Master's Thesis of Education

The Impact of Utilizing Errors in Text on Memory

텍스트 학습에서 오류 활용이 기억에 미치는 영향

February 2024

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Submitting a master's thesis of
Education

December 2023

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Confirming the master's thesis written by
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January 2024

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Abstract

The current study aimed to investigate the impact of utilizing errors in text-based environments on memory retention among 5^{th} grade students, taking into account their prior knowledge levels. A total of 158 participants participated in the experiment for two days and the data of 131 students were analyzed. The participants were assigned to one of two groups. The control group studied text that included only correct information. On the contrary, the experiment group studied text that included intentional errors. The participants in the experiment group were asked to discover and correct the errors by themselves to rectify their misconceptions. Corrective feedback was provided to them if needed. Afterwards, the immediate and delayed posttest scores of the control and experiment group were compared.

The findings of the study showed that utilizing errors in text-based environments led to higher memory retention. Specifically, the experiment group performed significantly better than the control group on the delayed posttest, but not the immediate posttest. This finding is in line with previous research that shows that studying with erroneous examples is beneficial for memory retention. In addition, prior knowledge partially mediated the relationship between utilizing erroneous examples and memory retention. The interactive effect of learning condition and prior knowledge was only significant in the immediate posttest. The interactive effect of learning condition and prior knowledge showed that students with low prior knowledge performed better on the immediate posttest than students with high prior knowledge. This demonstrates that students with low prior knowledge benefited more from studying with erroneous examples.

This result contrasts with some previous studies that showed that students with high prior knowledge perform better when studying with erroneous examples. However, other studies show that prior knowledge does not have an interactive effect with learning condition. This means that students with low prior knowledge may benefit from studying with erroneous examples as well. Thus, the current study adds to the literature by demonstrating that students with low prior knowledge can also benefit by learning from erroneous examples.

Although the study has some limitations such as not asking the students to find all the errors in the text and not asking the students to self-explain the errors, it contributes to a more comprehensive understanding of utilizing errors in the learning environment. The study particularly adds to the literature by having explored erroneous examples in the domain of science, since previous literature only examined erroneous examples in the domain of mathematics. The study supports the notion that utilizing erroneous examples leads to better memory retention and highlights the importance of addressing prior knowledge when dealing with erroneous examples.

Keyword : study strategy, error, erroneous example, delayed test effect, prior knowledge, misconception

Student Number : 2022-27583

Table of Contents

Table Table of Contents

Picture Table of Contents

Chapter 1. Introduction

1.1. Purpose of Research

In the past, advocates of errorless learning believed that errors should be avoided at all costs because errors might be ingrained and reproduced in the future. The rationale for this view is that if the goal is to achieve errorless performance, students should learn in an errorless environment where only correct behavior is encouraged, only correct information is presented, and errors are ignored. This error-prevention approach might work in some learning contexts, but it has two major limitations. First, since errors are inevitable in some learning contexts that include challenging tasks, endorsing in errorless learning in all educational contexts is impractical. Second, constructivist and generative views of learning have demonstrated that errors can provide valuable opportunities for learning. Thus, as students are likely to make errors, proper support must be provided for errors to facilitate new learning (Zhang & Fiorella, 2023).

Contemporary empirical work has shown that errors can be more beneficial for learning than previously assumed. Previously, errors were negatively connoted since rules, standards, or norms are violated and the “correct” is separate from the “wrong.” However, from a psychological perspective, this is not necessarily true because “good” and “bad” errors can be distinguished. Specifically, when errors promote learning and foster productivity, they can positively influence human behavior (Beege et al., 2021).

Recently, a growing body of research in cognitive and educational psychology has demonstrated that errors in low-stakes contexts enhance learning when they are followed by corrective feedback. Since errors are inevitable in the learning process, it may be worthwhile to embrace them and consider how we can best learn from them (Wong & Lim, 2019). Errors may be utilized as an effective study strategy.

Previously, learning from errors has mostly been investigated in terms of pretesting and productive failure. Studies on pretesting and productive failure show that generating errors can enhance learning compared to not generating them at all. Thus, there is evidence that taking pretests before new content is presented and attempting to produce solutions before receiving instruction benefits learning (Pan et al., 2020).

Waiting for errors to occur spontaneously does not maximize learning opportunities. One way to fully take advantage of errors is by presenting erroneous examples to students. Erroneous examples are worked examples that include at least one incorrect solution step. By studying erroneous examples, students can identify, explain, and correct the errors that are included in the example. This leads to an in-depth counter-experience and helps students develop metacognitive skills (McLaren et al., 2012). Utilizing erroneous examples in the learning environment has many positive effects. For example, erroneous examples help students further deepen their understanding of the concept, help them consolidate the concepts, methods, and skills that they have learned, and improve their problem-solving and application abilities (Wang et al., 2022). Furthermore, some researchers believe that learning from errors help students develop critical thinking skills, error detection, and error awareness skills (Zhao & Acosta-Tello, 2016).

Previous research has explored erroneous examples in mathematics because when first learning a mathematics topic, students may acquire some misconceptions related to the topic. A misconception is a misunderstanding between new and old concepts (Stein et al., 2008). One study shows that students who compared worked and erroneous examples of decimal problems learned more than students who compared only correct worked examples (Durkin & Rittle-Johnson, 2012). Another study depicts that self-explaining both correct and incorrect examples of mathematical equality was more beneficial than self-explaining correct examples only (Siegler, 2002).

Several studies on erroneous examples have shown that compared to the problem-solving condition, students in the erroneous examples condition did significantly better on the delayed posttest than the immediate posttest (Adams et al., 2014; McLaren et al., 2012; McLaren et al., 2015). These results indicate that the use of erroneous examples leads to long-term memory retention than simply solving problems. However, previous research only investigated this delayed test effect in the domain of mathematics. Thus, the current study aims to examine whether these results can be replicated with text-based environments covering science topics. The study will compare the results of an immediate and delayed posttest to see whether a significant difference arises between the errorless and errorful condition.

The literature on erroneous examples show that the beneficial effect of erroneous examples may be influenced by students' prior knowledge. Research in cognitive psychology show that prior knowledge may facilitate or inhibit subsequent learning. For example, students with greater prior knowledge usually understand and remember more than students with limited prior knowledge. However, at times, when the prior knowledge is inaccurate or incomplete, having greater prior knowledge can impede learning new information. Thus, the study aims to investigate whether having high prior knowledge is beneficial to learning from erroneous examples (Thompson & Zamboanga, 2003).

Since the majority of the literature is in consensus about the benefits of utilizing erroneous examples in mathematics, the impact of erroneous examples must be investigated in other domains where students are prone to acquire misconceptions. In other words, it is necessary to explore the impact of erroneous examples in domains other than mathematics in order to determine whether utilizing errors in learning is beneficial across various domains. Specifically, scientific concepts should be investigated since many students first learning scientific topics also acquire misconceptions related to the topics.

Therefore, the current study aims to investigate the use of erroneous examples not with mathematics, but with science. In contrast to mathematics, scientific topics are usually learned in text-based environments. The study will focus on creating text-based experiments to help students discover and correct misconceptions related to important scientific concepts. The current study will examine whether utilizing erroneous examples in scientific text-based environments leads to higher memory retention as shown on the delayed posttest compared to the immediate posttest.

1.2. Research Question

The current study aims to investigate the impact of studying science-based texts that include errors on memory retention. The participants of the study include elementary fifth graders. According to prior research, students in the upper elementary school are prone to misconceptions in the domain of science (Stein et al., 2008). Thus, it was of great interest to see if including errors in science-based texts would correct their misconceptions. Furthermore, the study aimed to explore whether prior knowledge moderates the relationship between utilizing erroneous examples and memory retention. The specific research questions of the current study are as follows.

Research Question 1. Does studying text in an errorful condition lead to a difference in memory retention on the immediate posttest and delayed posttest?

Research Question 2. Does prior knowledge moderate the relationship between utilizing erroneous examples and memory retention?

Chapter 2. Body

2.1. Study Strategy

Effectively regulating study is an essential part of the educational experience. Since learning takes place as much, if not more, outside the classroom as inside the classroom, equipping students with effective study strategies is vital to their educational success. Thus, as students progress through school – from elementary to (middle to) high school and into higher education – their need for self-regulation increases, as they are expected to take more control over their own learning (Rea et al., 2022).

Psychologists have been developing and evaluating the efficacy of strategies for study and instruction for more than 100 years (Dunlosky et al., 2013). Recent interest in applying cognitive principles to enhance educational practices has produced substantial literature on effective study strategies. Both cognitive and educational psychologists have reviewed effective study strategies. Effective study strategies are those that assist meaningful knowledge construction and long-term memory retention, not simply rote memorization and short-term performance.

These effective study strategies involve several components that make them so effective. First, students must effortfully process the information, engaging in generative activities in order to select, organize, and integrate new information into their already existing knowledge networks. Second, students must repeatedly return to previously studied information. Studies show that spacing out repetitions promotes better long-term retention. Third, students should not just reread but also retrieve information from their long-term memory. The act of retrieval is believed to strengthen what is retrieved, making it more accessible in the future (Rea et al., 2022).

Thus, the good news is that there are a variety of study strategies that can help students learn more efficiently. However, the bad news is that students usually do not use the learning strategies that researchers have identified as being effective. For example, an examination of students' self-reported study strategies have listed five popular strategies that students prefer: (a) rereading, (b) highlighting and underlining, (c) note-taking, (d) outlining, and (e) using flashcards. Dunlosky et al. (2013) gave reading and highlighting or underlining a low utility rating relative to other more potent techniques, such as testing and spaced practice (Dunlosky et al., 2013).

Despite evidence suggesting that the techniques can benefit student achievement with little added effort, some effective techniques are underutilized because many teachers do not learn about them, hence many students do not use them. In addition, since students often hold strong preferences for study techniques that they have used throughout their educational career, attempting to sell them on new strategies is met with resistance (Dunlosky et al., 2013; Miyatsu et al., 2018).

A current study that examined what, how much, and when study strategies are used by undergraduate students revealed that students rely on relatively ineffective study strategies, massed practice, and use around four hours of study to prepare for exams. Although most of the students intended to start studying a week before an exam and use efficient strategies, their intentions did not match their actual behavior. One explanation for this inconsistency is that when students run out of time, they end up using easier-to-use strategies such as rereading. The results show the need to educate students not just about the best strategies to use while studying, but also the importance of scheduling enough study time prior to each exam so that more effective strategies can be used (Blasiman et al., 2017).

A number of student characteristics can influence the effectiveness of study strategies. For example, compared to more advanced students, younger students may not benefit from a technique. Students' basic cognitive abilities, such as working memory capacity or general fluid intelligence may influence the efficacy of a technique. Domain knowledge, the valid, relevant knowledge a student has, may be required for students to use some learning techniques. For example, the use of imagery while reading text requires students to know the ideas and objects that the words refer to so that they can produce images of them. In addition, students with some domain knowledge about a specific topic may find it easier to use self-explanation and elaborative interrogation, which are two strategies that involve answering "why" questions about a particular concept. Domain knowledge may also enhance the benefits of summarization and highlighting. Nevertheless, although some domain knowledge may benefit students within a given domain, it is not a prerequisite for using most of the learning techniques (Dunlosky et al., 2013).

Furthermore, other individual differences may moderate the effectiveness of study strategies. For example, rereading is a much more useful study strategy for good comprehenders than poor comprehenders. Martin et al. found that good comprehenders demonstrated better metacognitive control, the ability to effectively guide restudy opportunity. Good comprehenders were more likely to distribute more study time for information that they believe to be less well learned than information that they believe to be well learned during a second reading. The results show that students who are already good comprehenders benefit from a variety of study strategies, even strategies that provide little guidance. On the contrary, poor comprehenders might benefit more from strategies that provide them with specific instructions on how to study.

There are potent ways to augment effective study strategies. One method is to train students on how to use the study strategies. Research has demonstrated that more robust benefits have been shown after learners have been trained on utilizing effective strategies. Thus, it is necessary that students receive training on how to effectively use study strategies to reap the full benefits. Furthermore, there is evidence that these training programs can even benefit students as young as fifth graders. Thus, starting training at an early age may be beneficial. Another method is for instructors to assist students in using effective study strategies. For example, instructors can quiz students on a given topic several times, which would indirectly require students to take part in spaced review. Instructors may also incentivize the effective implementations by awarding a small portion of the course grade for doing well on the quizzes (Miyatsu et al., 2018).

2.2. Errors in Learning

Although committing and dealing with errors is inevitable in the learning process, producing errors is considered detrimental to learning. The educational setting prefers errorless learning because errorless learning is expected to provide the most effective results. It is believed that errors are likely to capture attention and divert attentional resources from the given task, leading to impairments in subsequent learning (Mera et al., 2022).

As so, in the mid-to-late twentieth century, Skinner, Bandura, and other behavioral psychologists believed that generating errors increases the likelihood of their recurrence (Pan et al., 2020). Thus, these behavioral psychologists advocated for errorless learning, which states that errors should be eliminated from educational situations.

Specifically, Ausubel (1968) cautioned against the dangers of errors in the learning environment and believed that permitting learners to make errors encourages them to practice incorrect and inefficient approaches which may be difficult to overwrite later with correct approaches. In addition, Bandura (1986) believed that learners should receive a step-by-step guidance that leads to flawless behavior from the outset (Metcalfe, 2017). Furthermore, Skinner (1958) argued that learning should be attentively scaffolded to avoid having learners make mistakes. For example, when learning how to spell the word ‘manufacture’, a student would first copy the word and then fill in missing letters repeatedly before writing the entire word from memory. Taking small steps ensures that learners do not make errors (Clark & Bjork, 2014).

However, due to the inevitability of errors, the error-prevention approach is impractical (Zhang & Fiorella, 2023). Errors are a natural by-product of attempting challenging tasks and they may even provide learning opportunities. Contemporary research provides evidence for the fundamental role of errors in learning: Overcoming impasses through the reflection of errors and self-explanation of the underlying misconceptions is important for the learning process because these processes help to establish accurate mental models (Tulis et al., 2016). Thus, instead of advocating for errorless learning, it is important that educators focus on how errors can be utilized to maximize learning. Recent empirical research has suggested that experiencing errors during learning, as long as corrective feedback is given, can enhance subsequent memory retrieval (Mera et al., 2022). As so, constructivist learning theories state that errors provide a great learning potential and improve learners' understanding (Heemsoth & Heinze, 2014).

The idea that errors can be effective learning tools is shown by Ohlsson's (1996) theory of learning from errors. According to the theory, individuals choose between possible actions when solving a problem, but beginning learners often choose incorrect options. Ohlsson suggests that in order to improve task knowledge, learners must first detect an error, identify the knowledge that caused the error, and explain what additional conditions or features must be added in order to make the knowledge correct (Booth et al., 2013).

The theory of negative knowledge helps to explain the benefits of errors. Negative knowledge is the knowledge of how something is not in contrast to how it really is (Wernecke et al., 2018). This theory states that an understanding of errors is necessary to distinguish between correct processes or facts and incorrect knowledge. Individuals acquire two complementary types of knowledge: positive knowledge and correct facts and procedures and negative knowledge and incorrect facts and procedures. According to this theory, negative knowledge is necessary to differentiate between correct and incorrect facts or processes. Since individuals are not taught about incorrect facts or processes, individual experiences in error situations are necessary to obtain this knowledge (Rach et al., 2013).

According to the theory of negative knowledge, incorrect parts of an initial mental model may be labeled as incorrect or as not belonging to the concept, resulting in the construction of a more comprehensive mental model. Oser and Spychiger (2005) state that negative knowledge is inherent in every piece of knowledge and claim that it serves various functions. Through the acquisition of negative knowledge, the scope of a concept may be sharpened by clarifying what does not belong to it. Thus, certainty is gained because correct and incorrect conceptions can be more clearly distinguished (Wernecke et al., 2018).

Prior research has proposed a process model describing two different ways of dealing with errors. According to the model, a pragmatic, outcome-oriented path of action and an analytic, process-oriented path of action are distinguished. The former moves directly from error detection to error correction, whereas the latter includes a detailed analysis of the error and the generation of error prevention strategies. In regard to the generation of negative knowledge, the latter approach is seen to be more beneficial (Rach et al., 2013).

Previous research that has investigated why experiencing errors enhances learning focused on pretesting, where students generate errors before or after initial learning of the target knowledge. In pretesting, students are encouraged to generate an answer before being exposed to the learning material. Thus, they are almost always incorrect and make many errors. The prevalent result is that pretesting is more beneficial than simply studying unknown information (Mera et al., 2022).

For example, participants in an experiment by Kornell, Hays and Bjork (2009) either studied associated word pairs intact (*whale-mammal*) for 13 seconds or were first required to make a guess (*whale-?*) for 8 seconds before receiving feedback for 5 seconds. Pairs for which learners had to guess first were remembered better than pairs that had been studied intact on a final cued-recall test. This study shows that by guessing incorrectly, participants strengthened the incorrect pairings in memory (Clark & Bjork, 2014).

Similarly, studies of productive failure also support the counterintuitive finding that generating errors benefits learning. In studies of productive failure, students try to produce solutions to novel problems before receiving any instruction on the correct solution. Since the students attempt to solve unfamiliar problems, they usually fail to solve them and generate erroneous solutions. The results show that when students are given the chance to solve new problems before the correct answer is presented, they may be able to learn the solutions more effectively (Pan et al., 2020).

In one study by Kapur and Bielaczyc (2012), students were assigned to either a “direct instruction” group or a “productive failure” group. Students in the direct instruction group completed typical lessons on complex math problems with the assistance of their teachers. On the other hand, students in the productive failure group were given complex problems and asked to work in groups with other classmates to attempt to solve the problems. The problems were very difficult, therefore the productive failure group was not able to solve them. During a final lesson, a teacher helped the productive failure group examine their failed attempts and provided correct methods. On a final test, the productive failure group outscored the direct instruction group on solving complex and straightforward problems (Clark & Bjork, 2014).

Experiencing errors does not benefit memory in all situations. Thus, it is important to understand the specific conditions which make errors useful and investigate the factors that influence this benefit. First, students must receive corrective feedback after committing the error in order to optimize the benefits of experiencing errors. Receiving corrective feedback helps to encode the correct answer. Most importantly, it is not enough to simply tell students whether they were right or wrong. Instead, the corrective feedback must explicitly include the correct answer (Metcalfe, 2017). Second, the extent to which students are motivated to learn the material may impact the benefits of experiencing errors. One study showed that generating errors increased correct performance on the final exam when the students were more motivated. The students' motivation may be related to their curiosity of the corrective feedback that occurs after an error has been made (Mera et al., 2022).

2.3. Erroneous Examples

One study strategy that is effective for learning is the use of worked examples. Worked examples consist of a problem statement, the steps taken to reach a solution, and the final solution. One reason why worked examples are effective in the learning process, compared to problem solving, is because they provide fully worked-out problem solutions. These solutions lead to reduced extraneous processing and cognitive load. Worked examples focus the student's attention on the correct solution procedure to follow, which helps the student to avoid searching through prior knowledge for solution methods and lessens extraneous processing. The freed up cognitive resources can then be used for generative processing, specifically understanding, and eventually automatizing the steps in a problem's solution procedure (Adams et al., 2014).

The worked example effect can be explained by cognitive load theory, which assumes that individual working memory resources are limited. Cognitive load can be divided into three types: intrinsic, extraneous, and germane load. The first type called intrinsic load refers to the complexity of the learning contents regarding a learner's prior knowledge. The second type called extraneous load refers to activities which are irrelevant for learning. The third type called germane load refers to cognitive resources that are bound by learning – relevant activities of the learner (Große & Renkl, 2007). Extraneous and germane load can be influenced by instructional intervention. Thus, the goal of instructional designs should be to decrease extraneous load and increase germane load in order to increase the effectiveness of instruction. This goal can be achieved by providing learners with worked examples rather than using problem solving (Yang et al., 2016).

Especially for mathematical content, the addition of self-explanation to worked examples can lead to the improvement of student understanding of the underlying concepts as well as their ability to carry out the relevant steps. Explaining instructional material has been shown to improve learning by forcing students to make new knowledge explicit. Thus, asking students to explain examples can further improve their learning compared with simply studying examples. For example, Hilbert et al. (2008) found that adding self-explanation to worked examples improves students' conceptual knowledge of geometry (Booth et al., 2013). Research has also shown that the quality of students' explanations predicts learning outcomes (Richey et al., 2019).

However, one possible problem with worked examples is that students may not use the freed cognitive capacity for generative processing. Furthermore, while worked examples may free up cognitive resources, it is a passive form of instruction (Jaeger et al., 2020). Passive instructional activities tend to promote shallow learning. Also, even when students engage with worked examples through explanation, there is still the risk that students who are exposed only to correct solutions may miss opportunities to test their understanding and limits of the examples, or to identify areas they might be confused (Richey et al., 2019).

One method to overcome the passive nature of worked examples is to use erroneous examples. Erroneous examples are worked examples that incorporate at least one incorrect solution step. They contain a common, well-documented misconception in a particular domain, a few self-explanation hints, and the correct solution. These components provide scaffolding so that the learners can identify errors, correct the erroneous problem-solving steps, and generate solutions and solve problems correctly. Experienced teachers can determine which parts of the material are prone to mistakes and create erroneous examples, thus allowing students to see the examples, find the mistakes, and explain and correct them (Wang et al., 2022). Several studies have shown that studying erroneous examples improved performance on deeper measures of learning, for example conceptual understanding and far transfer, but not on more shallow knowledge measures such as near transfer (Richey et al., 2019).

Although the benefits of erroneous examples have been proven, their use remains controversial. One the one hand, some teachers are afraid that presenting errors to students will make them more inclined to make those errors. Many teachers are skeptical about discussing errors in the classroom because they believe that exposing students to errors can lead to incorrect solutions being assimilated by the students (Tsovaltzi et al., 2010). This idea is supported by behaviorist theory. On the other hand, some educators argued that presenting students with errors for review and discussion can be valuable experiences for learning. For example, Borasi stated that mathematics education might benefit from students working with errors by encouraging critical thinking about mathematical concepts and by motivating reflection and inquiry (McLaren et al., 2012).

As so, although erroneous examples might appear to risk reinforcing students' misconceptions or introducing an inaccurate understanding, exploring students' errors can play an important pedagogical role in the domain of mathematics. Evidence shows that showing students the errors of others can foster reflection and can help students to recognize and correct errors in their own work. Other research has shown that comparing students' own incorrect models to accurate models and prompting them to self-explain the differences can lead to greater learning gains than explaining only a correct model. These results appear to contradict intuitions that showing students incorrect examples might strengthen existing misconceptions or introduce new errors (Richey et al., 2019).

Studies show that Japanese math students outperformed their counterparts in most of the western world. The key curriculum difference was that Japanese educators present and discuss incorrect solutions and ask students to locate and correct errors (Tsovaltzi et al., 2010).

Erroneous examples are likely to be helpful to students under three conditions. First, the errors should be false examples of other students' errors, so the student reviewing errors is free from embarrassment and possible demotivation. Second, the erroneous examples should be interactive and engaging. They should produce explanations, ask students to find and correct errors, and provide feedback. Mathan and Koedinger (2005) focused on learners' error-detection and error-correction skills. They provide evidence that feedback which allows students to detect, correct and reflect on their own errors fosters learning at a faster rate (Tulis et al., 2016). Finally, the erroneous examples should adaptively target the needs of individual students. That is, the problems presented to students should be aimed at their misconceptions and misunderstandings about the target domain (McLaren et al., 2012).

When students use erroneous examples, they must find, explain, and fix errors. Erroneous examples include the same steps as regular worked examples; however, one or more parts of the example are incorrect. Erroneous examples require generative processing because students must locate and explain the errors, then make appropriate corrections (Jaeger et al., 2020).

It is not useful to present learners examples with errors from the beginning. For this reason, correct solutions should be given to the learners first. Learning with incorrect solutions means that after providing some correct solutions, incorrect solutions in worked examples are presented to the learners to deepen the knowledge that has already been acquired (Große & Renkl, 2007).

Recently, some studies focused on the use of erroneous examples and suggested that the integration of errors into worked examples may make it easier for students to reflect upon their errors, which would lead to deeper learning (Yang et al., 2016). Erroneous examples help students to further deepen their understanding of the concept, help them consolidate the concepts, methods, and skills that they have learned, and improve their problem-solving and application abilities (Wang et al., 2022). Furthermore, by integrating errors into worked examples, learning efficiency can be enhanced. Siegler and Chen (2008) believed that students pay closer attention to potential explanatory variables, formulate more advanced rules, and generalize the rules for solving new problems by comparing the similarities and differences between correct and erroneous solutions. Some researchers believe that learning from errors help students develop critical thinking skills, error detection, and error awareness skills. In addition, erroneous examples can help students improve their cognitive and metacognitive skills (Zhao & Acosta-Tello, 2016).

In addition, erroneous examples may guide the learner toward a learning orientation than a performance orientation. This may be especially true when the erroneous examples are presented in combination with feedback that increases student's understanding and their involvement in the learning process (Tsovaltzi et al., 2010).

Recent research shows that explaining both correct and erroneous worked examples is more effective than explaining only correct worked examples (Jaeger et al., 2020). Other empirical research on erroneous examples shows that students who explained both correct and erroneous solutions outperformed those who explained only correct solutions in algebra, physics, and medicine (Yang et al., 2016).

Especially, research in mathematics education has explored this phenomenon of erroneous examples and provided evidence that studying errors can aid student learning. Research in mathematics has attempted to better understand whether, how, and when erroneous examples can make a difference to learning. For example, one study found that students who compared worked and erroneous examples of decimal problems learned more than students who compared pairs of correct worked examples. Students who compared worked and erroneous examples were twice as likely to discuss correct concepts as students who compared worked examples only (Durkin & Rittle-Johnson, 2012). Similarly, another study investigated whether self-explaining correct and incorrect examples of mathematical equality were more beneficial than self-explaining correct examples only. The results of the study show that students who studied and self-explained both correct and incorrect examples led to the best learning outcomes (McLaren et al., 2012). Furthermore, one study found across two experiments that as long as some form of feedback was provided, a mixture of correct and incorrect examples facilitated the best performance (Corral & Carpenter, 2020).

Compared to the above examples which were paper based, research has also been conducted to examine the benefits of learning from erroneous examples with intelligent tutoring systems. One study demonstrated the effect of learning from erroneous examples of fractions in an intelligent tutoring system. The study showed that erroneous examples with feedback improved 6^{th} graders' metacognitive skills compared to the problem-solving condition and erroneous examples condition with no feedback. In addition, 9^{th} and 10^{th} grade students improved their problem-solving skills and conceptual knowledge by studying erroneous examples with feedback. A similar study that used the Algebra I Cognitive Tutor found that students who explained correct and incorrect examples improved their posttest performance compared with students who received worked examples only (Chen et al., 2016).

2.4. Delayed Test Effect

The testing effect occurs when students perform better after taking a test than restudying the same learning material. This phenomenon states that retrieving information from memory improves long-term retention of information more than continuing studying. For example, students benefit less from restudying a foreign vocabulary word and its translation than from retrieving the translation from memory on a test. However, these benefits of testing are often visible only after a delay and not immediately after practice. Like so, there is considerable evidence that the testing effect is more likely to be obtained after a delayed than an immediate test (Leahy & Sweller, 2019; van den Broek et al., 2014).

One study examined how different types of post lecture activity affected memory retention of lecture material. The result shows that taking a short answer test produced superior retention of lecture material after one month relative to studying a lecture summary. In particular, the short answer test condition produced superior retention relative to the multiple-choice condition. This result provides evidence that testing can improve the retention of classroom lecture material. In accordance with this result, many previous studies have found that taking a test leads to greater retention of material relative to a restudy condition, especially when the test involves response production. Practicing retrieval is beneficial when it requires effortful processing, for example production rather than recognition tests. One explanation for this result is the idea that greater depth or difficulty in retrieval leads to better retention of the information tested. Since short answer tests involve a greater degree of retrieval difficulty than multiple choice tests, the short answer condition led to greater retention than the multiple-choice condition (Butler & Roediger, 2007; Roediger & Butler, 2011).

Furthermore, one study revealed that repeated studying improved performance relative to repeated testing on final tests given after a five-minute retention interval, but the effect reversed on delayed tests. This pattern of results is similar to the finding that massed presentation improves performance on immediate tests, whereas spaced presentation leads to better performance on delayed tests. Thus, massed study leads to a short-term memory benefit, whereas testing or spaced studying has a greater effect on long-term memory retention. This result reflects the role of desirable difficulty in promoting long-term memory retention (Roediger & Karpicke, 2006).

According to one study that investigated the benefits of erroneous examples, students in the erroneous example condition did significantly better than students in the problem-solving condition on the delayed posttest, although there was no difference on the immediate posttest. This occurred even though the students did not receive further training or practice between the immediate and delayed posttests. The results of this study show that the students who were presented with erroneous examples learned better than those who were presented with problems to solve. The delayed posttest results suggest that erroneous examples may provide a deeper learning experience, leading to a deeper understanding over time (McLaren et al., 2012).

Similarly, students studying decimal problems in an erroneous examples group outperformed students in a problem-solving group. Although the two groups did not differ significantly on an immediate posttest, students in the erroneous examples group performed significantly better on a delayed posttest administered one week later (Adams et al., 2014). This study was replicated one year later, but with a much larger population. The replicated study investigated middle school students learning about decimals either by working with erroneous examples or with traditional problem-solving. The results show that the erroneous examples group performed significantly better on a delayed posttest, although the two groups did not differ on an immediate posttest. The results replicated the pattern of the prior study (McLaren et al., 2015).

A possible explanation for the longer-term retention of erroneous examples is due to desirable difficulty. Learning from erroneous examples can be seen similar to desirable difficulty because presenting students with challenge is central to the notion of learning with erroneous examples. Research on desirable difficulties has shown that it is possible to achieve long-term benefits if lessons are designed to make them more challenging during learning. Desirable difficulties include varying the conditions of learning, interleaving instruction on separate topics, spacing study sessions on a given topic, and using tests as study events (Bjork & Bjork, 2011). Not only that, but erroneous examples also introduce cognitive conflict by presenting students with information that contradicts their existing knowledge. Therefore, desirable difficulty leads to deeper and longer-lasting learning by making the learning task more difficult and presenting students with a cognitive conflict. This phenomenon can be explained by the cognitive load theory. In order to update long-term memory and make it flexibly accessible, students must engage in deeper processing of the instructional material. Erroneous examples may promote generative processing while traditional instructional approaches such as presenting students with problems on the topic may not promote such processing (Adams et al., 2013; McLaren et al., 2015).

Erroneous examples present desirable difficulties to students in two ways. First, erroneous examples are an unusual and challenging form of a problem, in which students must find, explain, and correct errors. This type of challenge, which promotes deeper cognitive processing, can be seen as a form of desirable difficulty. Second, erroneous examples prompt students to learn with both correct and incorrect examples. The varying of tasks may lead to desirable difficulty (Adams et al., 2013).

2.5. Prior Knowledge

The term schema or prior knowledge is used to refer to the ways in which existing knowledge structures interact with new information. Schema refers to a general cognitive structure that links multiple representations of a phenomenon. The existence of a schema may alter an individual's interpretation of new information (Shing & Brod, 2016).

Extensive reviews of behavioral research have been conducted to investigate the effects of prior knowledge on memory. First, prior knowledge facilitates memory for incoming information because it provides a structure into which the new information can be integrated. This applies to various stages of memory processing, including encoding, consolidation, and retrieval. Second, knowledge needs to be activated appropriately to benefit memory processing of new information. Simply possessing prior knowledge is not enough; it needs to be activated properly to facilitate creation of an elaborated memory trace (Shing & Brod, 2016). Thus, prior knowledge needs to be activated for it to affect learning processes, which then influences learning outcomes (Simonsmeier et al., 2022).

According to a recent article, there are several determinants for whether and how prior knowledge affects learning. In other words, prior knowledge can guide learning differently in different learning tasks and can thus both help and hinder learning. Three determinants are important in this context: whether prior knowledge is activated, whether it is relevant for the learning task at hand, and whether it is congruent or incongruent with the to-be-learned content (Brod, 2021).

First, to have any effect on learning, prior knowledge needs to be activated. It is not sufficient that prior knowledge is available, but it also has to be activated and used in the learning process. Second, if prior knowledge has been activated by learners, it has to be relevant for the learning task at hand. If the activated prior knowledge is largely irrelevant for the learning task at hand, it may not be useful in the learning context. Third, even if prior knowledge is activated and relevant, it has to be congruent with the to-be-learned information to have a beneficial effect. Congruency refers to the fit or agreement between prior knowledge and new information. According to the memory congruency effect, new information that is congruent with prior knowledge tends to be better remembered than information that is incongruent with it (Brod, 2021).

Research in cognitive psychology has shown that individuals with greater preexisting knowledge about a topic usually understand and remember more than those with limited prior knowledge. In accordance, constructivist theory argues that all new learning builds on prior knowledge. As so, research reviews in educational psychology have concluded that prior knowledge within a specific domain benefits students' learning and achievement (Thompson & Zamboanga, 2003).

However, at times, prior knowledge can make it difficult to understand or learn new information. This is especially true if the preexisting information is inaccurate or incomplete. This may happen when students generalize information from everyday experiences or from what they learn in the popular media. Although interference from prior misconceptions is most often observed with young children, mistaken assumptions and prior beliefs can also undermine college students' learning (Thompson & Zamboanga, 2003).

The effectiveness of learning from errors may depend on the student's prior knowledge. Prior knowledge can enhance memory processes including encoding, consolidation, and retrieval considerably, thus fostering knowledge acquisition. However, prior knowledge can also hinder knowledge acquisition, especially when the to-be-learned information is inconsistent with the presuppositions of the learner. Thus, it is important to take into account students' prior knowledge and know about how it affects memory processes to optimize students' learning (Shing & Brod, 2016).

Some empirical research shows that only advanced students benefit from the inclusion of incorrectly worked examples. Hence, students with low prior knowledge learn more from the use of correctly worked examples. The authors of a study investigating erroneous examples in the domain of mathematics hypothesized that erroneous examples will be more beneficial to students with high prior knowledge because understanding the incorrectly worked equations requires a strong mathematical foundation. In contrast, students with minimal prior knowledge in mathematics will not understand the appropriate concepts from studying incorrectly worked examples. In accordance with their hypothesis, the study showed that students with high levels of prior knowledge performed better than students with low levels of prior knowledge when presented with incorrect examples. The study shows that erroneous examples are more beneficial to students with high prior knowledge because understanding the incorrectly worked equations requires a solid mathematical foundation. Thus, students with minimal prior knowledge in mathematics will not grasp the appropriate strategies or concepts from studying incorrectly worked examples (Zhao & Acosta-Tello, 2016).

Similarly, Große and Renkl reported that learning with both correct and incorrect examples is beneficial for university students with high prior knowledge. On the contrary, students with low prior knowledge benefit more from learning with correct examples. It was found that prior knowledge is needed to identify and explain errors. Since highlighting an error lowers the demand on the learner, highlighting errors may benefit students with low prior knowledge (Große & Renkl, 2007).

Other research, however, has produced different results. One study found that 4^{th} and 5^{th} graders show no indications of an interaction between amount of prior knowledge and either learning with correct examples or learning with correct and incorrect examples of decimal fractions (Durkin & Rittle-Johnson, 2012). Mixed results regarding prior knowledge highlight the importance of investigating the impact of prior knowledge on utilizing erroneous examples.

2.6. Misconceptions

A misconception is a misunderstanding between new concepts and old concepts that are already formed in peoples' minds, so that the wrong concepts are formed. Fisher (1983) defined misconceptions as ideas that are at a variance with accepted views. Misconceptions are especially found in the domain of science. The term misconception is often referred to students' ideas that are different from the ones generally accepted by scientists. Research has shown that most people develop ideas about a variety of science topics before beginning formal science education and that these ideas tend to remain despite efforts to teach scientifically accepted theories and concepts (Stein et al., 2008). It is common for people to experience misconceptions. Not only students, but also experienced adults including teachers, lecturers, and even professors experience misconceptions.

Research has shown that erroneous examples may be particularly effective for addressing misconceptions. Erroneous examples can be designed to address common misconceptions or pitfalls that students often encounter. Misconceptions can be difficult to change and when they involve more than one incorrect beliefs, they are often resistant to direct refutation. Furthermore, their deep, conceptual nature means they tend to disrupt students' learning across a wide range of new topics within a domain and can significantly diminish a student's progress in more advanced concepts (Richey et al., 2019). However, by confronting and correcting these misconceptions that are included in erroneous examples, students can develop a more accurate understanding of the material.

Children and adults develop misconceptions when they attempt to make sense of the surrounding world. Their common sense of physical phenomena, which developed over their lifetime and influenced by many factors including news items, popular science journals, and misleading science texts, are difficult to challenge. It was found that when physics students were presented with experiences that challenged their beliefs, they were more likely to argue that outside laws or principles were interfering with the results rather than change their conceptions (Stein et al., 2008).

Most studies have focused on common misconceptions in chemistry, physics, and physical science which are subject areas that include concepts that are particularly abstract for learners to understand (Stein et al., 2008). Of 700 investigations regarding misconceptions, many were related with different domains of science including earth and space and modern physics. Misconceptions found in the domains of science or other social domains have been investigated since the early 80s and have been at the center of empirical research in learning science for many years (Suprapto, 2020).

Compared to other areas of science, physical science concepts including force and motion are often abstract and difficult for students to understand. Watts and Zylbersztajn (1981) studied what children thought about force. Students were asked to think about forces and motion through several scenarios. The results showed that students had difficulty understanding the force of gravity on the moon, at different elevations on Earth, and when objects are at rest.

Furthermore, they had trouble understanding and representing forces involved during a tug of war game when one person is winning.

Similarly, Lawrenz (1986) studied physical science misconceptions among elementary school teachers. The results indicated that misconceptions in physical science were prevalent among the elementary teacher sample although they had strong educational backgrounds (Stein et al., 2008).

According to research, there are many ways that misconceptions can occur. Specifically, misconceptions can arise from students, teachers, teaching materials or literature, and teaching methods. First, misconceptions in the domain of science mostly come from students themselves. Misconceptions originating from students have many different names including initial knowledge, preconceptions, prior knowledge, etc. For example, many students already have an initial concept about a concept before they receive formal education. This initial concept often contains misconceptions. In addition, teachers who have not mastered the material or understood the material incorrectly will cause students to get misconceptions. Some science teachers do not understand the science concepts themselves, which can be passed on to the students (Suprapto, 2020).

It is important to guide students to consider adopting more generally accepted science concepts. However, this challenging task cannot be achieved if instruction is undertaken without knowing the students' currently held beliefs. Furthermore, nothing can be changed if the teachers have misconceptions and are not aware of them. Thus, in order for children's misconceptions to be changed, a change must first occur in their teachers (Stein et al., 2008).

Chapter 3. Research Hypothesis

3.1. The Impact of Utilizing Erroneous Examples in Text-based Environments on Memory Retention

Research Hypothesis 1. Utilizing erroneous examples in text-based environments will lead to higher memory retention on the delayed posttest compared to the immediate posttest.

3.2. The Moderation Effect of Prior Knowledge between Utilizing Erroneous Examples and Memory Retention

Research Hypothesis 2. Participants with high prior knowledge in the errorful condition will have higher memory retention compared to participants with low prior knowledge.

Chapter 4. Research Method

4.1. Participants and Research Design

The current study is an experimental study. For the study, a total of 158 elementary fifth graders were recruited from three different elementary schools from Seoul and Cheongju district. The data of 27 elementary fifth graders were excluded from the analysis because they failed to conduct the pretest. Thus, the data of 131 elementary fifth graders were included in the analysis. The data of 67 male participants (51.5%) and 64 female participants (48.9%) were used in the final data analysis. A between-subject design was used for the current study. Furthermore, three schools from two different districts were used to maximize the external validity of the study.

The participants were randomized according to class. The study recruited eight classes from three different schools. However, only seven classes were included in the final analysis because one class failed to conduct the pretest. Each class was randomly assigned the control group or experiment group. Three control group classes and four experiment group classes were utilized in the analysis. The control group studied text that did not include any errors, and the experiment group studied text that included intentional errors. The immediate and delayed posttest that the participants in each group took were compared for the study. Literature states that discovering and correcting errors is beneficial for memory retention (Durkin & Rittle-Johnson, 2012; McLaren et al., 2012).

The total number of participants that participated in the study were 58 participants (44.3%) in the control group and 73 participants

(55.7%) in the experiment group. A demographic overview of the number of participants that participated in the study is summarized in <Table 1>.

<Table 1> Distribution of gender according to group

		Control	Experiment	Total
Gender	Male	30	37	67
	Female	28	36	64
	Total	58	73	

The independent variable in the current study is the learning condition. Learning condition is divided into the control group and experiment group. The control group studied text that does not include any errors and the experiment group studied text that includes errors. The moderating variable is prior knowledge. The score of the pretest was used for prior knowledge. All references to prior knowledge in the results refer to the pretest scores. The dependent variable is memory retention, which is measured by the immediate and delayed posttest. The posttest was implemented twice during the experiment, once immediately after the experiment and once two weeks after the experiment.

4.2. Research Process

The study was proceeded after the review of the Institutional Review Board (IRB) of Seoul National University. The participants and participants' legal representatives consented to the research. The homeroom teacher of each class explained the procedure of the experiment before the experiment was implemented. The first part of the experiment took place in each classroom for approximately 80 minutes. Then, the second part of the experiment took place two weeks after the first part of the experiment. During the second part of the experiment, around 15 minutes were allocated to fill out the posttest questionnaire. The overall procedure of the experiment is depicted in the following table (Refer to <Table 2>).

Procedure	Content		Time
Guide	Control group	Guide and confirmation of consent	Before the experiment
	Experiment group		
Pre-survey (Before the intervention)	Control group	Measure moderating variable	30 minutes
	Experiment group		
Study phase	Control group	Review of science material	15 minutes
	Experiment group		
Practice phase	Control group	Study text without errors	15 minutes
	Experiment group	Study text with errors	15 minutes
Immediate posttest	Control group	Measure dependent variable	15 minutes
	Experiment group		
Delayed posttest	Control group	Measure dependent variable	15 minutes
	Experiment group		

<Table 2> Procedure of experiment

The participants of the experiment conducted a pretest before the intervention. The results of the pretest (prior knowledge) were used as the moderating variable in the analysis.

Afterwards, the participants reviewed some science materials that they had learned the previous semester. The science materials covered the solar system and stars. All students had already learned this topic in class. Each homeroom teacher showed the students a PowerPoint presentation that included information about the solar system and stars. The homeroom teacher taught the participants about the solar system and stars, as if they were in a science class.

Then, the participants either studied text without errors or text with errors, depending on the intervention. Participants in the control group studied text that did not include any errors. The participants in this group simply had to study correct information regarding the solar system and stars. On the contrary, participants in the experiment group studied text that included intentional errors. The participants had to discover and correct errors regarding the solar system and stars while studying the text by themselves. They received corrective feedback from their homeroom teacher if needed.

All of the participants completed an immediate posttest immediately after the practice phase. The questions on the pretest and immediate and delayed posttest questionnaires were identical. The questionnaire included eight questions about the solar system and stars that the participants had studied in the study and practice phase. A delayed posttest was implemented two weeks after the immediate posttest. Prior work has shown that a delayed posttest can often be more diagnostic of learning than an immediate posttest. In addition, including a delayed posttest may add ecological validity to the experiment because students are typically tested on content several weeks if not months after the content has been learned (Corral & Carpenter, 2020). Therefore, a delayed posttest was included to verify whether the present results hold after a given delay between the learning phase and the posttest.

4.3. Measures

A. Intervention

In order to check the adequacy of the erroneous examples text intervention, the text was examined by three current elementary school teachers.

The participants in the current study were divided into the control group and experiment group. Both groups studied passages dealing with the solar system and stars. The control group had to study passages that included correct information about the solar system and the stars. The participants in the control group spent 15 minutes studying the text. The experiment group also had to study passages, however, the passages included intentional errors. Specific errors that are important for understanding the text were chosen by the experimenter. The participants in the experiment group had to discover and correct the errors on their own. They were able to receive corrective feedback by their homeroom teacher, if needed. The participants in the experiment group spent the same amount of time studying the text.

After both groups finished studying the text, they took an immediate posttest. The immediate posttest included eight questions regarding the solar system and stars topic that the participants had studied earlier. The eight questions were chosen after considering the main idea of the text. The questions included both multiple-choice and short answer questions.

Two weeks later, both groups took a delayed posttest. The delayed posttest included the same eight questions as the immediate posttest. The participants of the study were not informed of the delayed posttest beforehand.

B. Motivation

To measure motivation, Self-Regulation Questionnaire-Academic(SRQ-A) developed by Ryan and Connell(1989) was used. The Korean version of the Self-Regulation Questionnaire-Academic was validated by Kim A-Young(2002) and revised in 2008. The current study used the version by Seo Hye-Yoon(2018), which was revised to meet the elementary school level. The scale includes amotivation, external regulation, introjected regulation, identified regulation, and intrinsic motivation. Integrated regulation, which is one of the factors of self-determination motivation, was not measured in the current study because integrated regulation is expected to be acquired after the teenage years (Deci et al., 1991). The questionnaire has a total of 30 questions, with 6 questions for each sub factor. The questionnaire is comprised of a 5-point likert scale starting from ‘strongly disagree(1 point)’ to ‘strongly agree(5 point)’. The reliability for overall motivation is Cronbach $\alpha = .77$. The reliability for overall motivation in the current study(Cronbach’s α) is .75.

4.4. Method of Analysis

Before conducting the main analysis, the descriptive statistics of the variables were examined to check the characteristics of the main variables. In addition, a correlation analysis was conducted to examine the relationship between the variables. Afterwards, in order to check group homogeneity for prior knowledge between the two groups, an independent t-test was conducted. Furthermore, to investigate whether the error intervention influenced memory retention, a 2 (Group: experiment, control) x 2 (Time: immediate posttest, delayed posttest) one-way ANOVA was conducted.

Then, regression analysis was conducted to test whether the results of the immediate and delayed posttest are moderated by prior knowledge. In order to investigate the interactive effect between error intervention and prior knowledge, an interactive term was created between learning condition and prior knowledge. To prevent the problem of multicollinearity, the analysis was conducted after the mean-centering of the variables.

All analysis was conducted using IBM SPSS 25.0.

Chapter 5. Research Results

5.1. Homogeneity Check

Before conducting the regression analysis, an independent t-test was conducted to investigate whether there was a difference in pretest results between the experiment and control group before the intervention was implemented. Levene's homogeneity of variance showed that the variance was not different across the two groups on the pretest($F(1,130) = .941$, $p = .334$). In addition, an independent t-test was conducted to investigate the difference between the two groups. The results indicate that the difference on the pretest($F(1,130) = 3.186$, $p = .077$) was not significant. This shows that the comparability of the two groups was the same before the intervention. The participants in both conditions had about the same prior knowledge.

5.2. Descriptive Statistics of Main Variables

The descriptive statistics of each variable is presented in <Table 3> and the mean and standard deviation of the control and experiment group are presented in <Table 4>. Pretest had a significant positive correlation with immediate posttest(.58) and delayed posttest(.58). Furthermore, immediate posttest had a significant positive correlation with delayed posttest(.65).

The skewness of all variables were between −1.28 and −.713, and the kurtosis of all variables were between .836 and 3.05. The absolute value of skewness did not exceed 2 and the absolute value of kurtosis did not exceed 7. Therefore, normal distribution was achieved.

<Table 3> Descriptive statistics of main variables

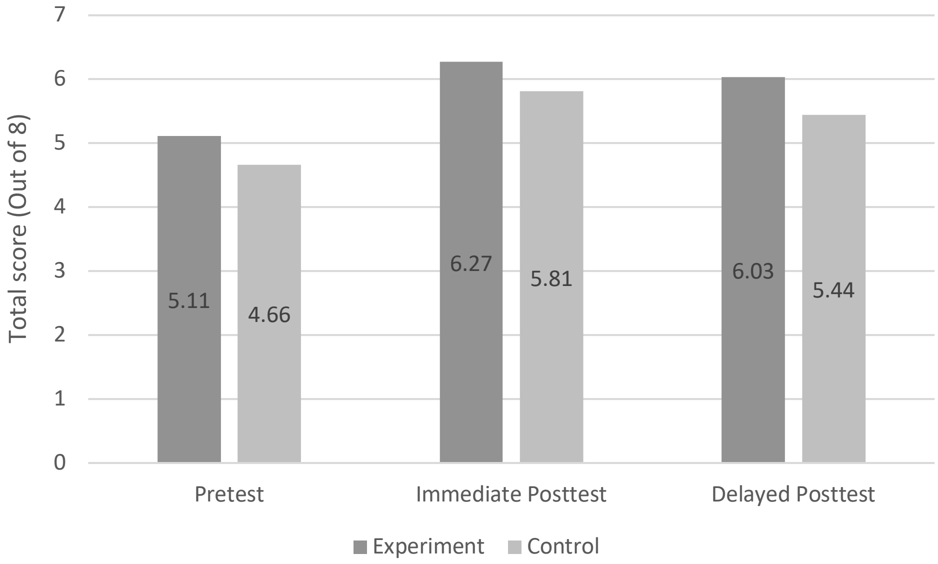
Variable	1	2	3
1. Pretest	-		
2. Immediate Posttest	.577**	-	
3. Delayed Posttest	.583**	.651**	-
M	4.91	6.07	5.77
SD	1.46	1.47	1.43
Skew	-.713	-1.28	-1.04
Kurt	.836	3.05	1.94

*p<.05, **p<.01, ***p<.001

Additionally, an independent t-test showed that there was no difference between the experiment and control group in the pretest($t = 1.785$, $p = .077$) and immediate posttest($t = 1.711$, $p = .091$), but a significant difference existed in the delayed posttest($t = 2.374$, $p = .019$). The results of the study are in line with previous research that showed a delayed test effect.

<Table 4> Mean and standard deviation of main variables

Variable	Control group		Experiment group	
	M	*SD*	*M*	*SD*
Pretest	4.66	1.54	5.11	1.37
Immediate Posttest	5.81	1.83	6.27	1.07
Delayed Posttest	5.44	1.50	6.03	1.32



<Picture 1> Mean of main variables

5.3. Gender

In order to check whether there were any gender differences regarding the results, an independent t-test was conducted. The results show that gender did not significantly affect the results of the pretest($F(1,130) = .543$, $p = .183$), immediate posttest($F(1,130) = .021$, $p = .208$), and delayed posttest ($F(1,130) = .018$, $p = .523$).

<Table 5> Results of independent t-test

Variable	Group	*M*	*SD*
Pretest	Male	5.07	1.40
	Female	4.73	1.50
Immediate Posttest	Male	5.91	1.44
	Female	6.23	1.48
Delayed Posttest	Male	5.85	1.43
	Female	5.69	1.44

5.4. The Effect of Utilizing Erroneous Examples on Memory Retention

To check whether the error intervention led to higher memory retention measured by the posttest, a one-way ANOVA was conducted on immediate posttest and delayed posttest. The results show that there was no difference in the immediate posttest between the two groups($F(1,130) = 3.278$, $p > .05$), however, a significant difference existed in the delayed posttest($F(1,130) = 5.637$, $p < .05$). The results of the one-way ANOVA are presented in <Table 6>.

<Table 6> Results of one-way ANOVA

		N	*M*	*SD*	F	p
Immediate Posttest	Control	58	5.81	1.830	3.278	.073
	Experiment	73	6.27	1.071		
Delayed Posttest	Control	57	5.44	1.500	5.637	.019*
	Experiment	73	6.03	1.323		

*p<.05, **p<.01, ***p<.001

Gender, motivation, and pretest was inserted as control variables to observe if the results remain constant with the addition of control variables. Since the study randomized the participants according to class instead of individuals, it is difficult to say that the intervention was completely homogeneous on the control and experiment groups. Thus, several variables were utilized as the covariate to decrease the difference between the groups. The results of the regression analysis show that the difference in the delayed posttest disappeared with the addition of the three control variables. The results of the regression analysis are presented in <Table 7>.

<Table 7> Results of regression analysis

		B	*SE*	*β*	t	R^2	F
Immediate Posttest	Gender	.316	.217	.114	1.456	20.633	16.381
	Motivation	−.063	.269	−.018	−.235		
	Pretest	.596	.076	.609	7.843		
	Learning condition	.183	.218	.065	.839		
Delayed Posttest	Gender	−.034	.211	−.013	−.160	17.077	14.505
	Motivation	−.103	.260	−.032	−.396		
	Pretest	.528	.074	.570	7.167		
	Learning condition	.267	.212	.101	1.262		

5.5. Moderation Effect of Prior Knowledge on Immediate Posttest

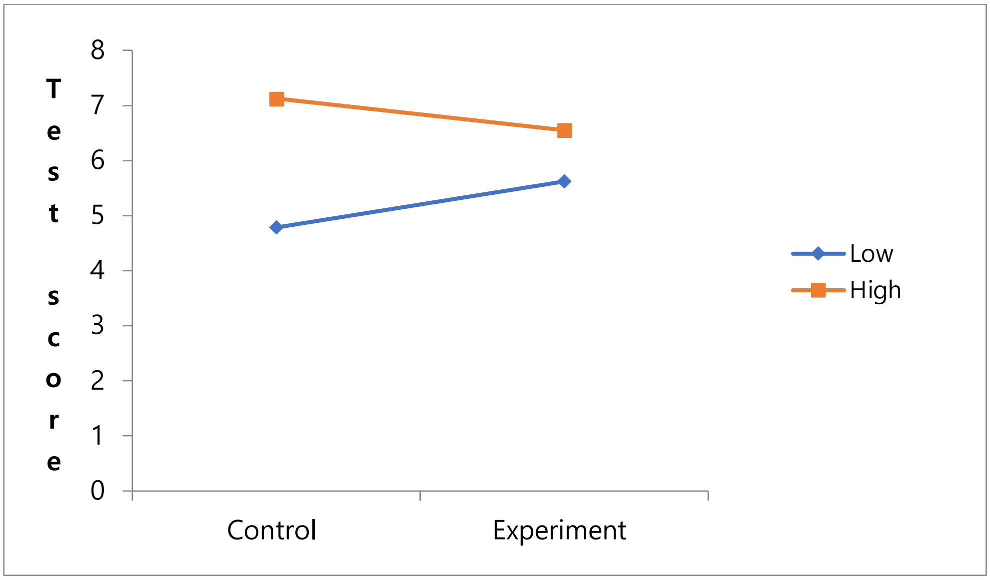
A regression analysis was used to investigate the moderation effect of prior knowledge on utilizing erroneous examples and memory retention on the immediate posttest. The results show an interaction effect between learning condition and prior knowledge (B = −.506, SE = .140, β = −.353, t = 3.615, p = .000). The interaction effect between learning condition and prior knowledge is indicated in <Picture 2>.

In order to examine the interaction effect of learning condition and prior knowledge in more detail, Johnson-Neyman analysis was conducted. The conditional effect of learning condition on the immediate posttest moderated by prior knowledge was analyzed. The results show that the conditional effect was significant when prior knowledge was below −.58 and above 0.93 (Refer to <Picture 3>).

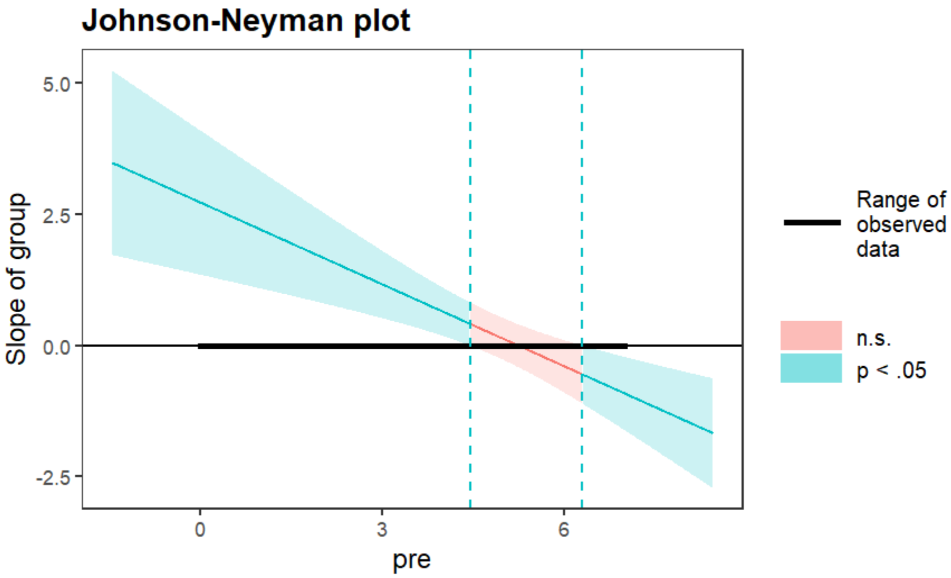
<Table 8> Results of regression analysis on immediate posttest

	B	SE	β
Learning condition(A)	.191	.205	.065
Prior knowledge(B)	.823***	.099	.818
A X B	−.506***	.140	−.353

*p<.05, **p<.01, ***p<.001



<Picture 2> The interaction effect of learning condition and prior knowledge



<Picture 3> Result of Johnson-Neyman plot

5.6. Moderation Effect of Prior Knowledge on Delayed Posttest

A regression analysis was used to investigate the moderation effect of prior knowledge on utilizing erroneous examples and memory retention on the delayed posttest. The interaction effect between learning condition and prior knowledge was not significant on the delayed posttest.

<Table 9> Results of regression analysis on delayed posttest

	B	*SE*	*β*
Learning condition(A)	.319	.207	.111
Prior knowledge(B)	.632***	.100	.647
A X B	-.160	.141	-.115

*p<.05, **p<.01, ***p<.001

Chapter 6. Conclusion and Discussion

6.1. Discussion

The study aimed to investigate the impact of utilizing errors in text-based environments on memory retention.

To sum up the results of the experiment, a one-way ANOVA showed that utilizing erroneous examples in text-based environments led to higher memory retention on the delayed posttest, but not the immediate posttest. Thus, significant differences were found in the means of the groups on the delayed posttest. In addition, a regression analysis showed that the interaction effect of prior knowledge was only significant on the immediate posttest, not the delayed posttest.

According to previous research, utilizing erroneous examples in the domain of mathematics led to higher posttest scores than only studying worked examples or solving problems. As so, explaining both correct and incorrect mathematical concepts was shown to be more beneficial than only explaining correct mathematical concepts (Durkin & Rittle-Johnson, 2012; McLaren et al., 2012). Furthermore, prior research shows that when an immediate and delayed posttest was implemented, the beneficial effects of erroneous examples was mostly found in the delayed posttest. This depicts that utilizing erroneous examples may be beneficial for long-term memory retention (Adams et al., 2013; McLaren et al., 2015).

The current study investigated the usage of erroneous examples not in the domain of mathematics, but in the domain of science. The results of the study show that students who studied text that included errors performed significantly better on the delayed posttest than students who studied text that did not include errors. These results are in line with previous literature that show a delayed test effect. Furthermore, previous research shows that tests involving short answer questions lead to superior retention relative to tests involving multiple-choice questions. Since the current study included short answer questions in the posttest, this factor may have contributed to higher memory retention (Butler & Roediger, 2007; Roediger & Butler, 2011).

The results have different implications theoretically and practically. Theoretically, the study proved that using erroneous examples leads to a delayed test effect. Currently, the delayed test effect of erroneous examples can be explained by desirable difficulties (Adams et al., 2013). However, since desirable difficulties may not fully explain the underlying mechanism of erroneous examples, additional research is needed to uncover why the usage of erroneous examples is beneficial for memory retention. Practically, utilizing erroneous examples in the learning environment may be beneficial for students' memory retention. Research demonstrated the benefits of erroneous examples in the domain of mathematics, and the current study showed the benefits in the domain of science. Future research must be conducted to examine whether these results can be replicated in other domains. Also, further research must be implemented to investigate how erroneous examples can specifically be utilized inside the classroom. For example, textbook publishers and classroom teachers should consider including erroneous examples more frequently in their lessons (Durkin & Rittle-Johnson, 2012)

The interaction effect of prior knowledge was significant on the immediate posttest. This shows that the effect of learning condition on the immediate posttest significantly depended on prior knowledge. An interesting finding from the analysis was that students with less prior knowledge benefited more from utilizing erroneous examples than students with more prior knowledge.

Research on erroneous examples show mixed findings about whether prior knowledge interacts with erroneous examples. Some studies show that students with higher prior knowledge perform better when studying erroneous examples than students with lower prior knowledge. Specifically, students with higher prior knowledge benefit more from erroneous examples than students with lower prior knowledge when little to no scaffolding is provided. In the experiment conducted by Große and Renkl, the participants in the correct and incorrect solutions groups were not given the correct solutions. Thus, they did not receive feedback of how to correct the errors (Große & Renkl, 2007; Zhao & Acosta-Tello, 2016). On the other hand, other studies show that there are no indications of an interaction between amount of prior knowledge and either learning with correct examples or learning with correct and incorrect examples. Thus, erroneous examples can help students with low prior knowledge under some conditions. Similarly, the results of one study show that the errorful condition was just as effective for participants with low prior knowledge as it was for participants with high prior knowledge. However, this was only true when students engaged in more scaffolded comparison of correct and incorrect examples. The results suggest that the benefits of erroneous examples may depend on the level of support (Adams et al., 2013; Durkin & Rittle-Johnson, 2012).

The current study showed that students with low prior knowledge benefit more from erroneous examples than students with high prior knowledge. These results are in line with previous research that report that erroneous examples may help students with low prior knowledge. Research shows that students who do not have high prior knowledge may benefit from erroneous examples if they are provided with sufficient scaffolds. One potential scaffold that was used in previous studies was comparison. Encouraging students to directly compare correct and incorrect examples could help students learn from erroneous examples (Durkin & Rittle-Johnson, 2012). The current study used corrective feedback as a scaffold. The participants received corrective feedback while discovering and correcting the erroneous examples in the text. Thus, this scaffold may have contributed to the high performance of students with low prior knowledge.

In addition, the interaction effect of learning condition and prior knowledge shows that not only did students with low prior knowledge perform significantly better in the errorful condition compared to the errorless condition, but students with high prior knowledge performed significantly worse in the errorful condition compared to the errorless condition. Students may experience greater confusion and frustration when studying in the errorful condition compared to studying in the errorless condition. Previous research showed that students in the errorful condition experienced greater confusion and frustration than students in the problem-solving condition, and confusion and frustration was associated with worse test performance. The results proved that the negative relation between confusion and frustration and test performance remained significant even when controlling for pretest (Richey et al., 2019). The results show that learning from erroneous examples may be mediated by confusion and frustration. Similarly, the participants in the current study may have experienced confusion and frustration in the errorful condition, leading to low performance.

6.2. Limitations and Future Research

There are several limitations to the study. First, although the results of the current study show that the errorful condition led to higher memory retention than the errorless condition on the delayed posttest, some additional conditions might have led to more robust results. For example, if the participants in the errorful condition had been asked to find all of the errors in the text and given feedback on them, they might have been able to better correct their misconceptions and therefore performed better on the posttest. In addition, if the participants were asked to self-explain the errors that were included in the text, they might have received higher posttest scores. Research shows that self-explaining both correct and incorrect examples leads to better performance (Booth et al., 2013; Richey et al., 2019; Tulis et al., 2016). Future research should consider including these conditions in the experiment.

Second, the study only explored the benefits of erroneous examples, without measuring whether the students were aware of the benefits of erroneous examples. According to prior research, accurate metacognitive knowledge is important for metacognitive control and strategy selection. If students are not aware of the potential efficacy of a study strategy, they might not utilize the strategy. Thus, students' metacognition about the effects of errors may be as important as the effects of the errors themselves (Huelser & Metcalfe, 2012). Future research should additionally investigate whether participants in the study believe that utilizing erroneous examples is a helpful study strategy. Students will not utilize erroneous examples in their learning if they are not aware of the benefits.

Third, the current study did not include any questions to check whether the intervention was correctly implemented. Previous studies that included an intervention asked the participants how much of the intervention they understood and how easy they thought the intervention was. If such questions had been included in the study, it would have been possible to determine what the students thought about the intervention. Since questions to check the effectiveness of the intervention were not included in the study, it was difficult to figure out what the students thought about the science topic and how familiar they were with the topic. Since the experimenter chose a science topic that the students had already learned, some students might have believed that the topic and test questions were too easy. Thus, future studies must include questions to check the intervention of the study.

Fourth, the study was randomized on class-level although the analysis was conducted on individual-level. Since the study was randomized on class-level instead of individual-level, a confounding effect could occur. However, after controlling for the effects of class using hierarchal linear modeling, the main effects and interaction effects stayed constant. Nevertheless, future studies must randomize on individual-level in order to draw more accurate results.

The current study investigated erroneous examples with paper and pencil. However, several recent studies have dealt with erroneous examples in the context of technology. For example, several studies have explored the benefits of erroneous examples using intelligent tutoring systems (Chen et al., 2016). As more students become familiar with technology and as more schools utilize technology in the learning environment, future research should explore how erroneous examples can be utilized using different technological apparatus. Previous research has demonstrated that using technology, such as various intelligent tutoring systems, can sometimes increase learning benefits and usually leads to the reduction of learning time. Thus, future studies must examine the best way to optimize learning using interactive, computer-based features.

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Appendix

Appendix A. Text Example

1. Errorless Condition

태양은 생물과 우리 생활에 많은 영향을 미칩니다. 식물은 태양 빛을 이용하여 양분을 만들고, 초식동물은 식물이 만든 양분을 먹고 살아갑니다. 또한, 태양 빛을 이용해 전기를 만들 수 있고, 물이 순환하는 데 필요한 에너지를 공급합니다. 태양이 없으면 우리는 지구에서 살아가기 어렵습니다.

태양계는 태양과 행성 등으로 이루어져 있습니다. 태양은 태양계에서 유일하게 스스로 빛을 내는 천체입니다. 태양은 태양계의 중심에 있고, 태양계 행성에는 수성, 금성, 지구, 화성, 목성, 토성, 천왕성, 해왕성이 있습니다. 수성, 금성, 지구, 화성은 표면이 딱딱한 땅으로 되어 있고, 목성, 토성, 천왕성, 해왕성은 표면이 기체로 되어 있습니다.

지구는 태양에서 매우 멀리 떨어져 있습니다. 한 시간에 900km를 이동하는 비행기를 타고 가도 지구에서 태양까지 가는 데 약 19년이 걸립니다. 이와 같이 태양에서 행성까지의 거리가 매우 멀기 때문에 상대적인 거리로 비교해야 됩니다. 태양계 행성의 크기는 다양합니다. 수성, 금성, 화성은 지구보다 크기가 작고, 목성, 토성, 천왕성, 해왕성은 지구보다 크기가 큽니다. 수성이 가장 작고, 목성이 가장 큽니다.

별은 태양처럼 스스로 빛을 냅니다. 하지만 행성은 별과 달리 스스로 빛을 내지 않고 태양 빛이 반사되어 우리에게 관측됩니다. 여러 날 동안 밤하늘을 관측하면 별은 행성보다 지구에서 먼 거리에 있기 때문에 움직이지 않는 것처럼 보입니다. 반면에 행성은 태양 주위를 돌며 별보다 지구에 가까이 있기 때문에 위치가 변하는 것을 볼 수 있습니다.

2. Errorful Condition

태양은 생물과 우리 생활에 많은 영향을 미칩니다. 식물은 태양 빛을 이용하여 양분을 만들고, 육식동물은 식물이 만든 양분을 먹고 살아갑니다. 또한, 태양 빛을 이용해 전기를 만들 수 있고, 물이 순환하는 데 필요한 에너지를 공급합니다. 태양이 없으면 우리는 지구에서 살아가기 어렵습니다.

태양계는 태양과 행성 등으로 이루어져 있습니다. 행성은 태양계에서 유일하게 스스로 빛을 내는 천체입니다. 태양은 태양계의 중심에 있고, 태양계 행성에는 수성, 금성, 지구, 화성, 목성, 토성, 천왕성, 해왕성이 있습니다. 수성, 금성, 지구, 화성은 표면이 기체로 되어 있고, 목성, 토성, 천왕성, 해왕성은 표면이 딱딱한 땅으로 되어 있습니다.

지구는 태양에서 매우 멀리 떨어져 있습니다. 한 시간에 900km를 이동하는 비행기를 타고 가도 지구에서 태양까지 가는 데 약 19년이 걸립니다. 이와 같이 태양에서 행성까지의 거리가 매우 멀기 때문에 상대적인 거리로 비교해야 됩니다. 태양계 행성의 크기는 동일합니다. 수성, 금성, 화성은 지구보다 크기가 크고, 목성, 토성, 천왕성, 해왕성은 지구보다 크기가 작습니다. 목성이 가장 작고, 수성이 가장 큽니다.

행성은 태양처럼 스스로 빛을 냅니다. 하지만 별은 스스로 빛을 내지 않고 태양 빛이 반사되어 우리에게 관측됩니다. 여러 날 동안 밤하늘을 관측하면 별은 행성보다 지구에서 먼 거리에 있기 때문에 움직이는 것처럼 보입니다. 반면에 행성은 태양 주위를 돌며 별보다 지구에 가까이 있기 때문에 위치가 변하지 않는 것을 볼 수 있습니다.

Appendix B. Test Example

1) 태양이 우리에게 소중한 까닭은 무엇인가요?

2) 보기 중 태양이 생물과 우리 생활에 미치는 영향에 대한 설명으로 옳지 않은 것은?
a. 식물은 태양 빛을 이용하여 양분을 만듭니다.
b. 육식동물은 식물이 만든 양분을 먹고 살아갑니다.
c. 태양 빛은 물이 순환하는 데 필요한 에너지를 공급합니다.

3) 태양계란 무엇인가요?

4) 표면이 땅으로 되어 있는 행성을 하나 써 봅시다.

5) 지구보다 크기가 큰 행성을 하나 써 봅시다.

6) 태양계에서 가장 작은 행성은?

7) 별의 특징을 한 가지 써 봅시다.

8) 보기 중 행성과 관련된 내용을 옳지 않은 것은?
a. 태양처럼 스스로 빛을 냅니다.
b. 여러 날 동안 같은 밤하늘을 관측하면 위치가 변하는 것을 볼 수 있습니다.
c. 표면에 닿은 태양 빛이 반사되어 우리에게 관측됩니다.

Appendix C. Motivation Questionnaire

번호	질문 내용	전혀 아니다	아니다	보통이다	그렇다	매우 그렇다
1	나는 수업내용을 이해하는 데 도움이 되기 때문에 공부한다.	①	②	③	④	⑤
2	나는 공부하는 것을 즐기기 때문에 공부한다.	①	②	③	④	⑤
3	나는 나중에 공부할 때 좀 더 어려운 내용을 이해하는 데 도움이 되기 때문에 공부한다.	①	②	③	④	⑤
4	나는 친구들이 나를 똑똑한 학생으로 봐주기를 원하기 때문에 공부한다.	①	②	③	④	⑤
5	나는 부모님이 하라고 시키시기 때문에 공부한다.	①	②	③	④	⑤
6	나는 성적이 나쁘면 창피하기 때문에 공부한다.	①	②	③	④	⑤
7	인생에서 공부는 중요한 것이 아니다.	①	②	③	④	⑤
8	나는 공부를 하면 선생님이 칭찬을 하시기 때문에 공부한다.	①	②	③	④	⑤
9	나는 부모님이 실망하시는 것을 원하지 않기 때문에 공부한다.	①	②	③	④	⑤
10	나는 지식을 쌓아 가는 것은 가치 있는 일이라고 믿기 때문에 공부한다.	①	②	③	④	⑤
11	나는 모르는 것에 대한 해답을 알고 싶어서 공부한다.	①	②	③	④	⑤
12	나는 선생님께 인정받기를 원하기 때문에 공부한다.	①	②	③	④	⑤

13	공부는 나의 관심사가 아니다.	①	②	③	④	⑤
14	나는 공부를 하면 부모님이 상(용돈, 선물, 칭찬 등)을 주시기 때문에 공부한다.	①	②	③	④	⑤
15	나는 공부를 하면 실생활에 유용하게 쓰일 수 있기 때문에 공부한다.	①	②	③	④	⑤
16	나는 어려운 도전들로부터 기쁨을 얻기 때문에 공부한다.	①	②	③	④	⑤
17	나는 지식을 쌓는 것이 재미있어서 공부한다.	①	②	③	④	⑤
18	나는 경쟁상대를 이기기 위해서 공부한다.	①	②	③	④	⑤
19	나는 선생님이 하라고 시키시기 때문에 공부한다.	①	②	③	④	⑤
20	나는 공부를 왜 해야 하는지 모르겠다.	①	②	③	④	⑤
21	나는 공부하지 않으면 부모님이 화를 내시기 때문에 공부한다.	①	②	③	④	⑤
22	나는 솔직히 학교에서 시간을 낭비하는 것 같은 느낌이다.	①	②	③	④	⑤
23	나는 선생님이 나를 무시하는 것을 원하지 않기 때문에 공부한다.	①	②	③	④	⑤
24	나는 왜 학교에 가는지 모르겠고, 솔직히 전혀 신경을 쓰지 않는다.	①	②	③	④	⑤
25	나는 생각하기를 좋아하기 때문에 공부한다.	①	②	③	④	⑤
26	나는 공부하는 것이 재미있기 때문에 공부한다.	①	②	③	④	⑤
27	나는 수업 시간에 배운 내용을	①	②	③	④	⑤

	확인하려고 공부한다.					
28	나는 내가 학교에서 뭘 하고 있는지 모르겠다.	①	②	③	④	⑤
29	나는 공부하면서 모르는 것들을 알아 가기 위해서 공부한다.	①	②	③	④	⑤
30	나는 공부하지 않으면 선생님이 벌(야단, 체벌)을 주시기 때문에 공부한다.	①	②	③	④	⑤

Abstract

텍스트 학습에서 오류 활용이 기억에 미치는 영향

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본 연구는 텍스트 기반 환경에서 오류가 사전지식 수준에 따라 기억에 미치는 영향을 살펴보았다. 초등학교 5학년 158명이 연구에 참여하였으며, 이 중 131명의 데이터가 최종 분석에서 활용되었다. 연구참여자는 통제 집단과 실험 집단 중 하나에 할당되어 2일 동안 실험에 참여하였다. 통제 집단은 오류가 포함되지 않는 텍스트를 학습하였다. 반면, 실험 집단은 의도적으로 오류가 포함된 텍스트를 학습하였다. 실험 집단에 할당된 학생들은 오류를 발견하고 수정하라는 지시를 받았다. 필요할 경우 피드백이 제공되었다. 통제 집단과 실험 집단의 사후 및 추후 시험 결과를 비교하고자 하였다.

연구결과 텍스트 기반 환경에서 오류를 활용하는 것이 더 높은 기억으로 이어졌다. 구체적으로, 실험 집단이 통제 집단보다 추후 시험에서 더 높은 점수를 받았다. 이 결과는 오류가 포함된 예제를 학습하는 것이 기억에 효과적이라는 선행 연구와 일치한다. 또한, 사전지식이 오류 처치와 기억 간의 관계를 부분적으로 조절하였다. 오류 처치와 사전지식은 사후 시험에서만 유의미한 상호작용효과를 보였다. 흥미로운 결과는 사전지식이 낮은 학생들이 사전지식이 높은 학생들보다 사후 시험에서 더 높은 점수를 받았다는 점이다. 이는 사전지식이 낮은

학생들이 오류가 포함된 텍스트를 학습하는 것에 더 긍정적인 효과를 보였다는 것을 시사한다.

이러한 결과는 사전지식이 높은 학생들이 오류가 포함된 예제를 통해 공부하는 것에 긍정적인 효과를 보인다는 선행연구와 상반된 결과이다. 그러나 다른 연구에서는 사전지식이 오류 처치와 의미 있는 상호작용효과를 보이지 않는다고 보고하기도 하였다. 이에 따르면 사전지식이 낮은 학생들도 오류가 포함된 예제를 통해 긍정적인 효과를 기대할 수 있다. 따라서 본 연구는 사전지식이 낮은 학생들도 오류가 포함된 예제를 통해 학습할 수 있다는 선행연구와 일관된다. 본 연구는 오류가 포함된 예제를 통해 긍정적인 효과를 보일 수 있는 특정 조건들을 밝히는 것의 중요성을 다시 한번 확인하였다.

본 연구는 자기 설명과 같은 조건들을 연구에 포함하지 못한 한계가 있다. 이러한 한계점에도 불구하고 본 연구는 오류가 포함된 예제를 학습 상황에서 활용할 수 있는 방법에 대한 포괄적인 이해에 기여한다. 특히 선행연구에서는 오류가 포함된 예제를 수학 분야에서만 살펴보았지만, 본 연구는 과학 분야를 살펴보았다는 것에 의의가 있다. 본 연구는 오류가 포함된 예제가 더 높은 기억에 기여하며 사전지식의 영향을 함께 살펴볼 필요성을 시사한다.

주요어 : 학습전략, 오류, 오류가 포함된 예제, 지연된 시험 효과, 사전지식, 오개념

학번 : 2022-27583