

Article

Effects of Science Reader Belief and Reading Comprehension on High School Students' Science Learning via Mobile Devices

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Abstract: This research examines senior high school students' earth science learning effects, focusing on the influence of science reading beliefs when employing mobile devices. The revision of the Science Reader Belief Inventory (SRBI) was used to examine the connections for high school students' personal scientific reading beliefs and reading comprehension of earth science learning effectiveness conditions when using mobile devices to learn. The learning outcome was determined using achievement tests. In this research, 97 students from three classes of first-year high school students were enrolled in an eight-week experimental teaching study followed by an achievement test. The major findings are as follows: (1) High school students' transaction beliefs were stronger than transmission beliefs. Transaction beliefs were significantly correlated with transmission beliefs. (2) Scientific beliefs may take a long time to change. (3) Whereas traditional reading comprehension strategies seem to have relied more heavily on vocabulary development, in an e-learning environment, students tend to rely on sentence-level parsing to understand scientific texts. This research provides a reference for teachers within learning environments in which information is incorporated into technology instruction, and various learning scenarios are used.

Keywords: mobile devices; science reader belief; science learning outcomes



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1. Introduction

Reading is the main source of knowledge construction and an important basis of learning. Students acquire knowledge and have their learning and growth promoted through reading. Under the trend of the global knowledge economy, improving one's reading ability is increasingly crucial. Reading education is being actively promoted as the focus of developed countries worldwide, and it is listed as a core policy. Since 1995, UNESCO has set 23 April as World Book and Copyright Day and promoted various reading education policies. In addition, the Organization for Economic Cooperation and Development (OECD) indicated in an international rating of education competitiveness that reading is an indispensable process of acquiring new knowledge and that national reading interest and public science education are crucial core competency indices. The Programme for International Student Assessment (PISA) led by the OECD compares education system indicators of different countries to provide these countries with reflections related to education policymaking as well as a reference for education system efficacy evaluations. PISA 2012 employed traditional pen-and-paper assessments to test students and also added an online problem-solving test. PISA 2015, which was completely computerized following the concept of digital assessment, added a test of online collaborative problem-solving skills.

Facing the prospective trend of digital learning, advanced training for teachers to improve their teaching competence has become crucial. PISA also emphasizes digital learning and the ability of interpersonal collaboration and combines education research and practice communities to ponder on an approach that helps students develop abilities for the challenges in their life, studies, and career in the future. Furthermore, projects for the three major competencies of mathematics, science, and reading are actively promoted. Students' core competencies as modern global citizens are expected to be effectively cultivated. In particular, reading is the key cornerstone for the promotion of science education and a basic personal competency. Students effectively improve their competencies in the long-term process of accumulatively reading and understanding articles [1,2]. Vygotsky's [3] cognitive development theory proposes that reading is the cognitive understanding process of texts by an individual. The development of cognitive ability is promoted through textual thinking and exchanges in social culture. Kintsch [4] indicated that reading comprehension is achieved through the interaction and fusion between article messages and readers' stimulated concepts. Therefore, reading comprehension is the key point of the entire reading activity. Reading is an ability with multiple integration points, and the meanings constructed by readers in the process do not necessarily conform to those constructed by the author. Different readers also construct different knowledge representations through reading the same text, and thus different interpretations and understandings occur. However, the reader factor has rarely been discussed in the domain of science text reading [5–7].

Previously, reading was done with traditional paper-based textbooks. However, according to the 2015 Horizon Report K-12 Edition published by the New Media Consortium, the expanded application of technology in classrooms has become the trend for teaching tools on campus [8,9]. In particular, the maturation of mobile learning and e-book products, as well as the popularity of tablets and e-readers, have facilitated the extensive application of community learning, just-in-time learning, and personalized learning. The learning method of using e-books will influence reading methods in the future. Although people are paying attention to the study of learners' reading comprehension with e-textbooks, studies on the influence of learners' science reading beliefs on e-book reading remain insufficient at present. This is a crucial topic worthy of attention considering the promotion of e-books in information education. Thus, to gain an in-depth understanding of the reading comprehension process of science texts, this study discussed the processes of reading comprehension and meaning construction from the perspective of science reading beliefs. In short, to understand the learning behaviors in a digital environment, apart from the study of the influence of the technique aspect, students' personal science reading beliefs and reading comprehension must be examined for analysis and research. Consequently, the researchers are interested in the discussion of the influence of readers' reading beliefs and reading comprehension on science learning outcomes in different learning environments. In accordance with the aforementioned motives, the concrete goals of this study are listed in detail as follows:

1. To understand the distribution of high school students' personal science reading beliefs.
2. To understand the situations of students' reading comprehension and learning outcomes in different reading environments.
3. To determine whether high school students' personal science reading beliefs and reading comprehension can predict learning outcomes in different reading environments.

1.1. Related Research on Personal Reading Belief Content and Reading Comprehension

Schraw and Bruning [10] believed that reader beliefs based on different literal constructions can result in variations in the epistemology of text, thus leading to variations in reading comprehension. From the perspective of methodology, scholars have proposed different belief models for the reading process. These belief models include the transmission model, the translation model, and the transactional model. The transmission model assumes that the meaning of the text transmits directly from the author to the reader, and readers are considered passive receivers whose main purpose is to extract the original

intention of the author, not to actively construct meanings. It is a belief with a basis in author transmission. The translation model assumes that the meaning of the text is independent of the author's original intention and the meanings are constructed based on readers' abilities. The hidden meanings are extracted by readers from the decoded information or are expressed with clear words. No personal experience of the reader or speculation of the author's intention is required. It is a belief based on textual meanings. The transactional model assumes that meanings are mainly constructed by readers rather than by the author's intention or the textual content. Readers interpret the texts according to their own personal purposes and intentions. Therefore, meanings are constructed by readers' prior knowledge, past reading experience, and situational goals. Reading is a subjective process, and meanings are not objectively provided by the author or the texts. It is a belief based on meanings given by readers. However, Straw and Sadowy [11] denied the existence of the translation model and considered it meaningless and not an independent belief model. Consequently, Schraw and Bruning [10] established the Reader Belief Inventory. Reading belief was divided into the author transmission belief and the meaning construction belief, and the transmission and transactional models were considered to have different levels of contribution to the reading process. The author's transmission belief is based on the transmission model. It enhances readers' memory of the author's transmission intention and important information in the text. It may also construct a comprehension framework that conforms to the major concept of the text. The meaning construction belief is based on the transactional model. Readers are not very influenced by the text information and construct multiple explanations according to their own beliefs and expectations, particularly when readers' personal beliefs and expectations differ from the main concepts of the text. In addition, the meaning construction belief may tend to elicit the participation of personal reactions and emotions compared with the author transmission belief. Various studies have demonstrated that the construction and comprehension of the meanings of text content are influenced by readers' own reading beliefs [5,11–15], and that different reading beliefs can influence the interaction between readers' effective reading ability [16], text construction ability [17], and the effective transmission of the author's message [18].

In the realm of mathematics and science, science texts are the main method for recording science knowledge and information. Consequently, the ability to read and understand science texts is a competence that must be cultivated in the process of learning science. Fleischner and Manheime [19] indicated that the difficulties students encounter in learning mathematics and solving problems often originate from problems in language comprehension. Studies related to science learning have also found that reading ability can predict science learning achievements [20–22]. The common viewpoint of such studies is that students' performance in learning mathematics and science is absolutely related to their abilities to read and comprehend the texts and related information. Various theories exist that are related to the reading comprehension process, such as the schema theory [23] and the inference construction theory [24,25]. The most extensively discussed theory is the construction–integration theory of reading comprehension proposed by Kintsch [4,26,27], which argues that in the comprehension process, a reader organizes concepts into propositions through the integration of vocabulary identification, syntax, and terminology, and then turns the propositions into the structure network of knowledge. During the process, readers connect the textual messages they receive to their related background knowledge to understand the text. The process of reconstruction, inference, and integration of the construction–integration theory has been supported in neuroscience research [28–32]. Furthermore, Anderson [33] proposed three similar stages for the language comprehension process: the perceptual, parsing, and utilization stages. The perceptual stage involves decoding and interpreting sentences before entering the parsing stage. In the parsing stage, the semantics perceived in the sentences during the previous stage are used to form concepts that are meaningful to the reader. Finally, in the utilization stage, readers can choose to implement, store, respond to, or abide by the meaning concepts as their way of utilizing the meaning concepts [34,35]. Simultaneously, although these three stages

basically proceed in this order, they also often partly overlap. This means that readers can utilize a sentence while simultaneously analyzing the next sentence. Barsalou et al. [36] asserted that when people comprehend a sentence, they construct a sensual comprehension of its meaning. According to the aforementioned literature, the process of reading an article is more complicated than reading a sentence, and thus it deserves more discussion. Regarding the reading comprehension theory of science, there is still no psychological study dedicated to this topic. Generally, researchers only interpret by following the general process of text reading comprehension. However, the terminology used in science texts differs greatly from the vocabulary used in people's daily lives. Various studies have indicated that students' science comprehension is related to their language abilities, but it cannot completely explain the complicated process of comprehending scientific concepts. Graesser et al. [37] referred to narrative texts as story texts, which mainly describe the situations of events, activities, or special cultural experiences. Kendra et al. [38] argued that expository texts mainly convey truthful information, whereas narrative tests often contain special vocabulary and concepts. In addition, Meyer and Poon [39] asserted that both narrative texts and expository texts have a hierarchical structure, but they differ in their main structures. Narrative texts only use one type of grammar, namely story grammar. By contrast, expository texts use multiple types of grammar, the purpose of which is to teach students new information. Articles in the domains of science, social science, and history are often displayed in the form of discourse text, and the function of such articles is to introduce or explain theories, facts, general principles, and data. The formation of science concepts and theories has a historical background. In various studies on science learning, scholars have consistently mentioned that understanding the development process of scientific knowledge is a crucial part of science comprehension [40,41]. Therefore, the research on science education should investigate the deep comprehension of science concepts from the development process of scientific knowledge. Science texts are often presented in discourses. Furthermore, studies have found that text structures influence comprehension [24,37,42–44]. Different text structures trigger different reading goals and beliefs, which in turn trigger the construction of different representations and mind models. Chen and Yang [45] indicated that prior knowledge influences the reading comprehension of different science texts. Furthermore, the forms of science texts can include explanatory texts, study theses, forums, refutation articles, controversial issues, and Internet messages. Scholars mostly divide the structures of science texts into expository texts and refutation texts. Expository texts are often seen in classrooms or professional settings. Numerous studies on science text reading have used this type of text as materials for reading studies, and well-structured problems have been used to evaluate reading outcomes. Such research has found that readers' prior knowledge influences reading comprehension [46–48].

Next, this study reviewed literature related to personal reading beliefs, science text reading comprehension, and the process of meaning construction. Schraw and Bruning [10] studied 154 American college students. They used expository texts to examine the relationships between personal reading beliefs and text reading. Reading beliefs were divided into the author transmission belief and meaning construction belief. Schraw [1] studied 247 American college students and discussed the relationships between personal reading beliefs, reading comprehension, and meaning construction. The study showed that author transmission and meaning construction beliefs are independent constructs of the reading process.

Dai and Wang [49] discussed narrative texts and expository texts. Their study and experiments related to reading beliefs all indicated that the author transmission belief and meaning construction belief are independent of each other. In addition, these two beliefs had no significant difference in terms of semantic comprehension, and the only obvious differences were in reader responses and overall expositions. When readers' meaning construction beliefs are strong, their responses and overall expositions are superior to those of readers with strong author transmission beliefs. Consequently, some scholars believe that the cultivation of the meaning construction belief is a critical link in the process

of reading comprehension. Based on the conclusion drawn from the aforementioned literature, this study started from reading beliefs to understand the relationships between them, reading comprehension, and the meaning construction process. Thus, the processes of reading comprehension and meaning construction were understood in more detail.

1.2. Development and Evolution of E-Textbooks and the Trend of the Digital Environment

Education is a long-term endeavor for a nation, and information technology teaching is the trend of education in the 21st century. With the development of 3G technologies, the first generation of mobile learning started in 2007. Subsequently, different companies launched their own mobile platforms successively, including three types of smartphones (e.g., iPhone, Google Pixel, and Samsung Galaxy). Learners can engage in mobile learning in the forms of group learning and integrated-environment perception learning. In addition, the applications of novel learning technologies are gradually emerging on mobile devices. Technology is developing at a tremendous pace, and all developed countries are devoted to the teaching of digital technologies. In addition, national education policies have been amended to actively promote the development of e-textbooks, which are included in regular teaching assistance materials and are expected to gradually replace traditional paper-based textbooks. Following the trend of promoting e-textbook teaching in various countries, the California state government in the United States has gradually promoted e-textbooks in middle and elementary schools. Since 2010, Japan has tested e-textbooks in elementary schools and provided tablets or interactive whiteboards for the promotion of e-textbook teaching. In 2013, South Korea promoted teaching using e-textbooks in middle and elementary schools nationwide to improve students' learning outcomes. The changes and advancement of information technologies accelerate the propagation and growth of new knowledge. The creation of paper-based textbooks entails a long process from editing, publishing, and reviewing to their adoption. In addition, the circulation of traditional textbooks must undergo the process of printing, production, and selling of hard copies. Thus, the publication speed of paper textbooks is slow and their content is fairly limited [50–53]. The massive release of current open educational resources and the popularity of free social platforms facilitate diverse sharing for teachers and learners. In addition, resources can be downloaded, edited, and utilized, promoting the booming development of e-textbooks [54]. As expounded in a novel learning technology application prediction graph in the 2011 New Media Consortium (NMC) Horizon Report, mobile learning, e-books, collaborative learning environments, and the rise of cloud computing have increased learners' venues for knowledge acquisition and prompted the transition of the digital learning environment from single-computer learning to network learning, and even mobile learning that involves tablets and smartphones. Thus, the education environment is gradually changing [55].

However, the learning methods and environmental preferences of "learning" in digital and traditional learning environments are different. Learners' learning methods when using e-books are closer to a digital learning environment. Methods that involve the Internet, smartphones, mobile devices, or personal computers all differ from traditional "teaching" and "learning" environments. McKiernan [50] indicated that e-textbooks transformed education from being teacher-oriented to student-oriented. The study indicated that digital environments transform the role of teachers, and learners' methods also differ. Furthermore, Nelson et al. [56] found that teachers' methods of technology utilization can gradually influence students' learning attitudes. Courses taught in digital environments are more likely to interest students and motivate them to learn, thereby improving their learning outcomes [57]. Petrides et al. [58] indicated that using e-textbooks can guide teachers to adopt new teaching methods, thereby developing students' knowledge exploration and problem-solving abilities. Utilizing interactive resources enables students to grasp course content more easily and improves their willingness to learn and exploration abilities. Students can use basic information abilities for e-textbook reading and in-depth issue exploration. The interactivity of e-textbooks not only improves students' learning

outcomes but also encourages them to be more focused in class. Furthermore, it cultivates students' problem-solving ability, active learning spirit, and science exploration and science thinking abilities [56,59–63].

The characteristic difference between paper-based reading and online reading lies in the reader's active degree of reading behavior and the way of input [49,59,64–72]. Although the readers of paper books also have the initiative to construct the text's meaning, basically, when readers read printed books they play the role of receivers, following the author's writing, the sequence and context of the text, and reading in a straight line from top to bottom, which usually requires continuous concentration and emphasizes in-depth reading, without paying attention to the reader's thoughts while reading [3,5,67–70]. In contrast, when reading online, readers often shift between multiple texts through hyperlinks. Reading activities can start at one text and end at another. Under the influence of the Internet's power, people's amount of time spent digital reading continues to increase browsing and scanning, keyword spotting, one-time reading, reading selectively, non-linear reading. However, sustained attention, in-depth reading, and concentrated reading are gradually decreasing. Paper-based reading has the characteristics of linearity, unidirectionality, stability, readability, and portability; while online reading texts include non-linear, interactive, immediate, aggregated, anonymous, and accessible characteristics [1,8–10,67–70].

The aforementioned literature has expounded the differences between the e-book learning environment and traditional learning methods. Regarding the design of multimedia teaching materials, various studies have discussed how different multimedia teaching materials influence learners' learning outcomes. However, insufficient Mandarin research exists related to the influence of learners' personal science reading beliefs' on digital environment learning and the application of e-textbooks on science reading beliefs. Thus, discussing these topics is necessary.

2. Research Methodology

2.1. General Background

The research tools were the Science Reader Belief Inventory (SRBI) and science text contents, which are described in the following subsections. This questionnaire was developed from Schraw's [1] Reader Belief Inventory. It addresses two belief elements, author transmission belief, and meaning construction belief, to measure readers' reading comprehension status. The researcher translated Schraw's inventory and developed it into a Chinese science reader belief questionnaire with items measured on a five-point scale. The text in the original inventory's Question 16 was revised to "science reader belief" [73,74]. The SRBI test can only determine high school students' overall comprehension levels after reading science texts; it cannot analyze their process of comprehension and meaning construction in detail. Consequently, this study used the construction–integration (CI) model developed by Kintsch [26] to design an open questionnaire. In relevant studies, comprehension has been considered a bottom-up thinking method that moves from divergence to convergence. Reading starts from word recognition and decoding and proceeds to the comprehension of sentences and propositions, and finally reaches the meaning construction of paragraphs. After paragraphs are constructed, the context is connected, thereby shaping the mental model of the text to explain its content. Consequently, the sentence analyses of reading comprehension and meaning construction are divided into text-related vocabulary, text-unrelated vocabulary, total vocabulary, propositions of the text subject, propositions of personal ideas, correct propositions of the text, correct propositions of personal ideas, unrelated propositions, and total propositions. The individual definitions are explained as follows. "Text-related vocabulary" refers to the vocabulary or keywords in the provided science text. "Text-unrelated vocabulary" refers to vocabulary or keywords that are not in the provided science text. The total vocabulary contains text-related and text-unrelated vocabulary. "Propositions of the text subject" refer to the propositions written in open questions after reading the science text that are related to the content of the science text. "Propositions of personal ideas" refer to the number of propositions related to personal

opinions that are not related to the science text. “Correct propositions of the text” refer to the propositions related to the science text that are correct. “Correct propositions of personal ideas” refer to the number of propositions related to personal opinions that are unrelated to the science text and correct. “Unrelated propositions” refer to the propositions that are not related to the science text. “Total propositions” refer to the total number of all propositions.

2.2. Sample

This study’s participants were 10th-grade students at one municipal high school in Keelung City, Taiwan, and the subject was basic earth science. Only students whose parents were notified of the purpose of the research and provided informed consent were eligible to take part in this research. Due to the need for informed consent from parents, limited resources, and other specifics of the experimental method used in the research, only a relatively small sample of students ultimately took part in the research. Specifically, the participants consisted of 97 high school students in three classes at a school. The teacher majored in earth sciences and specialized in teaching earth science with 10 years of teaching experience. The students are grouped into classes according to the S-type method upon enrolment at the high school, and therefore classes in a year group are about equal in students’ learning abilities. The teaching material in this study was an interactive e-book designed by the researcher. This e-book focused on marine energy resources, and it was designed to supplement basic earth science knowledge. Regarding the implementation method, one class learned by reading traditional paper-based science articles; another class learned by reading online e-books; and a third class learned using 9.7-inch mobile tablet devices (e.g., iPads). The teaching was conducted during summer vacation over 8 weeks for a total of 20 classes. The total number of student participants was 97. Before the experiment, differences in prior knowledge between the three classes were determined, for which the students’ scores on their final basic earth science (1) exam were used. Covariance analysis revealed no significant differences between the three classes, indicating that their prior knowledge of earth science exhibited little difference ($F = 0.31, p > 0.05$). The details are presented in Tables 1 and 2.

Table 1. Descriptive statistics of the semester scores in basic earth science (1) in the three classes receiving different teaching methods.

Class	Number of Students	M	SD	Min	Max
Paper-based	35	67.29	19.37	34.00	99.00
Computer	29	63.90	15.57	38.00	89.00
Tablet	33	66.21	16.58	33.00	99.00
Total	97	65.91	17.24	33.00	99.00

Table 2. One-way analysis of covariance (ANCOVA) of semester scores in basic earth science (1) in the three classes receiving different teaching methods.

Variable	Sum of Squares	df	Mean Sum of Squares	F	p
Between groups	186.81	2	93.40	0.310	0.73
Within groups	28,341.34	94	301.50		
Total	28,528.16	96			

2.3. Limitations

This study’s limitation may be the insufficient sample size, which was about 30 students per class. It is suggested that future studies may increase the sample size.

2.4. Reliability

After a pretest, the questions were divided into two dimensions—author transmission belief and meaning construction belief—through exploratory factor analysis. The Cron-

bach's alpha value of the overall scale's internal consistency was 0.86, which conformed to the requirement that the valid reliability coefficient must be over 0.80. Thus, it would possess educational value in usage [75]. The alpha values of the author transmission belief and meaning construction belief dimensions were 0.55 and 0.84, respectively, and they had an explanatory power of 55%. The test number of the official questionnaire was 97 people. After confirmatory factor analysis, the chi-square value of the entire model's goodness of fit in the first stage was 35.447 ($p = 0.31$). Thus, the null hypothesis was supported. The Root mean square error of approximation (RMSEA) value was $0.033 < 0.05$ and the Goodness of fit index (GFI) value was $0.934 > 0.90$. This meant that the hypothesis model fits the sample data. The composite reliability of the author transmission belief dimension was 0.61, and the average variance extraction (AVE) was 0.36. The composite reliability of the meaning construction belief dimension was 0.83, and the AVE was 0.42. According to Kline [76], the composite reliability must be larger than 0.50. In addition, AVE is the average of the total factor loadings, and a value above 0.36 is acceptable [77,78]. This means the SRBI was a suitable measurement tool. After correction, there were 10 question items [73], of which the following are two examples:

1. I am happy to interpret the content of the science article that I read in my own way.—Meaning construction belief.
2. The most important goal of reading a science article is to understand what the author is talking about.—Author transmission belief.

From the 97 questionnaires, 10 were randomly selected to be rated by another earth science teacher of the same school. The second teacher majored in earth sciences. The rating items included "text-related vocabulary," "text-unrelated vocabulary," "total vocabulary," "propositions of the text subject," "propositions of personal ideas," "correct propositions of the text," "correct propositions of personal ideas," "unrelated propositions," and "total propositions." The Pearson correlation coefficients of the items were between 0.82 and 0.95, and all correlations reached significance. Apart from propositions of personal ideas and correct propositions of personal ideas, most of the coefficients were equal to 0.86. This analysis method and rating possessed favorable reliability. When raters had different opinions, a consensus was reached following a discussion.

Question examples:

Part 1: Please recall the keywords (nouns) from the vocabulary (fill in forms) that you associate with the science text.

Part 2: Please make some sentences or paragraphs using the keywords (nouns) or vocabulary from Part 1.

3. Science Texts and Questionnaire

The science text was selected according to the principle of providing students space for self-thinking. The novel topic of the new marine energy resource—methane hydrates—was selected as the topic for the science text, which the students had not yet learned about. This unit of teaching material was the 2012 marine education pilot project for high schools from Taiwan's Ministry of Education. Five experts had examined the content and corrected it, and then it was made into an e-book and won an excellent teaching material of the year award. The course subject was methane hydrates, and the course content included questions for learning evaluation, which were used for measuring the learning outcomes of this study. The official questionnaire had 25 questions; the internal consistency was $KR_{20} = 0.82$ for the pretest and $KR_{20} = 0.79$ for the official test. The difficulty was between 0.30 and 0.82, with an average difficulty of 0.59. The discrimination was between 0.26 and 0.85, with an average discrimination of 0.46. This indicated that this test is suitable for use in examining students' learning outcomes.

4. Data Analysis

The study data were analyzed according to the study's purposes. The personal science belief distribution of the high school students was analyzed with descriptive statistics

and analysis of covariance (ANCOVA). The pretest was used as the covariance factor to understand the science reading belief status in different reading environments. In different reading environments, regarding students' reading comprehension and learning outcomes, the Pearson product-moment correlation was used to understand the levels of intimacy between the two variables. Finally, whether the personal science reading beliefs and reading comprehension of high school students could predict learning outcomes in different reading environments was discussed. The prediction conditions were understood through multiple regression.

5. Results

Before the experimental teaching activity, a Pretest with the SRBI was conducted. The total number of high school students was 97, and their test results are presented in detail in Table 3. The results indicated that the mean score of the meaning construction belief dimension was 3.87, and that of the author transmission belief dimension was 3.66. Thus, the mean of the meaning construction belief dimension was higher than that of the author transmission belief dimension.

Table 3. Descriptive statistics of the pretest using the Science Reader Belief Inventory (SRBI) on high school students.

Dimension	M	SD	Min	Max	<i>r</i>
Mean of the meaning construction belief dimension	3.87	0.40	2.43	5.00	0.53 **
Mean of the author transmission belief dimension	3.66	0.57	2.00	5.00	
Total score of the pretest	38.10	4.13	26	50	-

** $p < 0.01$.

Subsequently, a post-test was conducted with the three classes in different reading environments, and the test results are presented in detail in Table 4. The mean score of the meaning construction belief dimension was 3.77, and that of the author transmission belief was 3.62. Both were higher than 3.0, and the mean of the meaning construction belief dimension was significantly higher than that of the author transmission belief ($t = 4.19$, $p < 0.001$). The pretest and post-test of the personal science reading belief dimensions for high school students had moderately positive correlations. As shown in Table 3, the two belief dimensions in the pretest were moderately and positively correlated ($r = 0.53$, $p < 0.001$), and as shown in Table 4, the two belief dimensions in the post-test also were moderately and positively correlated ($r = 0.63$, $p < 0.001$).

Table 4. Descriptive statistics of the post-test means of the personal science reading belief dimensions for high school students.

Dimension	M	SD	Min	Max	<i>r</i>
Mean of the meaning construction belief dimension	3.77	0.55	2.71	5.00	0.63 ***
Mean of the author transmission belief dimension	3.62	0.58	2.33	5.00	
Total score of the post-test	37.26	5.12	27	50	-

*** $p < 0.001$.

To determine whether the students' science reading beliefs would exhibit differences in different reading environments, the reading belief pretest was used as the covariance factor for the ANCOVA. The results indicated that the meaning construction belief, author transmission belief, and total scores all failed to reach statistically significant differences in the three groups of traditional paper-based texts, online e-books, and mobile devices.

According to the study results, in both the pretest and post-test, the means of the meaning construction belief and author transmission belief dimensions were higher than

3.0. In addition, the means of the meaning construction belief dimension were higher than those of the author transmission belief dimension. Students could extract information from the text and organize the representations in the article. In both the pretest and the post-test, the two belief dimensions were moderately and positively correlated ($r = 0.53, p < 0.001$; and $r = 0.63, p < 0.001$, respectively). This differs from the results of the aforementioned studies, but conforms with a domestic study by Yang and Chang [73] on Taiwanese subjects. This study speculated that this is because differences exist in the beliefs because of habits, culture, and education atmosphere, or because the East and the West have different language habits and grammars. A third possibility is that the two dimensions are in fact correlated, but this would require more empirical research for verification.

5.1. The Reading Comprehension Items Were Significantly Correlated with Learning Outcomes

In the traditional environment, learning vocabulary was emphasized, whereas, in the digital environment, the comprehension of both vocabulary and propositions was emphasized. Regarding the correlation between learning outcomes and reading comprehension in the traditional reading environment, the correct text propositions exhibited a weak significantly positive correlation ($r = 0.29, p < 0.05$), whereas text-unrelated vocabulary exhibited a significantly negative correlation ($r = -0.44, p < 0.05$). This indicated that the greater the amount of text-related vocabulary, the lower the achievement test scores were for students.

Regarding the correlations between learning outcomes and reading comprehension in the computer reading environment, text-related vocabulary and achievement test were moderately and positively correlated ($r = 0.44, p < 0.01$). Total vocabulary and achievement test were moderately and positively correlated ($r = 0.39, p < 0.05$). Achievement test and text subject propositions exhibited a high significant correlation ($r = 0.67, p < 0.01$). Achievement test and correct propositions exhibited a moderate positive correlation ($r = 0.46, p < 0.01$). Achievement test and correct text propositions exhibited a strong significant and positive correlation ($r = 0.70, p < 0.01$). Achievement test and total proposition number exhibited a moderate significant and positive correlation ($r = 0.47, p < 0.01$).

Regarding the correlations between learning outcomes and reading comprehension in the mobile device reading environment, achievement test and text subject propositions exhibited a moderately significant and positive correlation ($r = 0.59, p < 0.01$). Achievement test and correct propositions exhibited a moderately significant and positive correlation ($r = 0.43, p < 0.01$). Achievement test and correct text propositions exhibited a strong significant and positive correlation ($r = 0.60, p < 0.01$). Achievement test and total proposition number exhibited a moderately significant and positive correlation ($r = 0.54, p < 0.01$). Achievement test and unrelated proposition number exhibited a moderately significant and positive correlation ($r = -0.50, p < 0.01$).

Among the different reading environments, readers' thinking emphasized the comprehension model of vocabulary for science texts in the traditional reading environment. In the digital technological environment with computers and mobile devices, according to the correlations of proposition numbers that students recalled and wrote, there were more recalled vocabulary items and text subject proposition numbers. Thus, the concepts and meanings that texts convey are gradually understood. Specifically, after readers read and understand the content of a science text, the keywords of the entire article are first understood and then the propositions are constructed according to the keywords. The higher the number of correct propositions, the higher the scores in the achievement tests were, and they exhibited a moderate to strong correlation. In the traditional environment, students might have understood the content with keywords, whereas in the digital environment, the science texts were read and understood with keywords and propositions.

5.2. High School Students' Reading Comprehension Items Could Predict Learning Outcomes

This study used the scores of the achievement tests as dependent variables, and personal science reading belief and cognitive load as independent variables. Regression

analysis and diagnostic models were conducted in the experiments. The variables are explained as follows. The independent variables of personal science reading belief were (1) meaning comprehension belief and (2) author transmission belief. The independent variables of reading comprehension were (1) text-related vocabulary; (2) text-unrelated vocabulary; (3) total vocabulary; (4) text subject propositions; (5) personal idea propositions; (6) correct text propositions; (7) correct personal idea propositions; (8) unrelated propositions; and (9) total proposition number. The self-evaluation table of cognitive load was also employed. The analysis in this stage was multiple regression analysis, which explores the coefficients between multiple variables. The optimal prediction equations of dependent variables were found. The greatest use of the mathematic model after the regression was prediction, and the relationships between variables could be explained. In this study, according to the literature review, independent variables that failed to pass the tests were deleted one by one until all the independent variables conformed to the standards set in advance. The regression model obtained at this point was the optimal model. The regression functions obtained from the analysis were different with different models or different standards. The statistics related to regression models are shown in Table 5. In the traditional reading environment, the multiple correlation coefficient of independent variables and dependent variables was 0.443. The square of the multiple correlation coefficient was 0.196 (coefficient of determination), and the adjusted coefficient of determination was 0.172.

Table 5. Regression model statistics of learning achievement in different reading environments.

Type	R	R Square	Adjusted R Square	DW
Traditional reading environment	0.443	0.196	0.172	1.578
Computer reading environment	0.703	0.494	0.475	2.227
Mobile device reading environment	0.706	0.499	0.466	1.504

Furthermore, Table 6 shows the function finally obtained after stepwise regression. The dependent variable was the learning outcome score, and the independent variable was the text-unrelated vocabulary. The explanatory power of the independent variable explaining the dependent variable was 17.2%. Table 5 also shows that the autocorrelation Durbin–Watson (DW) test value was 1.578. The residual value did not violate the basic assumption of no autocorrelation. In the computer reading environment, the multiple correlation coefficient of the independent variables and dependent variables was 0.703. The square of the multiple correlation coefficient was 0.494 (coefficient of determination), and the adjusted coefficient of determination was 0.475. This function was the function finally obtained after stepwise regression. The dependent variable was the learning outcome score, and the independent variable was the correct text proposition number. The explanatory power of the independent variable explaining the dependent variable was 47.5%. The autocorrelation DW test value was 2.227. The residual value did not violate the basic assumption of no autocorrelation.

Tables 6 and 7 present details of the analyses of variance related to the regression models. The *F* value of the final function regression model in the regression analysis in the traditional reading environment was 8.068 ($p < 0.01$), attaining significance. This indicated that the unrelated vocabulary number could predict the learning achievement test. The *F* value of the final function regression model in the regression analysis in the computer reading environment was 26.344 ($p < 0.001$), attaining significance. This indicated that the correct text proposition number could predict the learning achievement test outcomes. The *F* value of the final function regression model in the regression analysis in the mobile device reading environment was 14.945 ($p < 0.001$), attaining significance. This indicated that the correct text proposition number and unrelated proposition number could predict the learning achievement test outcomes.

Table 6. Analysis of variance table of the regression model of the achievement test.

Reading Environment	Model	Sum of Squares	Degree of Freedom	Mean Sum of Squares	F
Traditional reading environment	Regression	102.611	1	102.611	8.068 **
	Residual	419.675	33	12.717	
	Total	522.286	34		
Computer reading environment	Regression	285.341	1	285.341	26.344 ***
	Residual	292.452	27	10.832	
	Total	577.793	29		
Mobile device reading environment	Regression	247.577	2	123.789	14.945 ***
	Residual	248.483	30	8.283	
	Total	496.061	32		

** $p < 0.01$; *** $p < 0.001$.

Table 7. Table of numerical test values of different parameters in the learning achievement regression model.

Reading Environment	Model	Unstandardized Coefficient		Standardized Coefficient	t	p
		B	Standard Error	Beta		
Traditional reading environment	(constant)	16.269	0.721		22.552	<0.001
	Text-unrelated vocabulary	−1.515	0.533	−0.443	−2.841	0.008
Computer reading environment	(constant)	6.082	1.610		3.779	0.001
	Correct text proposition number	2.577	0.502	0.703	5.133	<0.001
Mobile device reading environment	(constant)	10.821	0.736		14.697	<0.001
	Correct text proposition number	0.865	0.225	0.510	3.839	0.001
	Unrelated proposition number	−0.537	0.184	−0.386	−2.911	0.007

The standard regression models were as follows:

1. The learning achievement test in the traditional reading environment (dependent variable) = $-(0.515) \times \text{text-unrelated vocabulary}$.
2. The learning achievement test in the computer reading environment (dependent variable) = $(2.577) \times \text{correct text proposition number}$.
3. The learning achievement test in the mobile device reading environment (dependent variable) = $(0.865) \times \text{correct text proposition number} - (0.537) \times \text{text-unrelated proposition number}$.

The standardized regression coefficients can reveal the relative importance of independent variables. The larger the standardized regression coefficients, the higher the relative importance of the variance of the independent variables explaining the dependent variables. The results obtained in this study were as follows: the results in the traditional reading environment indicated that the unrelated vocabulary number could predict the learning achievement test outcomes, but they exhibited a negative correlation. In the computer reading environment, the correct text proposition number could predict the learning achievement test outcome, and they exhibited a positive correlation. In the mobile device reading environment, the correct text proposition number and the unrelated proposition number could predict the learning achievement test. The correct text proposition number exhibited a positive correlation, but the unrelated proposition number exhibited a negative correlation. The numerical values of the abovementioned regression equations indicated that in the traditional environment, the larger the amount of unrelated vocabulary required

for reading comprehension for high school students, the poorer their performance was in the achievement test. In the computer and mobile device reading environments, the higher the correct text proposition numbers were in the reading comprehension process, the higher the students' grades were. The results indicated that in the traditional environment, reading comprehension is focused on vocabulary memory, whereas in the digital environment, it is focused on propositions.

6. Discussion

The changes in belief require a longer time frame [79–81]. Another possibility is that high school students belong to the digital-native generation; they have been immersed in a digital technology environment since they were young, and they often read relevant data in documents using the Internet. This gives them the traits of being highly networked, interactive, and socialized [35,82–85].

According to Schraw [1], the score of the meaning construction belief dimension being higher means that readers are less influenced by the messages of the text. In addition, readers' beliefs and expectations are enhanced, and thus, various explanations and meanings are constructed. By contrast, when the score of the author transmission belief dimension is higher, the concepts and meanings that the author is attempting to convey are enhanced. In addition, readers' memory of the key messages of the text is enhanced. However, readers may also construct comprehension frameworks that conform to the main concepts of the text independently. Moreover, relevant studies have indicated that the meaning construction belief and author transmission belief dimensions are independent [1,49,86,87], yet they exhibited moderate correlations in the present study.

This result indicated that the influence of different reading environments on science reading beliefs was nonsignificant. This agrees with the results of Kintsch [4] in that readers construct mental models according to past experience in life and learning. That is, in the reading process, readers recall the prior knowledge and concepts from sentences and paragraphs and construct situational models of the article description.

7. Conclusions

This study discussed the effects of personal science reading belief and reading comprehension on learning earth science in three different reading modes: traditional paper, online e-books, and mobile devices. In the process, the SRBI scale and open questions were administered to students to understand the correlations between personal reading belief, reading comprehension, and learning outcomes in different teaching environments.

In different reading environments, the meaning construction belief and author transmission belief of the personal science reading belief of high school students were both higher than the average value of 3.0. The mean of the meaning construction belief was larger than that of the author transmission belief, and the two exhibited a moderately significant correlation. In addition, high school students exhibited no significant differences in personal science reading in the different teaching environments. This study speculated that this was because belief changes require a long time. It is also possibly because high school students belong to the generation of digital natives. They have been immersed in the digital technological environment since they were young and often read related information and documents using the Internet. Consequently, they possess the traits of being highly networked, interactive, and socialized.

In the traditional reading environment, the influences of high school students' science reading beliefs and reading comprehension on learning outcomes were as follows. For the correlations of learning outcomes and reading comprehension, correct text propositions exhibited a weak significant and positive correlation. However, text-unrelated vocabulary exhibited a significantly negative correlation. Regarding the correlations of learning outcomes and reading comprehension in the computer reading environment, text-related vocabulary and the achievement test exhibited a moderately positive correlation. Moreover, total vocabulary and the achievement test exhibited a moderately positive correlation.

The achievement test and text subject propositions exhibited a strong significant and positive correlation. The achievement test and correct propositions exhibited a moderately significant and positive correlation. Furthermore, the achievement test and correct text propositions exhibited a strong significant and positive correlation. The achievement test and total proposition number exhibited a moderately significant and positive correlation. In the mobile device environment, the correlations of learning outcomes and reading comprehension were as follows. The achievement test and text subject propositions exhibited a moderately significant and positive correlation. The achievement test and correct propositions exhibited a moderately significant and positive correlation. Furthermore, the achievement test and correct text propositions exhibited significant and positive correlations. The achievement test and total proposition number exhibited a moderately significant and positive correlation. Finally, the achievement test and unrelated proposition number exhibited a moderately significant and positive correlation.

In the traditional reading environment, the larger the amount of unrelated vocabulary the high school students required for reading comprehension, the poorer their performances were in the achievement tests. This indicated that reading comprehension focuses on vocabulary memory in the traditional environment. However, in the digital reading environment with online e-books and mobile devices, the greater the correct text propositions high school students required for reading comprehension, the greater their performances were in the achievement tests. This indicated that reading comprehension focuses on propositions in the digital environment.

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