***	.289	.093	.192**

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Predictors	Model 1			Model 2			Model 3		
	B	*S.E.*	*β*	*B*	*S.E.*	*β*	*B*	*S.E.*	*β*
Experienced variables during solving the question									
Perceived task difficulty				-.207	.224	-.063	-.229	.205	-.069
State curiosity				.146	.052	.238**	.140	.047	.228**
Generating an EH							2.290	.361	.386***
	R^2 (adjR^2) = .119(.097) F = 5.472***			R^2 (adjR^2) = .155(.125) F = 5.243***			R^2 (adjR^2) = .297(.269) F = 10.499***		

Note: EH= Explanatory Hypothesis; *p < .05, **p < .01, ***p < .001; Durbin–Watson value = 1.965

Study 2: Contribution of generating an EH for incongruent results to enhancing subsequent science learning

The pre-test scores of the group that engaged in think-aloud tasks were compared with those of the group that did not, as were the post-test scores of the two groups. No significant differences were observed in either comparison (t_{pre} = 0.008, p_{pre} = .994; t_{post} = -0.832, p_{post} = .423). Thus, engaging in think-aloud tasks was assumed not to affect the students' task success in this study.

The reading processes of the EH and nEH groups were analyzed in terms of reading time and patterns (the order of reading and parts focused on). The analysis of reading time revealed that the EH and nEH groups spent 130.00 ± 27.91 and 143.75 ± 90.36 s on learning, respectively. The differences in reading time between the two groups were not statistically significant (p > .05). Regarding the reading order, in the examination of usual reading patterns a week before commencing the research task (see Figure 2), all students in the EH and nEH groups showed a tendency to read texts in order. However, during subsequent learning after generating EHs, four out of six students in the EH group (66.7%) did not read the learning material sequentially from the beginning. Instead, they quickly scanned the text as a whole, focused on the subheadings, and then read the necessary parts to verify their EHs. These students explained why they did not read the learning materials sequentially in the interviews, offering responses such as, "I looked for that part and read it first because I was curious to see if what I expected was correct." Contrarily, except for one student (25.0%) in the nEH group who first checked the parts that they were most curious about, they all read the learning material sequentially from the beginning. These students responded with statements in the interviews, such as "I was curious about why that answer came out, but I didn't have any criteria for what to check first, so I just read the learning material sequentially." Consequently, the differences in reading order between the two groups indicate that students who generated an EH for incongruent results read strategically, initially focusing on the parts of the learning text that piqued their curiosity. Regarding the parts students focused on while reading the learning material, the EH and nEH groups read an average of 10.67 ± 2.25 and 10.00 ± 3.16 sentences out of 13 sentences presented in the learning material, respectively. The difference in the number of sentences read between the two groups was not statistically significant (p > .05). Furthermore, no difference was observed in the number of pictures checked by the two groups, because all students in both groups checked the two pictures in the learning material.

Figure 6 presents the results of comparing the average frequency of comprehension strategy types between the EH and nEH groups, using the Mann–Whitney U-test for each strategy type. The results indicated that students in the EH group organized information from the text more actively than those in the nEH group (p <.05). Specifically, significant differences between the two groups were identified in "paraphrase" (p < .05) and "verification" (p < .05) strategies, while the other strategies presented no significant differences. Overall, the EH group demonstrated greater use of active information organization strategies than passive information acquisition from the learning material; conversely, the nEH group exhibited a greater tendency toward passive information acquisition.

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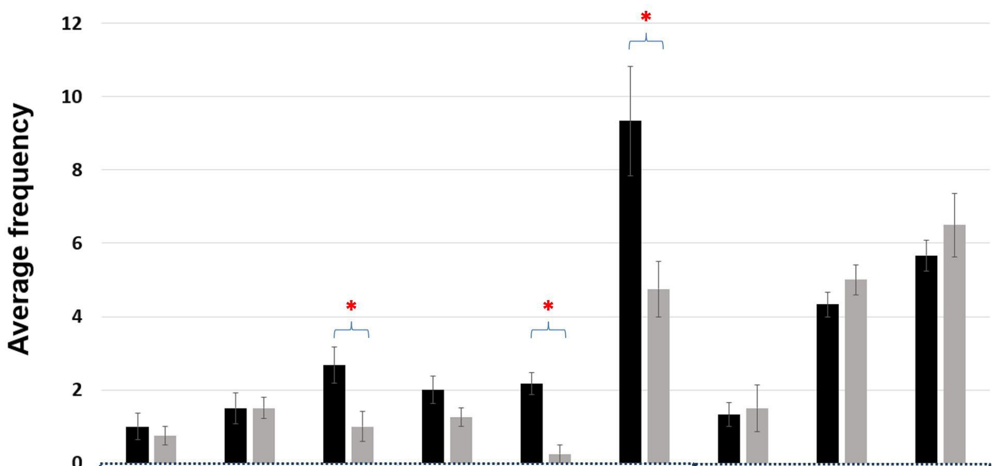
Figure 6

Comparisons of Average Frequency of Comprehension Strategy Types between the EH and nEH Groups While Reading the Learning Material



	Association	Bridging	Paraphrase	Query	Verification	Organization Total	Repetition	Monitoring	Acquisition Total
EH group	1	1.5	2.67	2	2.17	9.33	1.33	4.33	5.67
nEH group	0.75	1.5	1	1.25	0.25	4.75	1.5	5	6.5

Note. The error bars reflect standard errors. * indicates $p < .05$.

Students in the EH group verified their EH during reading the learning material. As shown in Table 2, a good match supported their hypotheses, and the students familiarized themselves with scientific concepts by paraphrasing them in their own words. The following demonstrates an example of the second think-aloud protocol from a student who generated the correct hypothesis (comprehension strategies are capitalized in parentheses).

Student A: "Yes, I was right (VERIFICATION). Yeah, metal transfers heat more than glass, so the ice on the metal melts faster (PARAPHRASE)."

Conversely, a poor match contradicted their hypothesis, leading students to conclude that their incorrect hypothesis should be replaced with a scientific concept. In other words, subsequent observations from the learning material that did not match their predictions led to the need to formulate alternatives (Lawson, 2010). Therefore, students who initially generated incorrect hypotheses revised or replaced them with scientific concepts after identifying their inaccuracies, as presented in the excerpts below. They then organized the content by paraphrasing the scientific concepts in their own words. Through this process, the students could better understand scientific concepts.

Student B: "Oh? What I thought was mistaken (VERIFICATION). Why's that (QUERY)?" … [*the student carefully read the corresponding sentence again* (REPETITION)] … "So, like, a larger contact area results in more effective heat transfer (PARAPHRASE). Aha, so that's what it is (MONITORING COMPREHENSION)."

Student C: "Ah... so this is it (MONITORING COMPREHENSION). I was stuck between the two, but I was wrong (VERIFICATION). Metal really does conduct heat better (PARAPHRASE). Oh, I get it now (MONITORING COMPREHENSION)."

The following is another example of the second think-aloud protocol of a student who revised the rationale for their EH after identifying the content that was inconsistent with their initial rationale. According to the first think-aloud protocol, the student hypothesized that ice ⓑ would melt faster because it was laid down, making it closer to the ground. However, during the subsequent science learning through the learning material, the student

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realized that ice ⓑ melts faster due to having a larger surface area in contact with the metal.

Student D: "Oh? It's not that the ice melts faster because it's lying down (VERIFICATION), but because the surface in contact with the metal is bigger, so it melts faster! (PARAPHRASE)"

This student (Student D) expressed a lack of confidence in their EH and was very curious about its accuracy, as presented in the excerpt from the retrospective interview below. Therefore, instead of reading the learning material in order, they focused on the part that they were curious about and interested in: first, searching for information on why ice ⓑ melts faster to verify their hypothesis.

Interviewer: (*Asking the question while showing the actual reading order of the learning material that Student D had read.*) "Why did you read the learning material in this order instead of starting from the beginning?"
Student D: "I was really curious about that part. So, I skimmed through the subheadings in the learning material first... and I thought this section would have the information I was most curious about, so I read it first."
Interviewer: "Why were you most curious about that part?"
Student D: "I wasn't sure if my thought (hypothesis) was correct, so I wanted to verify it."

Meanwhile, students in the nEH group failed to generate EHs for incongruent results; therefore, they had no hypotheses to verify while reading the learning material. Consequently, they demonstrated a tendency to acquire information from the text in a relatively passive manner, primarily relying on comprehension strategies such as repetition or monitoring comprehension.

Discussion

Benefits of Generating an EH for Incongruent Results in Subsequent Science Learning

The educational significance and benefits of presenting contradictory results have been extensively studied in science education (e.g., Bonawitz et al., 2012; Brod et al., 2018; Stahl & Feigenson, 2017). This study goes a step further by empirically revealing that when students are confronted with expectation-violating outcomes, generating an EH in response can lead to enhanced subsequent science learning. In Study 1, the EH group demonstrated higher academic achievements compared to the nEH group, and generating an EH for incongruent results positively predicted subsequent science learning. Moreover, its predictiveness surpassed that of the control variables, including motivational factors and prior knowledge (as measured by the pre-test scores). These findings could extend the research by Brod et al. (2018), suggesting that generating hypotheses for expectancy-violating results can improve the memory of those results, thereby enhancing subsequent learning. Study 2 focused on how generating an EH in response to incongruent results contributes to enhancing subsequent science learning (i.e., learning after EH generation) to elucidate the findings of Study 1. In Study 2, students in the EH group exhibited a strategic reading approach by first checking the parts they were curious about in the reading material. This suggests that students who generate EHs for incongruent results actively and effectively engage in learning by focusing on the information they want and need amidst a vast amount of information.

Science requires students to read with specific purposes relevant to scientific practice in mind, such as testing hypotheses or constructing explanations, often using expository texts (Norris & Phillips, 2003; Patterson et al., 2018; Pearson et al., 2010). Generating an EH prior to reading may have allowed them to anticipate the structure and content of the upcoming text-based learning material (Anderson & Pearson, 1984), which could serve as a cognitive scaffold (de Jong, 2006), thereby activating prior knowledge and focusing on integrating new information (Morrison et al., 2015; Olson, 1994; Patterson et al., 2018). Consequently, it is believed that students who generated EHs for incongruent results could read the learning material in a more focused and goal-oriented manner, thereby learning scientific concepts more effectively. This was because they had a clear goal of verifying their EHs in subsequent science learning, unlike students who failed to generate EHs. Previous research emphasizing the benefits of making predictions before reading (e.g., Afflerbach, 1990) or learning scientific principles (e.g., Morrison et al., 2015) corroborates these findings.

Moreover, contrary to students in the nEH group who passively absorbed scientific concepts in the learning

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material, students in the EH group used more active comprehension strategies. They demonstrated their understanding and acceptance of information by verifying their initial hypotheses with the scientific concepts presented in the text and then paraphrasing the text content in their own words. Learning typically proceeds through interactions between existing cognitive structures (i.e., EHs) and newly encountered information (Hashweh, 1986; Piaget, 1985). This also applies to learning through texts (Carrell & Eisterhold, 1988); therefore, successful learners do not merely passively absorb or accept textual material. Rather, like the students in the nEH group in Study 2, they actively utilize their prior background knowledge or experience to verify their hypotheses, reconstruct the text's information, and comprehend and assimilate the information (Block, 1992; Carrell et al., 1989). Analogous to the levels-of-processing theory (Craik & Lockhart, 1972), when students connect new information with their existing knowledge, they can process this information more deeply, enhance their memory retention, and make it more memorable (Morrison et al., 2015). Accordingly, testing and verifying the generated EHs serves as a deliberate and purposeful process to refine existing theories and foster new understanding based on available evidence (Kuhn & Dean, 2004; Kuhn et al., 2009). This cognitive framework is essential for generating and advancing scientific knowledge (Bao et al., 2022). Therefore, generating an EH for inconsistent results and testing it through follow-up reading materials encourages students to activate their existing knowledge and stimulate the construction of meaningful relations. Given that hypotheses serve to expand knowledge by providing explanations for phenomena (Lawson, 1995), the results suggest that generating an EH for incongruent results plays a key role in dealing with anomalous situations and understanding the scientific world.

As suggested by Piaget (1985), when the students' EHs did not match the information in the passage, their existing naïve cognitive structures were improved into more sophisticated ones by refining or replacing their hypotheses. Through these processes, the students gained a clearer understanding of the relevant scientific concepts by paraphrasing the content from the learning materials in their own words. Generally, paraphrasing requires students to rearticulate content in their own words, which can foster the integration of prior knowledge with new information, thereby reinforcing their memory of the new content (Wittrock, 1989; Wittrock & Alesandrini, 1990). Furthermore, paraphrasing helps students better absorb information when reading, making the information more memorable and enabling them to restructure or refine their existing knowledge frameworks (Morrison et al., 2015; Rummelhart & Ortony, 1977). Therefore, Study 2 reveals that paraphrasing scientific concepts in the learning material while verifying EHs promotes internalization and deeper understanding, which consequently enhances subsequent science learning. Previous educational studies demonstrating the facilitating effect of paraphrasing while reading also support this study (e.g., Bretzing & Kulhavy 1979; Glover et al. 1981; Morrison et al., 2015; Wittrock & Alesandrini 1990).

The findings of both studies suggest that generating EHs for expectation-violation outcomes in anomalous situations is crucial for enhancing subsequent science learning, specifically regarding conceptual understanding through texts. The EH group, capable of formulating an EH, actively engaged in the reading by verifying their hypotheses and coordinating them with information from the text in subsequent learning after the EH generation. Unlike the nEH group, they demonstrated a tendency to move between their EHs and the passage in the learning material, leveraging their prior knowledge or experience, and associating the ideas in the passage with their hypotheses. Comprehension improves when learners connect or integrate new information with existing knowledge and make meaningful relations between them (Patterson et al., 2018; Wittrock, 1989), which is a more constructive process (Chi, 2009). Additionally, new scientific knowledge is constructed through meaningful connections between students' pre-existing theories and evidence (Bao et al., 2022). Therefore, generating an EH for incongruent results is crucial for subsequent science learning, as evidenced by our results, because it facilitates the acquisition of scientific knowledge through the coordination and integration of existing theories and evidence while understanding the text after proposing EHs.

Implications for Science Education

Our study revealed that, despite the EH and nEH groups engaging in learning scientific concepts by reading the learning material, the EH group exhibited significantly better learning outcomes than the nEH group. This disparity in learning outcomes was further supported by the think-aloud protocol, indicating that the difference could not be explained by variations in the time spent reading and comprehending the material, or the number of sentences read. As aforementioned, the EH group demonstrated a strategic reading approach by initially identifying and checking the most curious and necessary parts of the learning material to verify their EHs. This indicates that the students in the EH group utilized their hypotheses to direct the targets of their exploration in reading the learning

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material. These results imply that students who generate EHs can learn efficiently by focusing on the information they desire from a vast amount of available information. Furthermore, through comprehension strategies such as paraphrase and verification, they either revised or replaced their existing theories or acquired new concepts. In contrast, students in the nEH group tended to read the text sequentially from the beginning and focused on acquiring new concepts without verifying the EHs. Therefore, generating an EH for incongruent results can change students' reading patterns and comprehension strategies during subsequent learning, ultimately enhancing their subsequent science learning.

In science, generating EHs for unexpected outcomes is critical for problem-solving and adapting to unexpected circumstances (Allchin & Zemplén, 2020; Zimmerman, 2000). Therefore, understanding the generation of EHs by students in science learning is crucial. This study is meaningful in that it empirically demonstrates the effectiveness of generating an EH when confronting contradictory results, which has a positive impact on subsequent science learning. In particular, this study contributes to the growing body of research on the reading-based comprehension of expository science texts (e.g., Fang, 2008; Lee et al., 2013; Norris & Phillips, 2003; Patterson et al., 2018; Pearson et al., 2010), offering new perspectives for science education.

Furthermore, the finding that science learning is higher in the EH group underscores the importance of enhancing the ability to formulate EHs to explain discrepant results. What is particularly noteworthy here is that the emphasis need not be solely on generating correct EHs, as has often been the focus of science education. Since even scientifically incorrect EHs resulted in educational effects comparable to those of correct hypotheses, generating an EH for incongruent results, regardless of its accuracy, can be beneficial for subsequent science learning. Therefore, science educators should develop and explore teaching methods and strategies aimed at improving students' hypothesis-generating skills when they encounter incongruent results.

Limitations and Future Directions

The interpretation of the results of this study should be approached with caution, given several limitations. First, despite controlling several variables such as prior knowledge and motivation that could influence EH generation and science learning in Study 1, and suggesting the role of EH generation for incongruent results in positively influencing science learning in Study 2, it is important to consider that individual cognitive abilities, such as higher-order thinking skills, intelligence, and reading comprehension skills, can also potentially contribute to differences in learning outcomes. Given the diverse and intricate cognitive factors influencing EH generation and subsequent learning, further research is required to delve deeper into this area. Second, in this study, learning occurred through reading materials explaining scientific concepts and not through explanations from teachers or experiment-centered classes. While using the think-aloud technique to illuminate the internal process of reading comprehension is appropriate (Afflerbach, 1990), results can differ with changes in learning methods. Therefore, investigating whether the benefits of generating EHs extend to different instructional methods, such as learning through teacher-led explanations or educational videos, is necessary.

Conclusions and Implications

This study empirically examined whether generating an EH for incongruent results can contribute to enhancing subsequent science learning. Even after controlling for several predictors (e.g., prior knowledge, interest, and state curiosity), generating an EH positively predicted subsequent science learning. Notably, generating an EH emerged as the most significant predictor contributing to improvements in subsequent science learning over and above other predictors. Additionally, compared to students in the nEH group who could not propose EHs for the discrepancy phenomenon, those in the EH group learned more effectively during the learning process subsequent to EH generation. They first checked the parts that they were curious about in the learning material and used active comprehension strategies, such as verifying hypotheses and paraphrasing the text. The findings of this study offer the first empirical evidence that generating an EH can be an important factor in facilitating better achievement among students who encounter unexpected outcomes. It presents converging evidence from several approaches—specifically, behavioral and psychophysiological—and offers theoretical insights into human cognition while having practical implications for improving instructional practices. Generating an EH for incongruent results would aid subsequent science learning, particularly when it involves reading materials. These findings underscore the necessity for educational guidance geared toward fostering students' hypothesis-generating skills.

This study is meaningful in that it reveals the connection between generating an EH and the subsequent learn-

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ing at the micro level, a topic that has received limited attention in existing science education research. It extends previous literature by empirically demonstrating a positive correlation between generating an EH for incongruent results and subsequent science learning, while also offering new insights for science education.

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Declaration of Interest Statement

The authors declare that they have no conflict of interest.

Ethics Statement

The study met all the ethical and human subject requirements of the institution at the time of data collection. Before participating in the study, all participants were informed about its objectives, absolute voluntariness of participation, ability to drop out at any time, guaranteed protection of data privacy (collection of only anonymized data), no-risk character of study participation, and contact information in case of any questions or problems. All participants provided written consent prior to participation, including permission to audio-record their thoughts in Study 2. Legal guardians and minor participants themselves provided written informed consent. The video recordings and written data were used only for research purposes. All the results were handled under strict anonymity and confidentiality.

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