IARTEM · e-journal

Vol. 18 no. 1

Peer-reviewed research article

DOI: https://doi.org/10.21344/iartem.v18i1.1068

ISSN: 1837-2104

Effects of multiple representations of climate change in high-school textbook exercises on the learning of students

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Abstract

This study addressed the issue of learning about climate change by examining the relationships among cross-cutting concepts, inquiry abilities, and multiple representations in high-school textbook exercises. Content analysis was applied to the exercise items in the climate change chapter of the high-school earth science textbooks used in two versions of the curriculum in Taiwan. The study analysed 88 exercise items (39 from 2019 and 49 from 2009). The findings revealed that the concept of climate change is relatively complex, requiring the comprehensive application of knowledge within the earth science knowledge system, particularly addressing the themes of "interaction" and "stability and change". Furthermore, the analyses indicated that multiple representations enable students to demonstrate their abilities and knowledge and form opinions about climate change. By reading the temperature table, they can determine whether global warming is occurring. The research analysis simultaneously revealed that the latest examination questions are beginning to incorporate topics that integrate the nature of science and cultivate student interest in science due to the requirements of the new curriculum. The findings of this study support the importance of textbook design and suggest that multiple representations should be utilised in exercises to assess students' learning and allow them to self-evaluate.

Keywords: climate change, inquiry abilities, multiple representations, textbook exercises, curriculum differences

Introduction

Textbooks are an essential medium for disseminating knowledge in school education and are often influenced by contemporary knowledge paradigms, national policies, and other factors (Alpaslan, Yalvac, & Loving, 2015; Gracin & Matić, 2021). Regarding paradigm transfer, Lemoni, Stamou, and Stamou (2011) analysed the images that refer to "human and nature" topics in Greek biology textbooks from the 1980s to the early 2000s. They found that these images can be divided into three periods: (1) human beings acting as bystanders, observing and recording how the natural world operates; (2) in the medium term, human beings presented as masters, wantonly plundering natural resources; and (3) recent pictures focus on people and their coexistence with the natural environment. These changes imply the social and economic development process from agriculture and industry to a post-industrial society. They also illustrate the biological philosophies of the authors and echo changes in the global climate and in an increase in global village thinking.

The recent wave of education reforms has emphasised literacy-oriented instruction to cultivate students' ability to apply knowledge and become lifelong learners (Taiwan Ministry of Education [TMOE], 2014). Scientific literacies, which refer to the knowledge, abilities, and attitudes that a person should possess to face the challenges of their current and future lives, are also the fundamental consideration of many countries in their national curriculum development. Such a fundamental consideration emphasises the combination of learning and life experience, integrates cross-disciplinary knowledge and skills, and focuses on students' meaningful understanding, learning transfer ability, and scientific attitudes and values (Organisation for Economic Co-operation and Development [OECD], 2017; Taiwan Ministry of Education [TMOE], 2014). Based on the meaning of science-for-all and literacy-oriented instruction, *The General Guidelines of 12-year Basic Education in Taiwan* suggest that all high-school students must elect the subject of earth science for at least two credits (TMOE, 2014). All high-school students can, thus, possess scientific literacy to retain problem-solving skills and deal with issues in their daily lives (NGSS Lead States, 2013), including climate change. However, climate change is a complex concept as it is affected by global systems.

Researchers have argued that science textbooks are "multimodal" because they combine language and pictures to help students deconstruct complex systems (Kress & van Leeuwen, 2020; Mayer, 1997). Science textbooks use different visual representations (e.g., graphics, tables, maps, photographs, and drawings) to clearly present scientific information, organise data, display patterns and describe relationships, and ultimately change scientific meaning (Mayer, 2014). Science textbooks integrate multiple representations using different visualisation modalities that may facilitate literacy-oriented instruction. Because representations are an important tool for communication among scientists, the ability of scientists to interpret diagrams was found to relate to their familiarity with representations, collecting data, and translating between natural environments and representations (Roth, Bowen, & McGinn, 1999). Science textbooks are the most important tool for disseminating scientific knowledge. They should, therefore, present rich representations to help students acquire this content knowledge and cultivate their scientific literacy in deconstructing multiple representations to learn from.

Given the importance of textbooks in shaping the literacy-oriented learning of students in various subjects, it is vital to investigate the quality of textbooks, especially the exercise items they contain. These can be used to connect and evaluate student learning to determine their opinions about climate change (Meehan et al., 2018). Moreover, the diverse information in the exercise items may support students in demonstrating their inquiry abilities. This study, therefore, aimed to determine the content of the exercise items and their presentation methods in high-school earth science textbooks in new curriculum guidelines that emphasise the development of core literacies in Taiwanese students. The study also examined changes in these exercise items between two curriculum versions.

Based on the purpose of this study, the analysis was guided by three research questions:

1. Do the textbooks' exercises refer to complex systems in climate change?
2. Do multiple representations facilitate assessment of student performance on exercise items for complex systems such as those underlying climate change?
3. How do the exercise items on climate change differ between curriculum guidelines?

By examining the relationships among cross-cutting concepts, inquiry abilities, emotions, and multiple representations in the exercise items on climate change, this study was expected to reveal the current picture of developing student assessments for the concept of climate change and designing high-school science textbooks.

Theoretical background

This section addresses the research questions first through a literature review on contemporary education reforms to identify the trend of literacy-based instruction, such as the cross-cutting concepts, emotion, and inquiry abilities. The possible roles of science textbooks in contemporary education reforms are then revealed. The paper uses the term presentation to mean signs that stand in for and take the place of something else. For example, *Fe* denotes elemental iron; that is, *Fe* is a symbolic representation of iron, whereas "elemental iron" is a verbal representation of iron. On the other hand, one can also use a pictorial representation of the chemical structural formula for representing iron ore. Multiple representations mean that the same information is expressed in different forms, such as symbolic and verbal. Thus, previous studies on multiple representations in textbooks are discussed to better understand the relationships between literacy-based instruction and science textbooks. Finally, based on the review, we propose possible relationships between literacy-based instruction and multiple representations in exercise items for climate change in science textbooks.

Curriculum reforms and literacy-based instruction

Scientific literacy in the 21st century is not limited to whether students can extract scientific knowledge from subject content (content knowledge) since they also need to be able to apply the acquired knowledge in new situations to solve real problems (Harlen, 2001; OECD, 2017). Prominent among current essential competencies are "learning and innovation skills," "digital literacy skills (information, media, technology skills)," and "life and career skills" (Binkley et al., 2012; Griffin & Care, 2014). In the digital-information society, students must be able to think independently and critically and develop their creativity through communication and cooperation.

New curricula worldwide, therefore, need to encourage the application of acquired scientific knowledge to new situations to help students face the ever-changing world and overcome problems in their future lives. For example, the new curriculum in the U.S. emphasises learning science and technology through inquiry and practice (NGSS Lead States, 2013), while that in the England not only focuses on both the acquisition of science content knowledge ("what you know") but also emphasises working scientifically ("how you know") (Department for Education, 2014).

The new curriculum in Taiwan emphasises that integrated issues can teach the conceptual knowledge of different disciplines and subjects through fundamental inquiry abilities. This curriculum can enhance students' scientific learning and promote their learning motivation through metacognition. The practical implementation of the scientific inquiry process can allow students to understand how scientific knowledge is obtained and to develop the habit of applying scientific thinking (TMOE, 2014). Therefore, the designs of science courses in the curriculum focus on the process of scientific inquiry and on scientific practices. This approach for science courses and teaching can simultaneously allow the mutual reinforcement of learning content (cross-cutting concepts, as shown in Table 1) and performance (inquiry abilities and emotion toward science, as shown in Table 2).

Table 1
Cross-cutting concepts

Topic	Cross-cutting concepts	Description
Composition and characteristics of nature	Energy and matter	Includes the composition and characteristics of matter and the form and flow of energy
	Structure and function	Covers the structure and function of matter and living things
	Scale and systems	Covers various material and biological systems and phenomena of various scales in nature
Phenomena, laws, and functions of nature	Stability and change	Includes the stability of various phenomena in nature and the process of change or evolution
	Interactions	Includes the phenomena of nature and the interactions and relationships between various substances and organisms
Sustainable development of nature	Science and life	Includes the relationships between science, technology, society, and humanities
	Resources and sustainability	Focuses on natural resources and their sustainable development

Source: TMOE (2014)

Table 2
A framework of inquiry abilities

Category	Subcategories		Codes
Inquiry abilities	Thinking ability	Imagination and creativity	ti
		Reasoning and argumentation	tr
		Critical thinking	tc
		Construction of models	tm
	Problem-solving	Observing and identifying	po
		Planning and executing	pe
		Analysing and finding	pa
		Discussing and communicating	pc
Attitude toward science and the nature of science	Cultivating interest in scientific inquiry		ai
	Developing the habit of applying scientific thinking and inquiry		ah
	Understanding the nature of science		an

Source: TMOE (2014)

Curriculum reforms and science textbooks

The *UNESCO Guidebook on Textbook Research and Textbook* Revision proposed that textbook research can proceed from two directions (Pingel, 2010, p. 31). The first direction is to conduct textbook research from the perspective of teaching analysis, mainly to explore the teaching implications behind the text (e.g., Chambliss & Calfee, 1998; van Merriënboer & Kester, 2014). This approach often focuses on how teachers use textbooks in their teaching process and what kind of support system the textbooks provide to help teachers carry out activities. The second direction is to conduct textbook research from the perspective of content analysis. Contrasted with teaching analysis, content analysis focuses on exploring the meaning of the texts, pictures, tables, and other material in textbooks. With the growth of technology and neuroscience, studies of presentation also use eye-tracking to conduct research in textbooks (e.g., Behnke, 2023).

Following the global wave of curriculum reforms, research into science textbooks has increasingly focused on their relationship with the curriculum. Many recent studies have focused on pictorial and visual representations because they can help students understand the concepts established by scientists (Ainsworth, 1999; Roth et al., 1999). For example, Lemoni and colleagues (2011) investigated the relationship between pictorial representation in textbooks and text content, as well as the evolution of the curriculum. Thus, many researchers explored the relationship between pictorial representations in textbooks and science learning: for example, the relationship between the effect of pictorial design on teaching transformation by teachers and scientific knowledge construction by students (Tang, 2023), and a cross-national comparison of pictorial representations in textbooks (Ge, Unsworth, Wang, & Chang, 2018). Moreover, the relationship between pictorial representations and myth concepts held by students was explored (Pozzer-Ardenghi & Roth, 2005), and the differences in visual representations between textbooks and scientific literacy in assessments of PISA were investigated (Anagnostopoulou, Hatzinikita, & Christidou, 2012; Behnke, 2023). Textbooks can also convey information through symbols, diagrams and charts,
The current study adopted the following definition of pictorial representation to analyse the exercise items in the textbook: a visual method of conveying information, ideas, or data using images, drawings, symbols, or diagrams rather than words alone (Mayer, 2014). That is, the term pictorial representations includes image representations.

Multiple representations in science textbooks

Scientific representation is essential for communication and interactions in the scientific community and in disseminating scientific knowledge (AAAS, 1993; McTigue & Croix, 2010). Reading diagrams is vital in students' life experiences and school teaching and learning processes (Roth et al., 1999).

However, representations in science textbooks may not always facilitate student learning. There are two possible reasons for students having difficulty understanding textbook representations. The first is unfamiliarity with their meaning. Representations have the function of abstracting and concretely presenting the interrelationships of natural phenomena. Students can experience difficulties in understanding a representation's meaning and constructing their own meaning (Ainsworth, 1999). For example, Henderson (1999) described how an arrow can represent six functions in science textbooks, including marking parts, recording sequences of events, and representing forces.

The second reason for difficulties is the inability to deconstruct the meaning integrated by a such a representation. For example, Roth et al. (1999) found that a representation itself may not have any meaning; therefore, it requires interaction with other symbolic representations (e.g., text or graphics) and constructs meaning through experiences of the world consistent with the readers. Therefore, when students cannot obtain correct knowledge or reconstruct natural phenomena from representations successfully, it is not due to low ability or cognitive defects but instead due to a lack of experience in using representations for reading and practice or insufficient demonstration and practice.

To address the aforementioned learning difficulties, Mayer (2014) conducted a series of empirical investigations, arguing that students can solve problems by referring to appropriate representative presentations and using complementary representations. In addition, Yeh and McTigue (2009) explored the effects of representation in science test items in textbooks on students' science learning. They divided the questions into three categories: (1) type of pictorial representation, (2) function of pictorial representation, and (3) type of answer. Based on these studies, the study proposed the frameworks of the types of multiple representations (Table 3) and the roles of multiple representations (Table 4). The types of multiple representations refer to the categorisation of the different ways information is presented in the scientific assessment context. For example, if a test item provides photographs, maps, drawings, stylised drawings and pictures, flow charts, tables, or hybrids, it would be identified as a pictorial representation.

After identifying the types of multiple representations, this study examines which roles these representations play in solving tasks, which is also the focus of the current study: for example, where a test item presents a photograph of a rocket but the task requires calculating the oxidation number of the fuel. That is, the photograph provides no information for solving the problem.

Table 3
Types of multiple representations

Category	Details and examples
1-1 Pictorial representation	The item provides pictorials to describe the contextual information, including photographs, maps, drawings, stylised drawings and pictures, flow charts, tables, and hybrids.
1-2 Verbal representation	The item provides text to describe the contextual information.
1-3 Symbolic representation	The item provides symbols to describe the contextual information, such as F = ma.

Source: Adapted from Mayer (2014)

Table 4
Roles of multiple representations

Category	Subcategories
2-1 Providing information	2-1-a No information
	2-1-b Partial information
	2-1-c All information
2-2 Abilities for solving tasks	2-2-a Recognising figures
	2-2-b Recognising tables
	2-2-c Completing tables
	2-2-d Completing figures
	2-2-e Drawing figures/charts
	2-2-f Verbal responses

Source: Adapted from Yeh and McTigue (2009)

Climate change in science textbooks

Previous authors have argued that teenagers are unconcerned or do not have strong opinions about climate change (Kuthe, Körfgen, Stötter, & Keller, 2020). Young students' lack of concern about climate change is often attributed to their lack of knowledge. For example, Román and Busch (2016) indicated that students confuse the causes of climate change with other atmosphere-related pollution issues, such as acid rain and ozone depletion. Moreover, some students think that human activities cause the greenhouse effect and climate change. By doing so, these students may be firmly convinced of their own views, rather than recognising that other factors may be influencing global warming. A lack of knowledge or misconceptions may be the leading cause of the lack of concern about climate change. Many authors of science textbooks, therefore, assume that increasing readers' perception of the scientific consensus on climate change may be more conducive to concern and action.

Many researchers have focused on climate change in science textbooks (Meehan, Levy, & Collet-Gildard, 2018; Román & Busch, 2016). However, science textbooks often mention great scientific uncertainty about climate change and the human influence of the climate. For example, Meehan et al. (2018) investigated high-school textbooks in the United States and found that most of those following the Assessment

Reports of the Intergovernmental Panel on Climate Change (e.g., IPCC, 2023) portrayed human activity as a significant cause of climate change. Román and Busch (2016) found that middle-school textbooks emphasised natural variations and human activity. Such uncertainty provides the opportunity to train students in critical thinking and inquiry practices, such as analysing carbon emission rates and finding the relationship between different scales of temperature warnings. The climate-change issue is abstract and complex on both time and spatial scales and an interdisciplinary social issue. This is consistent with the complexity, multiple solutions, multiple criteria, and uncertainty of high-level thinking. Furthermore, because climate change is data-driven and evidence-based, data tables and temperature charts are often utilised to illustrate the changing climate, such as charts of global surface-temperature anomalies. Climate change, therefore, affects culture, including its ability to elicit scientific inquiry and representations.

The above discussion highlights the assumption addressed by the current study: that pictorial representation could facilitate learning about climate change among high-school students. Content analysis was used to examine the relationships and investigate this hypothesis, and 88 exercise items in earth science textbooks were included.

Methods

Sampling

The 12-year Basic Education Curriculum in Taiwan is divided into three educational stages: elementary school (grades 1–6), middle school (grades 7–9), and three years of high school. As students enter 11th grade, they must choose a major field, such as science or the social sciences. Before confirming their major group, all 10 graders must study both the domain of science and social studies. The domain of science includes four disciplines: physics, chemistry, biology, and earth sciences. In addition, the discipline of earth science consists of the topics of Astronomy, Atmospheric Sciences, Geology, Geophysics, and Marine Sciences (TMOE, 2018, also see https://cirn.moe.edu.tw/Upload/file/38227/104346.pdf).

Because all 10th graders major in earth science, this study adopted a qualitative content-analysis methodology and collected exercise items described in the climate change chapter of high-school earth science textbooks. Moreover, for comparative purposes, two versions of the Taiwanese curriculum were collected before and after the curriculum was reformed: the 2009 version and the 2019 version. This sampling procedure yielded 39 exercise items from the 2019 version and 49 from the 2009 version (Table 5), which were analysed in this study. Table 5 indicates that although seven leading publishers (referred to here as T1–7) published high-school textbooks, only four issued versions for both curricula; T1 published only a textbook for the subject in English, T5 published only the 2009 version, and T6 only the 2019 version. Therefore, only the remaining four publishers were selected for analysis.

Table 5
Sampling items from four publishers for the two curriculum versions

Subject/chapter	Publisher[1]	2009 version	Chapter location	2019 version	Chapter location
Earth science/ climate change	T2	7	8th	12	6th
	T3	17	7th	10	7th
	T4	9	7th	8	9th
	T7	16	7th	9	6th
Total		49		39	

Note.
[1]Seven publishers publish high school textbooks in Taiwan, but only four have published the two versions. T1 only published the English textbook, T5 only published the 2009 version, and T6 only the 2019 version.

Procedure

After collecting all 8 textbooks from the 4 publishers, the exercise items in the climate-change chapter of each book were scanned into electronic form (i.e., PDF files) before performing the subsequent analyses. The PDF files were then imported into a qualitative data analysis software package, Nvivo 14, for content analysis. While the item pool was set up, the task of deciding whether the tasks were sufficient for the coding schemes used in this study was determined by two experts: a PhD candidate in science education and a high-school teacher of earth science. The experts then examined the reliability of coding schemes by using Cohen's kappa testing.

Data analysis

This study employed content analysis to examine the multiple representations used in textbook exercise items (Krippendorff, 2004). Following the curriculum reform in Taiwan, the 2019 editions of the science textbooks emphasised cross-cutting concepts and inquiry-based practices. To address the research questions, the framework proposed by Mayer (2014) was adopted to ensure comprehensive coverage of representation types. Additionally, the functions of each type of representation were examined in accordance with the analytical approach by Yeh and McTigue (2009). All items were subsequently coded using coding schemes derived from prior studies, including those by the TMOE (2018), Mayer (2014), and Yeh and McTigue (2009). Table 1 presents the seven cross-cutting concepts examining the content knowledge of the exercise items. In addition, the framework of inquiry practices was quoted from the curriculum guideline of the 2019 version for examining the inquiry abilities of the exercise items (Table 2). This study also considered the types of representations and roles of representations in these exercise items (Tables 3 and 4). The coding schemes and coded items were examined by three researchers (two experts and the author) to ensure the reliability of the analysis (Cohen's kappa = .83).

These coding schemes were utilised to identify the relationships among the cross-cutting concepts, inquiry practices, and representations. For example, Figure 1 shows an item from the 2019 version of publisher T2 that presents a table with the number of days and peak temperatures (highest and lowest temperatures) in winter and summer in six cities from 1957 to 2006. The task required students to respond to two questions: (1) What is the title of this research? (2) Please discuss this table and state at least two points about the phenomenon observed from the data. The first question was coded in the "interactions" of cross-domain concepts, with the inquiry practice of "observing and identifying" and the "statistics table" representation. The second question was coded as "interactions," "analysing and finding," and "statistics table."

附表是統計六個測站於 1957 ～ 2006 年冬夏二季日數與峰值溫度（最高、最低溫），季節日數的單位是日 / 十年，峰值溫度的單位是℃ / 百年。負值表示日數減少或溫度下降，反之，正值表示日數增加或溫度上升。

臺灣季節變化		臺北	臺中	臺南	恆春	臺東	花蓮
夏季	季節日數	＋6.47	＋8.41	＋5.95	＋0.43	＋6.33	＋6.42
	峰值溫度	＋2.48	＋1.28	＋1.12	＋0.19	＋1.01	＋1.00
冬季	季節日數	－8.50	－7.54	－5.12	－2.62	－6.00	－6.62
	峰值溫度	＋3.61	＋3.74	＋2.89	＋1.14	＋2.19	＋2.78

（摘自《臺灣氣候變遷科學報告 2017 －物理現象與機制》）

(1)此一研究的題目為何？

(2)請討論此表格，陳述由數據觀察到的現象，至少二點。

<translation>

The Table presents statistics from six meteorological stations for the winter and summer seasons during the period 1957–2006, including seasonal duration (number of days) and peak temperature (maximum or minimum temperatures). The unit for seasonal duration is days per decade, while the unit for peak temperature is degrees Celsius per century (℃/century). Negative values indicate a decrease in the number of days or a drop in temperature. In contrast, positive values indicate an increase in the number of days or a temperature rise.

Seasonal Change in Taiwan		Taipei	Taichung	Tainan	Hengchun	Taitung	Hualien
Summer	During days	+6.47	+8.41	+5.95	+0.43	+6.33	+6.42
	Peak Temperature	+2.48	+1.28	+1.12	+0.19	+1.01	+1.00
Winter	During days	-8.50	-7.54	-5.12	-2.62	-6.00	-6.62
	Peak Temperature	+3.61	+3.74	+2.89	+1.14	+2.19	+2.78

(1) What is the title of this research?

(2) Please discuss this table and describe at least two observable phenomena based on the data.

Figure 1: An example item from the 2019 version of publisher T2

Results

This study investigated the research questions by analysing the exercise items in the earth science textbooks using the coding schemes of cross-cutting concepts, inquiry abilities, and multiple representations. Figure 2 shows the content analysis results for the exercise items of the total 8 textbooks from the two curriculum versions in Taiwan. The figure shows that the curriculum versions comprised different patterns of cross-cutting concepts (blue labels), inquiry abilities (green labels), and multiple representations (yellow and pink labels). First, 108 and 99 denote the curriculum versions in Mandarin, and n denotes the total number of exercises across the four textbooks of each curriculum. In addition, the number on the line means the exercises from the version of the curriculum. Moreover, each exercise can be coded in multiple categories (e.g., thinking abilities and problem-solving), but only one code per category. That is, one exercise cannot be classified under the same category, i.e., under one major thinking ability, as Figure 1 shows. For example, the cross-cutting concept of "scale and system" was designed in two exercise items of the 2009 version but not in the 2019 version. These differences are described in more detail in the sections below.

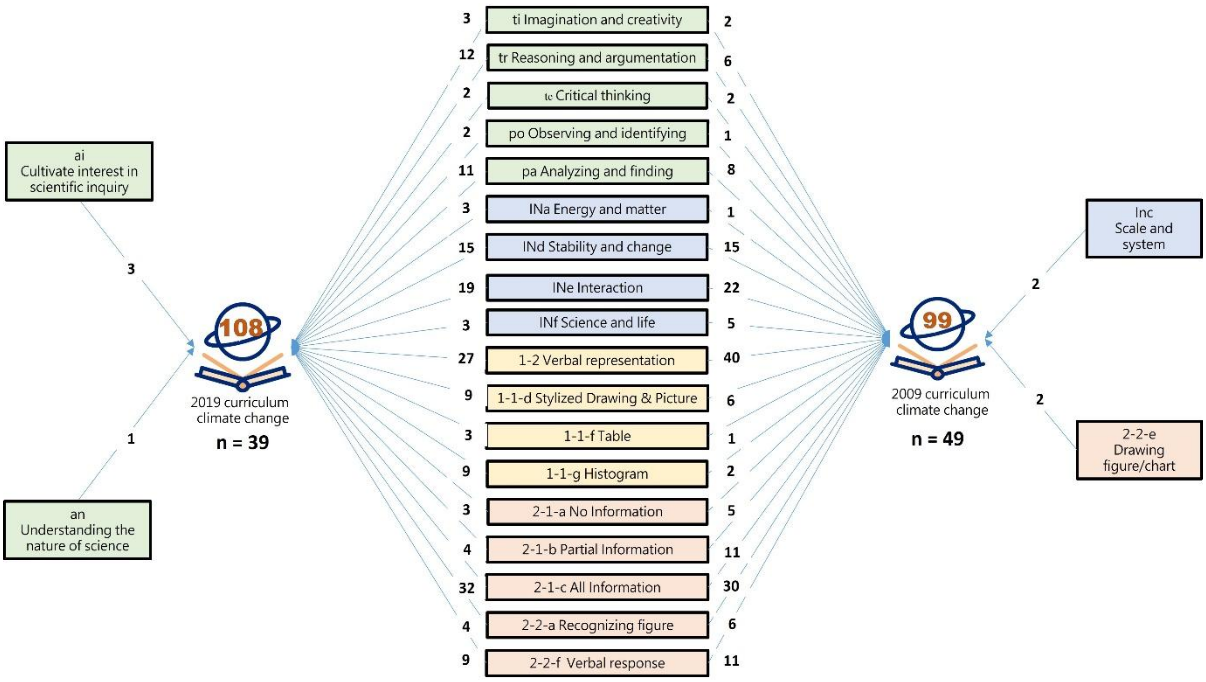

Figure 2: Results of the content analysis for the two curriculum versions

(Green labels represent the codes of inquiry abilities, blue represent the codes of cross-cutting concepts, yellow represent the codes of the types of representation, and pink represent the codes of the functions of representations.)

Climate change involves complex systems

Analysing the exercise items revealed that the chapter on climate change did not appear until very late in the earth science textbooks. For the example shown in Figure 3, climate change was mentioned in Chapter 6, which means students needed prior knowledge about the movements of the atmosphere (Chapter 3) and oceans (Chapter 4). Such arrangements also appeared in the textbooks of the other publishers (see Table 5). Based on this arrangement and the learning progression, the author assumed that the concept of climate change is relatively complex and needs the comprehensive application of knowledge about earth science. The factors that cause climate change include the current states of the atmosphere and oceans, while a volcano eruption can also affect climate change at small-scale locations.

Contents

Figure 3: Contents of the 2019 version of the publisher T2

The analysis of cross-cutting concepts further confirmed the assumption that climate change involves complex systems. As shown in Figure 4, the results for the cross-cutting concepts of the exercise items indicated that examination questions about climate change mostly encompass knowledge concepts spanning cross-disciplines (cross-cutting concepts), particularly addressing the themes of "interaction" (19 items in the 2019 version and 22 items in the 2009 version) and "stability and change" (15 items in both versions). To understand these items, students must clarify the relationships between variables that cause climate change, such as temperature increases related to carbon emissions, and understand temperature trends over long periods, as shown in Figure 1. Especially, the climate change issue involves interrelationships with multiple systems. For example, climate change would affect the atmospheric system, such as extreme weather, and the oceanic system, such as rising sea levels. Moreover, climate change and these systems are inherently linked and mutually causative.

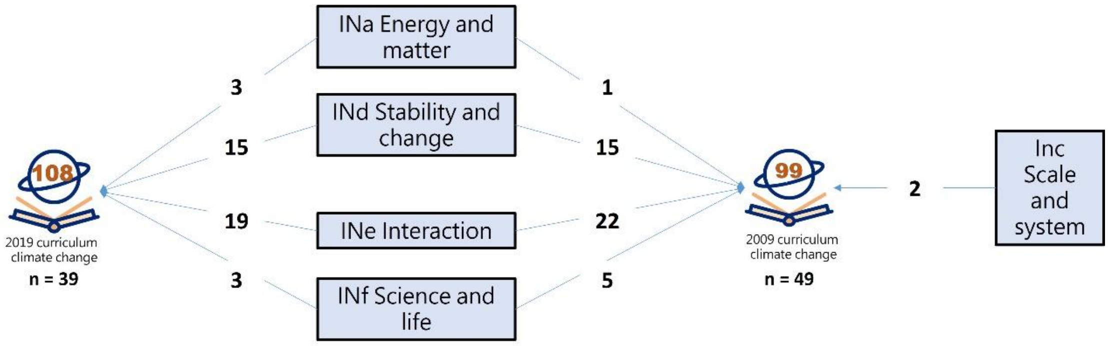

Figure 4: Results for the cross-cutting concepts

Pictorial representations create more opportunities for assessing students' inquiry abilities

To identify the relationships between multiple representations and inquiry abilities, the framework of inquiry abilities and multiple representations of exercise items was analysed simultaneously. Figure 5 presents the representations used in both curriculum versions and indicates that pictorial images were more commonly employed in recent items than in the old versions (e.g., in the 1-1-g histogram, there are 9 items in the 2019 but only 2 in the 2009). However, Figure 5 shows that the verbal representation was the most common type in both versions (40 items in the 2009 and 27 items in the 2019). While there was no evidence that the verbal representation item did not assess the inquiry abilities of students, the results indicated that most of the items for verbal representation were memorised recitation-style knowledge questions. For example, Figure 6 presents an example of verbal representation that includes all the necessary information to answer the question from publisher T4. In contrast, if exercise items provide a pictorial representation, such as a table or figure, students may demonstrate their ability to analyse and find the pattern by recognizing the representation, as shown in Figure 1.

The findings also revealed that pictorial representations would also code inquiry-based items, that is, the code of inquiry abilities resulting from a pictorial representation. Thus, the current study provides evidence that pictorial representations can facilitate assessments of students' inquiry abilities by creating more opportunities for them to demonstrate their inquiry abilities.

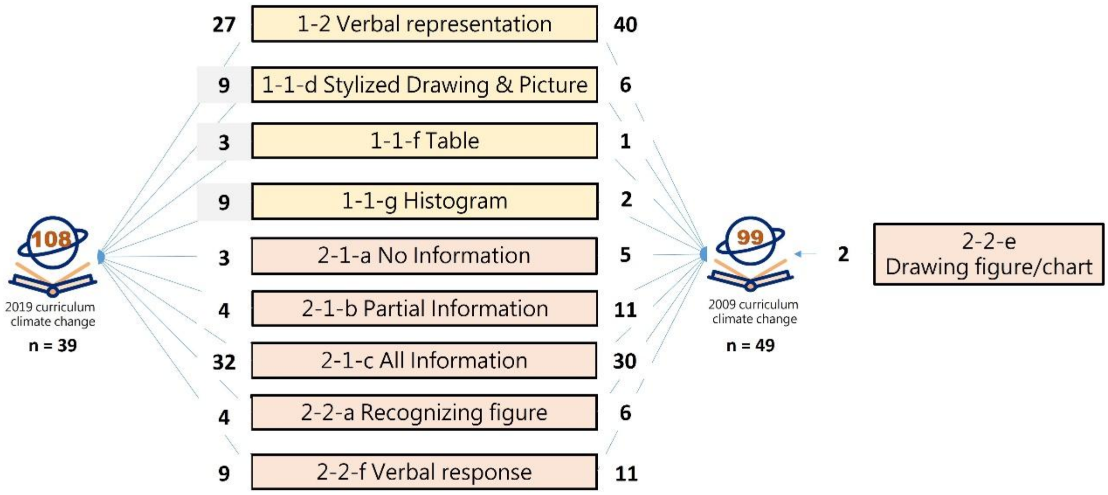

Figure 5: Results for the multiple representations

(Yellow labels represent the codes of the types of representations, and pink labels represent the codes of the functions of representations.)

10 氣候是長時間尺度下，地球系統中能量交換後呈現的現象。討論氣候變遷時的重點即是地球系統能量的收支平衡。下列有關能量平衡的敘述，何者正確？

(A) 冬季時，高緯度溫度較低緯度寒冷，主要是因為距離太陽較遠，單位面積接收到的能量較少

(B) 地球能量主要靠傳導散入外太空

(C) 地表接收到的能量大於放出的能量時會造成平均溫度上升

(D) 溫室氣體主要是透過吸收太陽輻射，而破壞地球能量的收支平衡

(E) 地表吸收太陽光後會反射短波輻射

<translation>

Climate change is a phenomenon that occurs after energy exchange in the Earth's system on a long-term scale. When discussing climate change, the focus is on the Earth system's energy balance. Which of the following statements about energy balance is correct?

(A) In winter, the temperature at high latitudes is colder than that at lower latitudes, mainly because they are farther from the sun and receive less energy per unit area.

(B) Earth's energy is mainly dispersed into outer space through conduction

(C) When the energy received by the earth's surface is greater than the energy released, the average temperature will rise.

(D) Greenhouse gases mainly destroy the earth's energy balance by absorbing solar radiation.

(E) The earth's surface will reflect shortwave radiation after absorbing sunlight.

Figure 6: Example of a verbal representation item from publisher T4

The types of exercise items differ markedly between the curriculum guidelines

As mentioned above, the exercise items differed markedly between the 2009 and 2019 curriculum versions, particularly in terms of inquiry abilities and multiple representations. Figure 7 indicates that the 2019 version contained more inquiry-based items than the 2009 version; for example, the 2019 version included 12 items related to the ability of “reasoning and argumentation,” compared with 6 items in the 2009 version. Figure

7 also shows that attitude-based items were only present in the 2019 version, with three items of interest and one item on the nature of science. These findings indicate that the 2019 version contained more inquiry-based exercise items. The increases in these items may have resulted from the 2019 curriculum guideline emphasising the positive effects of literacy-oriented instruction and culture on students' attitudes toward science.

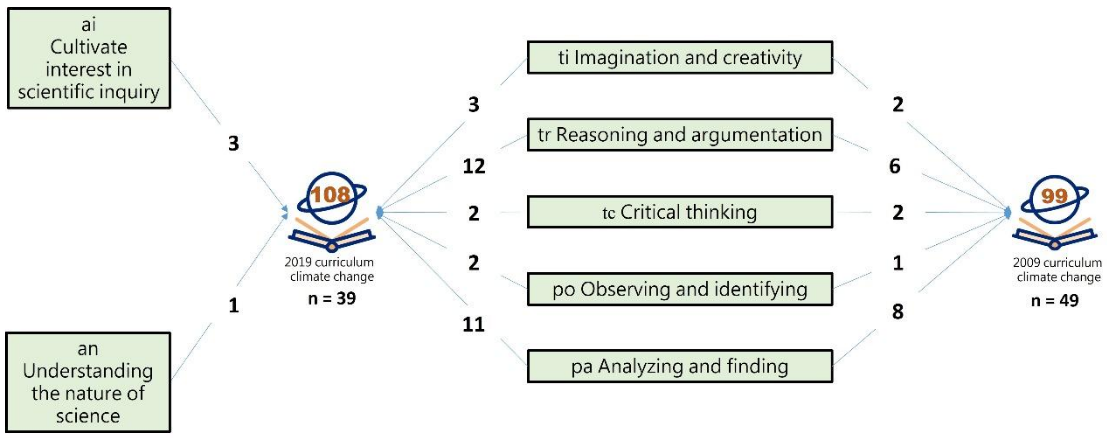

Figure 7: Results for the inquiry abilities

Conclusion and discussion

This study examined the role of exercise items in the climate change chapter of high-school earth science textbooks. Specifically, we examined the interplay between their cross-cutting concepts, inquiry abilities, and multiple representations. Content analysis, utilising valid coding schemes, was employed to discuss the proposed relationships. The results of this study indicate that climate change involves complex systems, so exercise items with pictorial representations may facilitate learning and evaluations of such systems among students.

Relationships between pictorial representations and assessments of inquiry abilities

The results of this study are consistent with Mayer (2014), who asserts that appropriate representational formats (e.g., pictorial representations) enhance students' problem-solving abilities. By providing visual context and supplementary information, these representations enable students to engage in deeper cognitive processes such as analysing data, identifying patterns, and formulating scientific explanations. This is particularly important in inquiry-based learning, where the ability to interpret and manipulate visual data is essential for generating valid scientific evidence. Using pictorial representations in assessment items thus verifies the recall abilities of students and evaluates their higher-order thinking skills and ability to apply knowledge in new and unfamiliar situations.

Furthermore, this study extended the work of Yeh and McTigue (2009) by examining the practicality and effectiveness of using pictorial-based assessment items in a literacy-oriented curriculum. The findings suggest that including pictorial representations in test questions can enhance the consistency of instruction and assessment by ensuring that both focus on fostering scientific literacy rather than mere content knowledge. This has significant implications for the design of science textbooks, which have traditionally relied heavily on text-based explanations. By incorporating more visual representations into educational materials, textbooks can better support the development of inquiry skills in students and enhance their ability to navigate the complexities of scientific problem-solving.

Moreover, the insights from this study into the role of pictorial representations in assessments have broader implications for educational practice. As educators and curriculum developers seek to prepare students for the demands of the 21st century, there is a growing recognition of the need to move beyond traditional forms of assessment that prioritise memorisation. Instead, assessments must be designed to evaluate students' cognitive abilities, including their capacity to think critically, solve complex problems, and apply scientific principles in real-world contexts. Pictorial representations are a valuable tool for facilitating this approach.

Effects of curriculum reforms on the content of science textbooks

The findings of this study highlight the pivotal role that curriculum reforms play in shaping not only the information content of science textbooks but also the nature of the exercise items that they include. Unlike previous studies that have primarily focused on shifts in teaching practices (Gracin & Matić, 2021) or changes in knowledge content (Alpaslan et al., 2015), the present research investigated how the exercise items in science textbooks evolved during curriculum reforms. The results highlight a significant shift toward assessing students' scientific literacy, particularly in terms of the nature of science, which is a crucial component of modern science education.

The increase in exercise items focusing on scientific literacy and higher-order thinking skills marks a departure from the traditional emphasis on knowledge-based and memory-based assessments. This shift indicates a broader educational trend toward fostering critical thinking and inquiry skills, which allow students to navigate and contribute to the rapidly changing world of the 21st century. The inclusion of tasks that require students to engage in scientific reasoning and argumentation further provides them with a deeper understanding of scientific concepts and processes, moving beyond rote memorisation to a more-nuanced and application-oriented approach to learning.

One of the key implications of these findings is the potential for such changes in exercise items to better prepare students for the demands of modern scientific inquiry and participation in society. By emphasising the development of inquiry abilities and critical thinking skills, the reformed curriculum aims to equip students with the tools they need to succeed academically and engage as informed citizens in a scientifically literate society. This is particularly important in an era where understanding scientific concepts is increasingly necessary for addressing global challenges, such as climate change, public health, and technological innovation.

However, it is important to note that while the shift toward literacy-based and inquiry-focused exercise items represents a positive development, the continued dominance of knowledge-based and memory-based items in science textbooks suggests that there is still work to be done. The balance between different types of assessment items needs to be carefully managed to ensure that students are adequately prepared for both the demands of standardised testing and the realities of scientific practice. Therefore, ongoing research and evaluation are necessary to monitor the effectiveness of these changes and ensure that they lead to desired outcomes in terms of student learning and development.

Implications and limitations

Suggestions

Scientific representations in science education have been conceptualised as an integral component of science learning. This study investigated the multiple representations of exercise items in science textbooks and identified the benefits of pictorial representations in literacy-based learning. By focusing on relationships among cross-cutting concepts, inquiry abilities, emotions, and multiple representations in the exercise items on climate change, this study has revealed how current knowledge can be utilised for developing evaluations of the concept of climate change and when designing high-school science textbooks. The study has further suggested the importance of researchers and designers using multiple representations in textbook exercise items to assess student learning and to allow them to self-evaluate. However, there are some important issues that the current study could not address without further empirical evidence.

This study also highlights the need for further research into the broader implications of these changes in exercise items. While this study has provided valuable insights into how textbook content has evolved in response to curriculum reforms, further investigations are needed into how these changes are being implemented in the classroom and their impact on student learning outcomes. Future research should investigate the interplay between textbook contents, teaching practices, and student performance to gain a more comprehensive understanding of the effects of curriculum reforms.

This study has contributed to the growing body of literature on curriculum reforms by performing detailed analyses of how exercise items in science textbooks have changed to support the development of the scientific literacy and inquiry skills of students. While the findings are promising, they also highlight the need for continued research and refinement to ensure that these changes are effectively implemented and lead to meaningful improvements in science education. By aligning textbook contents with the goals of modern science education, curriculum reforms have the potential to transform the educational landscape and better prepare students for the challenges and opportunities of the 21st century.

Limitations

Scientific uncertainty about climate change. This study only investigated the exercise items about climate change in earth-science earth science textbooks. It did not cover debates about the causes of climate change in textual descriptions (e.g., Román & Busch, 2016). However, the results indicate that pictorial representations can support student learning in inquiry and its evaluations. Thus, whether or not a course text addresses this debate, if it is included in the assessment, students can infer the possible causes of climate change from observational data on different timescales. However, this study did not analyse any data related to this assumption, so researchers and educators may wish to conduct follow-up research on this issue in the future.

Scientific representations facilitate the ability of students to solve inquiry-based exercise items. This study explored the multiple representations of exercise items in science textbooks and found that the information on representations may provide opportunities for students to demonstrate their inquiry abilities. Therefore, this study did not provide empirical evidence to demonstrate whether scientific representation helps students to complete assessment tasks or causes them difficulties during problem-solving (Ainsworth, 1999). Researchers and educators could also conduct follow-up research on this issue in the future.

Integrating neuroscience into the study of representations. Neuroscience – particularly the use of eye-tracking technology – has been employed to investigate students' visual-oriented reading behaviors (Behnke, 2023; Wu & Liu, 2024). For instance, Behnke (2023), in a study requiring students to complete textbook-based learning tasks, found that representations can help students form connections between pictorials and instructional tasks. However, this study primarily focused on the relationship between pictorial representations in textbook exercises and curriculum reform. The analysis was limited to exploring the functions and roles of these representations within the textbook, rather than examining how students actually interpret or interact with them. Therefore, future research should aim to reveal students' problem-solving processes through a representation-focused approach. Moreover, confirming the findings of the current study, researchers can investigate the empirical data on students' utilisation.

Biographical notes

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Acknowledgements

This study was based upon work supported by the National Science Council of Taiwan under NSTC 112-2410-H-656-011-MY2, NSTC 114-2410-H-656-012, and NAER-2025-012-C-2-1-E5-01.

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