education sciences

MDPI

Article

An Analysis of the Visual Representation of Redox Reactions in Secondary Chemistry Textbooks from Different Chinese Communities

Xiaoge Chen [1,*], Luciane F. de Goes [2], David F. Treagust [3] and Ingo Eilks [1]

1 Department of Biology and Chemistry, Institute for Science Education, University of Bremen, Leobener Str. NW2, 28359 Bremen, Germany; ingo.eilks@uni-bremen.de
2 Institute of Chemistry, University of São Paulo, Av. Prof. Lineu Prestes, 748, Butantã, São Paulo, SP 05508-000, Brazil; luciane.goes@usp.br
3 STEM Education Research Group, Curtin University, Perth WA 6845, Australia; D.Treagust@curtin.edu.au
* Correspondence: chen@uni-bremen.de; Tel.: +49-421-218-63276

Received: 4 December 2018; Accepted: 11 February 2019; Published: 19 February 2019

Abstract: This study provides an analysis of selected aspects of the intended curriculum related to redox reactions as represented in secondary chemistry textbooks from the People's Republic of China, with a special view also on Hong Kong, Shanghai, Taiwan, and the Chinese minority in Malaysia. This study reveals how chemistry textbooks deal with visual representations related to redox reactions and whether or not the visualizations provide any indication for the orientation of the intended curriculum, characterized by contexts suggested for chemistry learning. Specific criteria were derived from a literature review of the discussion on different levels of chemical representations and from a total of 346 visual representations related to redox reactions identified and analyzed from the textbooks. Based on the frequencies and levels of visual representations in the textbooks, this study showed that representations in textbooks from the People's Republic of China mostly focus on the macro and macro-symbolic levels and indicate some aspects of everyday life as well as orientations towards industry and technology. The findings show that the textbook from Taiwan uses multiple macroscopic, submicroscopic, and symbolic representations to illustrate the redox reactions. The textbook from Hong Kong has a strong orientation along the content structure of chemistry, with mostly macro level representations. The textbook from the Chinese minority in Malaysia follows a strong structure-of-discipline orientation with limited visual support.

Keywords: chemistry education; redox reactions; textbooks; visual representations

1. Introduction

A central concept of understanding common difficulties in teaching and learning chemistry suggested in 1991 by Johnstone [1] concerns the chemical thinking needed between three representational levels, namely, the macroscopic, submicroscopic, and symbolic levels. This central concept has been used for analysis of chemistry textbooks [2]. Macroscopically, students are required to observe, for example, combustion. In parallel, they are expected to imagine electron movements to provide an explanation at the particulate submicroscopic level. At the symbolic level, students are asked to represent the reaction by writing an equation of the chemical reaction by interrelating the symbolic level with both the macroscopic substances and submicroscopic chemical entities. Indeed, this is not an easy task and many students tend to most frequently focus their thinking at the macroscopic level because they live in a macroscopic world and can make experiences and observations at this level [3]. The concept of Johnstone's triangle of representational levels is not without critics and does need careful reflection, especially when planning assessment decisions on the use of the different representational levels [4] or how it is used by teachers [5]. Nevertheless, the triangle has become a standard in chemistry education because it sheds light on chemical thinking and learning by attending to the three different levels. The triangle has also been further discussed and enriched, e.g., by Sjöström and Talanquer [6], based on Mahaffy's work [7], to form a tetrahedron which has an apex representing the human or contextual element of chemistry.

Österlund, Berg and Ekborg [8] argue that chemical reactions can explain a large degree of the world we live in and redox reactions provide a wide range of daily applications of the corresponding content being studied. Redox reactions such as combustion belong to the central concepts taught in almost every secondary school chemistry curriculum [9] and this is the case for chemistry education in the People's Republic of China, with a special view also on Hong Kong, Shanghai, Taiwan and Malaysia. Redox reactions are related to, and important for, understanding everyday issues such as corrosion, the functioning of a battery, and electroplating [10]. Redox reactions provide fundamental knowledge for later learning in chemistry, for example, advanced electrochemistry or organic chemistry, and other subjects such as biology [8]. Redox reactions are, however, widely perceived as being difficult to comprehend both for secondary school pupils and university students [11–14] as well as being difficult to teach [15].

Redox reactions cannot be fully understood without integrating macroscopic and submicroscopic perspectives. They represent one type of chemical reaction that is based on the gain or loss of electrons. Redox reactions occur by electron transfer between different chemical species, namely, atoms, molecules or lattice structures. Shibley Jr. et al. [16] summarized different approaches of teaching redox reactions and suggested more straightforward ways to help students' learning chemistry based on understanding instead of rote memorization.

Problems in understanding redox reactions among students are often situated at the different representational levels of chemistry and their inter-relations, e.g., macroscopic (the identification of the reacting compounds, e.g., if gases are employed), submicroscopic and symbolic (redox process and reaction equations), or all three levels (reaction processes represented by compounds, particles, and formulae) [17]. Particularly when it comes to connecting the macroscopic and contextual levels with the submicroscopic and symbolic levels, a careful selection of models and related visual representations becomes important to avoid further misunderstanding [18]. A great deal of effort has been made in the past to analyze the application of different models of redox reactions, different teaching and learning difficulties and various teaching strategies [15]. There has been less discussion on the analysis of visual representations of redox reactions and their connection to the contextual domain shown in textbooks.

As already noted, research indicates that students often have difficulties in correctly relating the different levels of representations to one another [19] even when visual representations should help students make the right connections. Therefore, it is recommended to thoroughly use visual representations of the different representational levels of chemistry in chemistry teaching and learning [2]. To meet this recommendation, it is important for teachers to know how to deal with and how to connect the different representational levels in chemistry, and how to use different representations of redox reactions content [20]. However, studies have revealed that teachers can also have difficulties in dealing with the different representational levels by either moving between the levels in a non-reflective way or, as their students do, by prioritizing the macroscopic level [3]. Visualization can offer help in better dealing with the different representational levels [21], but this is only the case if students are guided on how to interpret the three levels [22]. Visual representations also have the potential to contribute to a better comprehension of the textbooks [23].

Pintó and Ametller [22] claim that an image goes beyond a thousand words, but this adage only applies when the viewer knows how to recode and interpret the image. One example where the image does not always help learning is when students are exposed to different historical representations of the models of the atom without clearly understanding the reason why they are being exposed to so many different models [24]. Recent research shows that one reason for the lack of understanding is that students often have difficulties in recoding and translating representations [25] and that more consideration should be given to aiding students' interpretation of images [26]. In this respect, unfortunately, sometimes teachers confuse the different models in their instruction [27].

Modern chemistry education should embed the learning of abstract content into meaningful and relevant contexts [28–30]. In doing so, chemistry education should combine learning about submicroscopic entities and processes with the relevant macroscopic phenomena [1]. Both representational levels can benefit from visual support because a lot of the concepts in science, technology, engineering and mathematics (STEM) are visual–spatial in nature [31]. Visual representation can significantly improve learning when learners interact with the representation appropriately [32]. Many students, however, also have difficulties in understanding and making sense of certain visual representations especially when there is more than one representation [33].

Different curriculum structures and orientations [34] enable different views on the relevance of science education [28] to be transferred to chemistry textbooks. Textbooks are influenced by the authors' writing and explanation styles and transmit the authors' interpretation of the national curriculum. However, if textbooks are approved officially by educational authorities, such as the given ministries of education, they then represent an intended official curriculum [35]. Textbooks, however, are also influenced by commonly used practices when written by experienced teachers. In this way, Devetak and Vogrinc [36] suggest that textbooks also provide indicators of common classroom practices.

Textbooks have an important place in education; they provide a particular resource for teachers and students. Textbooks define a subject to the students and help to represent a school subject as students experience it [36]. Textbooks present both the content and the orientation of the curriculum [37] by forming a bridge for the translation of the official standards or syllabi into the implemented chemistry curriculum [38]. Textbooks offer both text content and visual representation to students. It is hard to say how the individual teacher will use a certain textbook but the teachers´ usage of chemistry textbooks in many countries, e.g., in the People's Republic of China, is generally quite high [39]. Nothing, however, guarantees that teachers will follow the suggested path and activities [40]. Nevertheless, the textbook represents a kind of ideal and formal curriculum [41] that the teachers are expected to implement.

Since chemistry textbooks are the medium between chemistry and the learner [42], textbook analysis is gaining increasing interest in chemistry education in general (e.g., [2,25,43]), and in this journal in particular (e.g., [44,45]). Textbook analysis of visual representations can help to ensure that they are better used in future textbooks. The purpose of the current study is to analyze how grade 10 chemistry textbooks from different Chinese communities represent content related to redox reactions. The focus of this study is not to indicate conceptual errors but rather to characterize how the textbooks adapt visual representations related to redox reactions. This paper explores the visual representations of redox reactions and related content at the macroscopic, microscopic and symbolic levels as provided in grade 10 Chinese textbooks from the People's Republic of China, with a special view on Hong Kong, Shanghai, Taiwan and the Chinese minority in Malaysia to inform editors, authors or evaluators of chemistry textbooks about differences among the textbooks from this sample in order to identify areas for improvement. Analysis also focusses on whether the visual representations provide indications of the intended curriculum orientation [43]. Consequently, we investigated the following research questions:

1. Concerning visual representations (macroscopic, microscopic and symbolic)
    a. Are these present in Chinese chemistry textbooks related to redox reactions?
    b. How are they used?
    c. How are the different representational levels represented and related to one another?
2. Are there any indicators in the visual representations in the textbooks of a modern chemistry curriculum that use everyday life and societal illustrations to contextualize chemistry learning?

2. Materials and Methods

Chinese people account for one of the largest ethnic groups in the world. Aside from the People's Republic of China with about 1.4 billion citizens, there are Chinese communities in many countries or regions. In some environments, Chinese people form the majority, such as in Taiwan or Hong Kong. There are also many minorities of Chinese people in different countries of the world. In most countries, the Chinese minorities are integrated into the national educational systems. This is not the case for Malaysia, where the Chinese community forms 23.2% out of 32.0 million Malaysian citizens [46]. Independent Chinese Secondary Schools (ICSSs) use the Chinese language as the main medium of instruction in Malaysia and operate a self-standing school system to provide mother-tongue education with the intention to preserve cultural identity. The educational systems in the People's Republic of China, Hong Kong, Taiwan and the Chinese minority in Malaysia do have some commonalities in their structures in that grade 10 forms the first year of upper secondary education. Chemistry is a compulsory subject and redox reactions are a common topic, mainly starting in grade 10.

In the People's Republic of China, different textbook series are launched in the market. The books are approved by the national school textbook authorized committee's review. Currently, three versions of chemistry textbooks for upper secondary school have passed the review. They are compiled by the People's Education Press, Shangdong Science and Technology Press, and Jiangsu Education Press (see Table 1; CN1-CN3). Fundamental redox reactions knowledge is explained in all these editions in the grade 10 textbooks. These three sets of textbooks form the first sub-sample in this study. In 1985, Shanghai was allowed to abstain from the Chinese National College Entrance Examination (NCEE) and apply an independent proposition [47]. The textbooks analyzed in the present study are edited and reviewed by the Shanghai Primary and Secondary School Curriculum Reform Committee and Shanghai Primary and Secondary School Textbook Review Committee. One corresponding textbook is the Shanghai Edition (CN4).

Hong Kong, as a special administrative region of the People's Republic of China, has been deeply influenced by western countries, mainly during the colonial time under the United Kingdom. The Hong Kong Education Bureau recommends textbooks for senior secondary school students [48]. We chose the textbook from Jing Kung Educational Press, that is one of the popular textbook publishers in Hong Kong (HK).

Nine years of compulsory education were implemented in Taiwan in 1968. In 2014, a new policy of 12 years Basic Education Curricula was introduced and is intended to be fully implemented in the 2019 academic year [49]. We chose the textbook from LungTeng Cultural (later called TW1), which is one of the textbooks that passed the official review by the National Academy for Educational Research (NAER). Basic Chemistry 1, Basic Chemistry 2 and Selective Chemistry 1 (see Table 1) were chosen as they contain redox reactions content. Table 1 references the textbooks where most of the redox reactions content is covered in the textbooks from the four different Chinese communities.

In the context of Malaysia, Dong Jiao Zong is an allied organization of the United Chinese School Committees' Association of Malaysia, named as UCSCA or Dong Zong, and the United Chinese School Teachers' Association of Malaysia, named as UCSTA or Jiao Zong, which is responsible for the Chinese-community-run education that organizes Chinese Education in Malaysia and provides an unified curriculum and examination to ICSSs [50]. In our study, as our sample (MY), we chose the Chinese chemistry textbook used among ICSS students published by the United Chinese School Committees' Association of Malaysia (see Table 1), the Upper Secondary School Chemistry (volume 1) and Upper Secondary School Chemistry (volume 2), that contain the main redox reactions section.

Table 1. Information of the textbooks which include redox reactions content.

Textbook	Reference
CN1	Song, X. Q. (Ed.). (2007). Chemistry 1 (3rd ed.). Beijing: People Education Press.
	Song, X. Q. (Ed.). (2007). Chemical reaction mechanism (3rd ed.). Beijing: People Education Press.
CN2	Wang, L. (Ed.). (2007a). Chemistry 1 (3rd ed.). Shandong: Shandong Science and Technology Press.
	Wang, L. (Ed.). (2011). Chemical reaction mechanisms (4th ed.). Shandong: Shandong Science and Technology Press.
CN3	Wang, Z. H. (2014). Chemistry 1 (6th ed.). Nanjing: Jiangsu Education Press.
	Wang, Z. H. (2014). Chemical reaction mechanisms (5th ed.). Nanjing: Jiangsu Education Press.
CN4	Yao, Z. P. (Ed.). (2007). Chemistry (Volume 1) (1st ed.). Shanghai: Shanghai Scientific and Technical Publishers.
	Yao, Z. P. (Ed.). (2008). Chemistry (Volume 3) (1st ed.). Shanghai: Shanghai Scientific and Technical Publishers.
HK	Zhong, H. M. (2009). New 21st Century Chemistry 2B (1st ed.). Hong Kong: Jing Kung Educational Press.
TW	Huang, D. S. (Ed.). (2010). Basic Chemistry 1 (1st ed.). Taiwan: LungTeng Culture Lungteng Cultural.
	Huang, D. S. (Ed.). (2011). Basic Chemistry 2 (1st ed.). Taiwan: LungTeng Culture Lungteng Cultural.
	Huang, D. S. (Ed.). (2012). Selective Chemistry 1 (1st ed.). Taiwan: LungTeng Culture Lungteng Cultural.
MY	MICSS (1996). Upper secondary school chemistry (volume 1) (1st ed.). Malaysia: United Chinese School Committees' Association of Malaysia.
	MICSS (1997). Upper secondary school chemistry (volume 2) (1st ed.). Malaysia: United Chinese School Committees' Association of Malaysia.

This study focuses on visual representations related to redox reactions in Chinese textbooks which may be considered as a model of analysis from the chemistry curriculum. A glimpse at other topics from the chemistry curriculum did not provide any indications that other content is visually represented in different ways.

Basic tenets of qualitative content analysis were employed to analyze visual representations from the textbooks. In order to develop criteria for the analysis of the representational levels of the redox reactions, we adopted a scheme using criteria developed by Gkitzia et al. [25]. The criteria were employed to our three level representational framework and revised accordingly after several readings of the textbooks. The criteria looked at all levels of visual representations including figures, photos, and diagrams. Tables and straightforward chemical equations were not considered as being visual representations. Chemical reaction equations only became part of the analysis as part of figures, not when they were used as part of the text. In an iterative process, the criteria were applied to the sample in each round to a sub-sample of illustrations by three raters (first, second and forth author) until a fit of the coding scheme (Table 2) was achieved. The reliability of the data analysis was checked by independent rating (first and fourth author), and in the case of disagreement, re-rating was performed. The agreement rates were generally high in all three rounds from the beginning (above 90%) and rose to 97% due to joint re-rating of disagreed interpretations of the visual representations shown in Table 2.

Table 2. Criteria for evaluation on visual representation characteristics (adapted from Gkitzia et al. [25]).

Category	Subcategory	Description
Levels of representation	Macro	Presents only observable and realistic aspects (M)
	Submicro	Illustrates unobservable entities and abstract aspects (S)
	Symbolic	Uses symbols and codes of chemistry (S)
	Macro and submicro	Represents two levels: macro and submicro (M+S)
	Macro and symbolic	Represents two levels: macro and symbolic (M+S)
	Submicro and symbolic	Represents two levels: submicro and symbolic (S+S)
	Macro, submicro and symbolic	Represents the three levels: macro, submicro and symbolic (M+S+S)
Degree of correlation between representations comprising multiple ones	Sufficiently linked	Equivalence of the surface features of the components is clearly indicated
	Insufficiently linked	Equivalence of only some surface features is indicated clearly
	Unlinked	Includes subordinate representations that are placed next to one another and there is no indication of the equivalence of their surface features
Relation to text	Completely related	Representation depicts the exact text content
	Partially related	Representation depicts the subject or a familiar subject to the text, text does not direct the reader to the relationship between text and representation
	Unrelated	Representation is irrelevant to the text content. The text describes the content without mentioning the correspondence with the representation

In the first round, we mainly focused on three different categories (see Table 2). First, levels of representation according to the Johnstone [1] triangle, i.e., macroscopic, submicroscopic, symbolic, and multilevel representations were selected as the initial data. The textbooks were coded and analyzed using the criteria described in Table 2. Second, we examined the degree of the multiple correlations between representations to see if the multiple levels were sufficiently linked, insufficiently linked, or unlinked. Third, the relation between visual representations to the main text was also evaluated.

A second round of the analysis focused on the function of images in relation to the text related to redox reactions. We evaluated how much of the visual representation is connected to the text for providing support to better understand the content, aside from just having a decorative function. Subsequently, we categorized the evaluation of image representation into decorative, organizational, or interpretational (see Table 3), which is an adaptation from Carney and Levin [51], and this was also interpreted by Nyachwaya et al. [52].

Table 3. Criteria for the evaluation of the function of the images (adapted from Carney and Levin [51]).

Category	Subcategory	Description
Function of images	Decorative	Not relevant to the text—illustrations only help the reader enjoy the textbook by making it more attractive
	Organizational	Illustrations help the reader organize information into a coherent structure and encourage more detailed processing of text; captions name the fact but do not provide extra information to the text
	Interpretational	Strong relationship to the content—illustrations explain and help the reader understand concepts and ideas in the text; captions name the fact and add extra information about the fact

It is widely known that textbooks provide orientations of the curriculum and mirror the emphases behind them [53]. The third step of the analysis focused on the curriculum orientation transmitted by visualizations which were related to redox reactions obtained from the different textbooks. The scheme to analyze the curriculum orientations was adapted from the six categories related to curriculum orientation explicated by Eilks et al. [34] in the interpretation of Khaddoor, Al-Amoush and Eilks [43] (see Table 4). We analyzed the visual representation to see if the images represented the structure of the discipline orientation, history of science orientation, everyday life orientation, environmental orientation, or industry and technology orientation. The issue of socio-scientific orientation was also checked in relation to the text.

Table 4. Criteria for the evaluation of curriculum orientation (adapted from Eilks et al. [34]).

Category	Subcategory	Description
Curriculum orientation	Structure of the discipline orientation	Illustrations represent scientific theories and facts and their relation to one another
	History of science orientation	Illustrations represent scientific content as it emerged in the past or its historical development
	Everyday life orientation	Illustrations represent entities from everyday life
	Environmental orientation	Illustrations represent scientific content behind questions of environmental protection
	Industry and technology orientation	Illustrations represent chemical technology and its application in industry
	Socio-scientific issues orientation	Illustrations provoke the learning allowing the students to develop general educational skills to prepare them to become responsible citizens in future

3. Results

A total of 346 visual representations related to redox reactions were identified in the textbooks from Mainland China, Hong Kong, Taiwan, and Malaysia. In terms of the general content organization and structure, the differences in the textbooks between different Chinese communities are larger than the differences within the communities. From Figure 1, we can see that representations of the macroscopic (maximum 68%), symbolic (maximum 45%), and macro-symbolic (maximum 50%) levels are more prominent than other levels of representation.

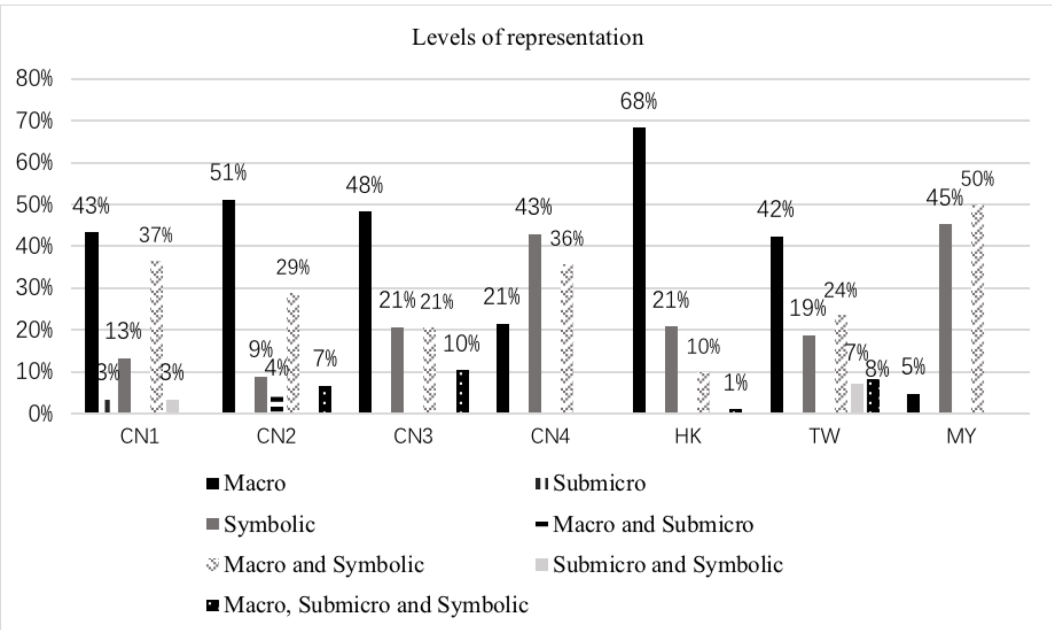


Figure 1. Distribution of different levels of visual representations in the textbooks. (Note: due to the numerical value limit, the sum value of CN1 is 99%).

Among the mentioned textbooks, the Taiwanese textbook and two of the textbooks from the PR of China (CN1 and CN2) cover a broader variety of representational levels than the textbooks from Hong Kong, Malaysia and two of the Chinese textbooks (CN3 and CN4).

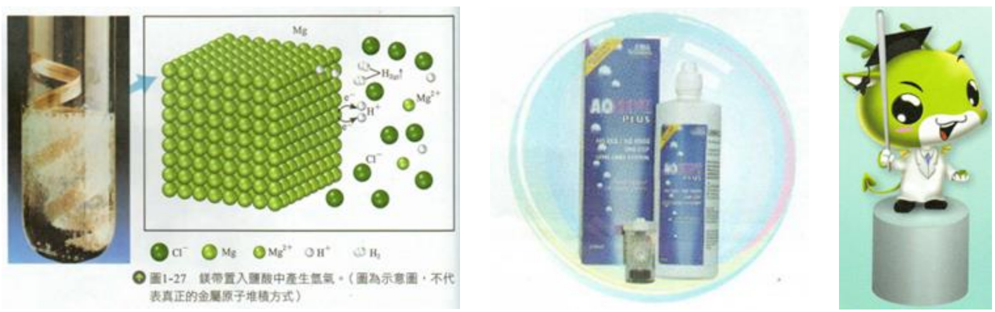
Initially, we considered the first research question: What visual representations (macroscopic, microscopic and symbolic) are present in Chinese chemistry textbooks related to redox reactions, how are they used, and how are the different representational levels represented and related to one another? The data show that the way the textbooks illustrate redox reactions are different.

3.1. Levels of Representation

The analysis indicates that all textbooks show a high use of macro representations, except the Shanghai and Malaysian textbooks (Figure 1). The Shanghai and Malaysian textbooks use more symbolic and macro-symbolic level representations than the other Chinese textbooks. The Taiwanese textbook and one of the books from the PR of China (CN3) show a higher degree of multiple visual representations with the combination of the macro, submicro, and symbolic levels compared to the rest of the textbooks. The Hong Kong textbook tends to employ mainly macro and symbolic representations to explain fundamental chemistry knowledge related to redox reactions and visual representations in the Hong Kong textbook, in terms of the macro level, mostly refer to experiments. The Malaysian textbook uses visual representations at the symbolic level to explain the oxidation/reduction number, gain/loss of electrons, higher/lower valence, and oxidation/reduction. In terms of electrochemistry, the Malaysian textbook uses many macro-symbolic visual representations to illustrate advanced knowledge related to redox reactions of different electrochemical cells.

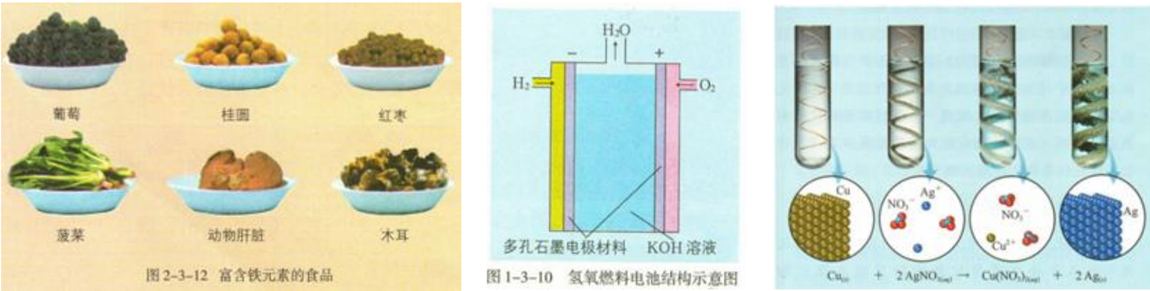
3.2. Multiple Visual Representations and Degree of Correlation between Representations

In terms of multiple representations, the Taiwanese textbook contains more multiple visual representation levels than the other books (Figure 1). A combination of macro-symbolic representations is notable in most of the mentioned textbooks, followed by macro–submicro–symbolic combinations. Most of the textbooks use arrows and lines to connect different representational levels when they contain more than one representation (e.g., Figures 2a and 3b). The correlation between the different levels is generally sufficiently linked (Figure 4), for example, Figure 2a is an image with multiple representations including the macro, submicro and symbolic levels (the reaction of hydrochloric acid and magnesium). The reaction at the macro level, which happens inside the test-tube, is connected to digital simulated atoms and ions by an arrow, and atoms and ions are connected to correspond to chemical symbolic representations by more arrows. Textbooks from Hong Kong, Taiwan and one from the PR of China have visual representations that are insufficiently linked, but these numbers are small (average 10%).



(a) (b) (c)

Figure 2. Example of a completely related (**a**), a partially related (**b**), and an unrelated (**c**) representation (reproduced with permission by Lungteng Cultural Company [Taiwan]).



(a) **(b)** **(c)**

Figure 3. Example of a decorative (**a**), organizational (**b**), and interpretational (**c**) image (reproduced with permission by [Lungteng Cultural Company (Taiwan)] and [Shandong Science and Technology Press (PRC)]).

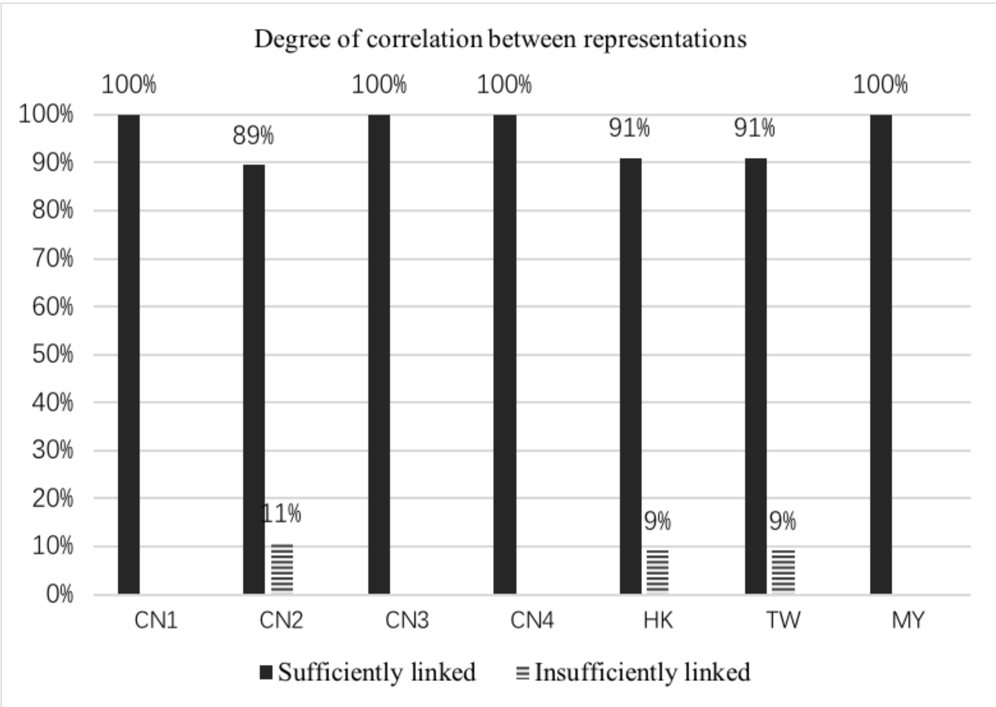


Figure 4. Degree of correlation between multiple representations in the textbooks.

3.3. Relation to Text

In terms of the relationship between pictures and text, most of the textbooks show a high relation to the text (Figure 5), with concrete references in the text and captions connecting the pictures with the text. Only the Taiwanese textbooks and one from the PR of China (CN1) contain a few pictures that are unrelated to the text. For example, Figure 2c is an unrelated representation in the Taiwanese textbook; the main text is about oxidation numbers but the picture is decorative, only providing visual enjoyment. It does not provide further help for deeper understanding. Figure 2a is an example of a visual representation that is completely related to the text and aids learners' understanding of redox reactions; the text is about the electron transfer of a reaction between magnesium and hydrochloric acid. The picture provides a comprehensive model that combines the macro, submicro, and symbolic levels. Figure 2b is an example of a visual representation that is partially related to the text. The text mentions that oxidizing agents can be used for sterilization and the picture illustrates this with a bottle of contact lens care solution. The caption of the picture refers to the main constituent (hydrogen peroxide).

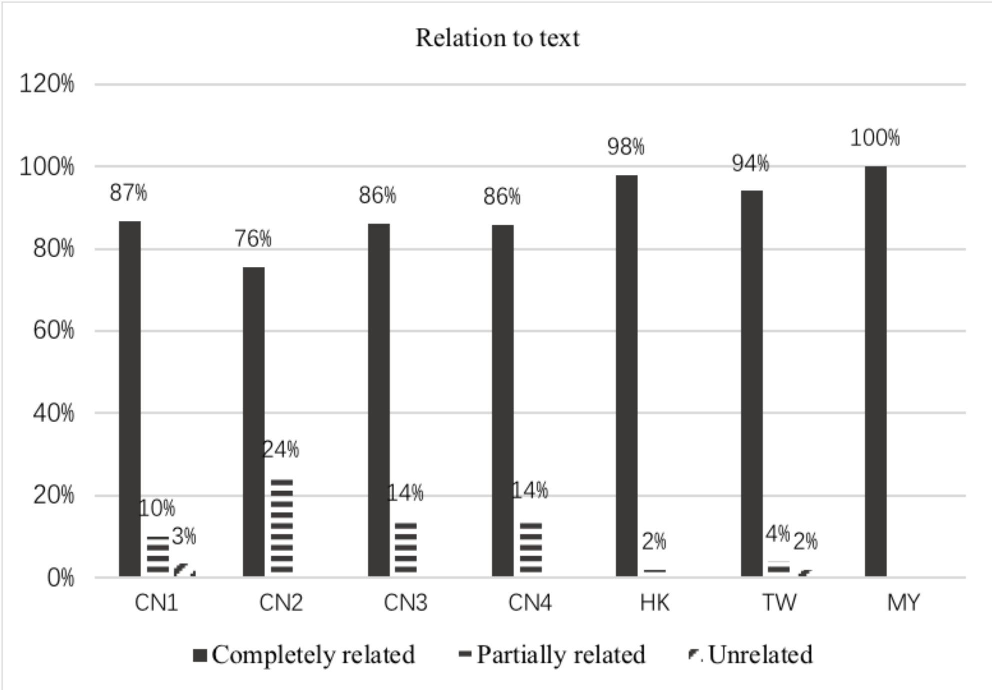


Figure 5. Degree of relation to text in the textbooks.

3.4. Function of Images

In terms of the function of images, decorative, organizational, and interpretational images appear in all the textbooks (Figure 6). The Shanghai textbook (CN4) has the highest use of images that focus on help for the learners to understand the text that are organizational. The Malaysian textbook has the highest rate of interpretational figures and the textbook from Hong Kong as well as one of the textbooks from the PR of China (CN2) have the highest degree of decorative pictures. Figure 3 shows examples of decorative, organizational, and interpretational representations from the different textbooks. Figure 3a shows an image of different iron-rich foods that plays a decorative role in enhancing the readers' imagination. Figure 3b aids the understanding of a hydrogen–oxygen fuel cell by showing the cell structure that reflects a redox reaction. Figure 3c is an example of an interpretational image that illustrates the reactions of copper wire and silver nitrate solution at the macroscopic, submicroscopic and symbolic levels, which aids in deeper comprehension for students.

3.5. Curriculum Orientation

Concerning the second research question, looked at as a whole, the results indicate that all the textbooks basically follow a structure of the discipline orientation (Figure 7), especially the textbooks from Shanghai and Malaysia. Everyday life orientation is covered by images in all textbooks to a certain extent, except in the Shanghai textbook. Industry and technology illustrations can be found in all textbooks. Environmental issues are addressed in the Hong Kong textbook and one of the textbooks from the PR of China (CN1) by pictures. History of science is represented only by visual representations in the Taiwanese textbook.

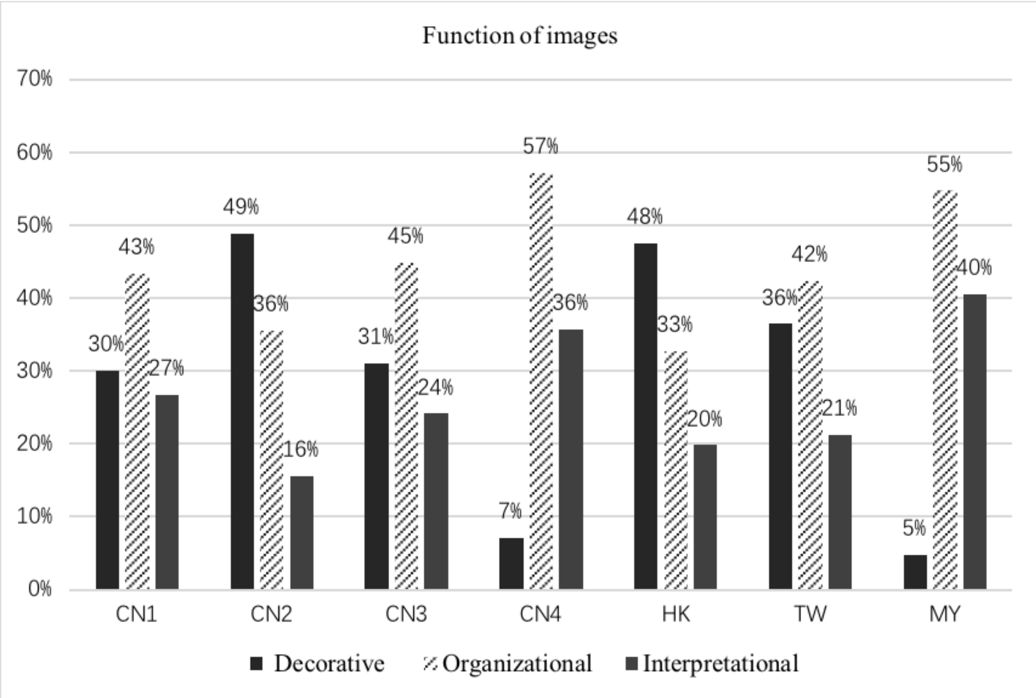


Figure 6. Degree of the function of images in the textbooks. (Note: due to the numerical value limit, the sum value of HK and CN2 are both 101% and the sum value of TW is 99%).

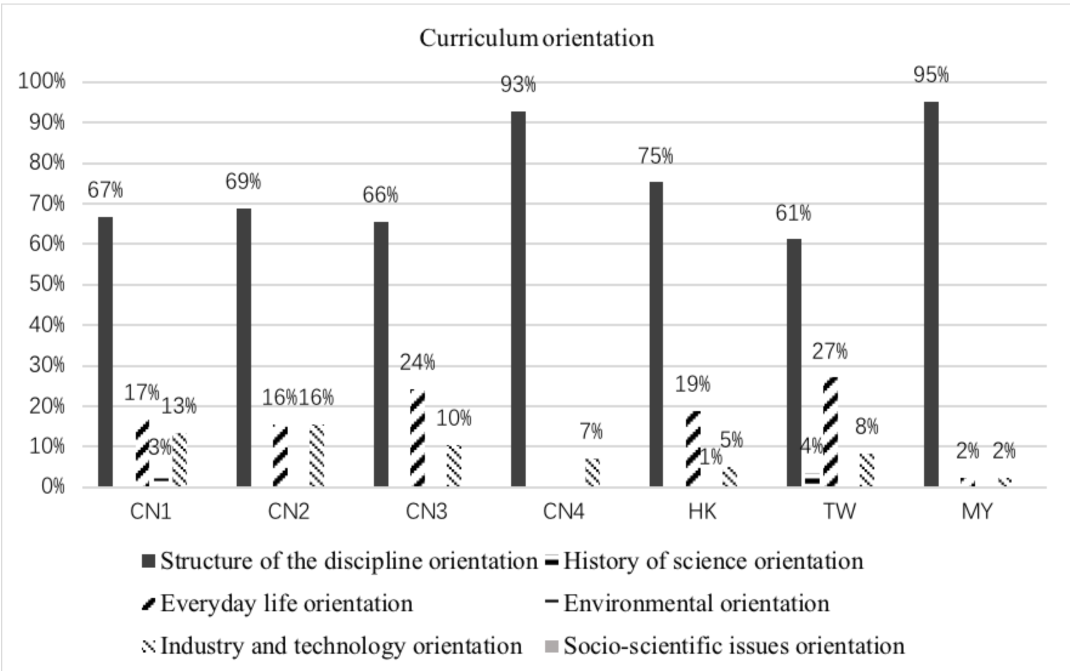


Figure 7. Degree of curriculum orientation in the textbooks. (Note: due to the numerical value limit, the sum value of CN2 is 101% and the sum value of MY is 99%).

4. Discussion

The abstract nature of modern chemistry expects that learners' understanding of macroscopic phenomena be enhanced by submicroscopic and symbolic explanations [54]. Johnstone's triangle [1] approaches teaching and learning with a thorough combination of these three representational levels.

Although chemistry experts, persons with fluent and flexible performance [55], can easily switch between the different representational levels, studies on students show that learners regularly have difficulties in correctly relating representations from the different representational levels [56], because students generally have conceptual difficulties when dealing with visual representations [33].

As stated by Mahaffy [57], chemistry education differs from country to country, school to school, and culture to culture; there are no universal solutions when the level of the learner, the learning objective, and the teaching style are not in the same context. Inevitably, the intended, implemented and attained curricula have a mismatch between each other [58]. However, the data in this study provide some ideas about the ways in which different Chinese textbooks address representations of redox reactions. The representations might potentially be useful to teachers.

In terms of the distribution of the different levels of representation from this sample, macroscopic representation is dominant among other visual representations. This finding is very different from recently reported findings on chemistry textbooks from Africa, for example, Upahi and Ramnarain [2] reported a dominance of symbolic representations for the textbooks in Nigeria. To suggest reasons for this difference, however, would be highly speculative, but the reasons may lie in different curriculum traditions and lack of practical work, more than in the aspects of culture or socio-economic development [43]. However, the curriculum orientation [34] and the function of visual representations [51] concerned with redox reactions were not defined [2]. Treagust et al. [54] suggest that macroscopic representations are the basis of chemistry learning, but macroscopic understanding relies on an explanation at the submicroscopic level. Combined representations could be helpful. Combined visual representations are, however, limited in the sample of textbooks in this study. But the degree of correlation between the representational levels is high (above 89%). The high correlation between multiple representations might be helpful. Russell et al. [59] suggest that the simultaneous use of macroscopic, submicroscopic and symbolic representations can help to reduce students' alternative conceptions in learning chemistry.

The curriculum orientation in the different textbooks shows that the structure of discipline orientation is dominant in the textbooks from this sample. Decontextualized chemistry representations are still prominent in many countries around the world [6]. As Eilks and Hofstein [60] state, "science learning should start from contexts that are connected to the life of the students, their prior experiences, their interests [. . .] everyday lives of students and the society which they live in have the potential to offer meaningful contexts to the students" (p. 17). This claim is in line with the works of Holman [29], Stuckey et al. [28], and Sjöström et al. [6]. Our findings indicate that everyday life application and industry and technology orientation are already observable in the textbooks from this sample. It seems, however, that more everyday and societal life orientation is needed in the visual stimuli in the textbooks because the proportion is small (no more than 27%). Socio-scientific issues and environmental orientation remain scarce. Visual support for these perspectives might also be strengthened in the future to better support a broader contextualization of learning with textbooks in Chinese chemistry education.

Even though all the textbooks placed more emphasis on the structure of the discipline, in terms of the way that science knowledge is represented, the textbook from Taiwan and one textbook from China (CN3) use a more comprehensive way to illustrate the abstract concept of redox reactions via multiple macro–submicro–symbolic representations. The Malaysian and Shanghai textbooks tend to focus on pure science by visual representations. The other textbooks from the PR of China (CN1-3), Hong Kong and Malaysia embed everyday life issues, but mainly with a focus on pure science learning. The Hong Kong textbook provides a pleasurable visual experience with colorful macro pictures but still mostly focuses on fundamental knowledge learning.

This study has attempted to identify the use of visual representation in chemistry textbooks produced for and used in grade 10 classes from different Chinese communities. There are several limitations. It was not possible to analyze all textbooks available and changes in textbooks occur over time. Currently, new textbooks have been announced for chemistry education in Taiwan and

Malaysia and further analysis might show whether or not they will be different from the current ones analyzed in this study. Another limitation is that the focus of this study was only on one topic in chemistry education, namely, redox reactions. This study also focused on selected aspects and cannot state anything about how and with what intensity the textbooks are used by the teachers, as well as to what extent teachers use other resources in chemistry classes.

5. Conclusions

To date, little is known about secondary chemistry textbooks from different Chinese communities. The present study shows the variety of chemistry textbooks from the selected regions although there is basically the same culture and language behind the four Chinese communities. The purpose of this study was not to evaluate whether the visual representations related to redox reactions and given in the textbooks are right or wrong, and was not intended to recommend one "best" textbook. The aim was to show how visual representations related to redox reactions are used and how textbooks might be improved by comparing them systematically to each other.

In this article, we examined visual representations related to redox reactions in secondary chemistry textbooks from different Chinese communities. This study has attempted to contribute to an understanding of the intended curriculum of secondary chemistry education in different Chinese communities based on the assumption that textbooks are important resources for teaching and learning [8,61].

Most Asian countries are making substantial efforts to improve the quality of science education and invest in corresponding research [62]. Specifically, since the late 1980s, Taiwan science education has developed substantially because of its economic boom. Since that time, Taiwan has built an active chain of researchers within East Asia [63] and western countries [64] for the development of science education. This might be a reason why the Taiwanese textbooks provide the richest representation content because it is based on research findings. These rich representations can provide ideas and directions for textbooks published in other Chinese communities. Specifically, one recommendation is to present rich illustrations of the redox content using visualizations that show a good balance between the relationships of the three representational levels of chemistry. Much research has shown that learners benefit when the relations of the different levels are clear and explicit, well connected to the text, and are related to meaningful contexts for the students. In most Asian countries, however, central examinations are still considered as the main component in educational assessment and promotion [65]. These central examinations mostly focus on the science content, with an emphasis on students being able to know information rather than understanding the relationships between concepts, and rarely refer to contexts and socio-scientific implications. Consequently, this might be the reason why most textbooks still tend to follow a structure of discipline approach. Perhaps there should be reflection on the central examinations to promote further development of the textbooks.

Author Contributions: Conceptualization, X.G.C. and L.F.G.; methodology, X.G.C., L.F.G. and I.E.; validation, X.G.C., L.F.G., D.F.T. and I.E.; formal analysis, X.G.C. and I.E.; writing original draft, X.G.C.; writing—review and editing, X.G.C., L.F.G., D.F.T. and I.E., supervision and project administration, I.E.; funding acquisition, X.G.C.

Funding: This research was funded by the China Scholarship Council (CSC), grant number 201608080083.

Acknowledgments: The authors would like to acknowledge the China Scholarship Council (CSC) for funding this research, Chua Kah Heng (Malaysia) for cooperating with us and the Lungteng Cultural Company (Taiwan) and Shandong Science and Technology Press (PRC) for permission to reproduce pictures from their books.

Conflicts of Interest: There are no conflict of interest to declare.

References

1. Johnstone, A.H. Why is science difficult to learn? Things are seldom what they seem. *J. Comput. Assist. Learn.* **1991**, *7*, 75–83. [CrossRef]
2. Upahi, J.E.; Ramnarain, U. Representations of chemical phenomena in secondary school chemistry textbooks. *Chem. Educ. Res. Pract.* **2019**, *20*, 146–159. [CrossRef]

3. Gabel, D. Improving teaching and learning through chemistry education research: A look to the future. *J. Chem. Educ.* **1999**, *76*, 548. [CrossRef]
4. Talanquer, V. Macro, submicro, and symbolic: the many faces of the chemistry "triplet". *Int. J. Sci. Educ.* **2011**, *33*, 179–195. [CrossRef]
5. Taber, K.S. Revisiting the chemistry triplet: Drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chem. Educ. Res. Pract.* **2013**, *14*, 156–168. [CrossRef]
6. Sjöström, J.; Talanquer, V. Humanizing chemistry education: from simple contextualization to multifaceted problematization. *J. Chem. Educ.* **2014**, *91*, 1125–1131. [CrossRef]
7. Mahaffy, P. The future shape of chemistry education. *Chem. Educ. Res. Pract.* **2004**, *5*, 229–245. [CrossRef]
8. Österlund, L.-L.; Berg, A.; Ekborg, M. Redox models in chemistry textbooks for the upper secondary school: Friend or foe? *Chem. Educ. Res. Pract.* **2010**, *11*, 182–192. [CrossRef]
9. Basheer, A.; Hugerat, M.; Kortam, N.; Hofstein, A. The effectiveness of teachers' use of demonstrations for enhancing students' understanding of and attitudes to learning the oxidation reduction concept. *Eurasia J. Math. Sci. Tech. Educ.* **2017**, *13*, 555–570. [CrossRef]
10. Barke, H.D. Two ideas of the redox reaction: Misconceptions and their challenge in chemistry education. *Afr. J. Chem. Educ.* **2012**, *2*, 32–50.
11. Finley, F.N.; Stewart, J.; Yarroch, W.L. Teachers' perceptions of important and difficult science content. *Sci. Educ.* **1982**, *66*, 531–538. [CrossRef]
12. Obomanu, B.; Onuoha, C. Students conceptual difficulties in electrochemistry in senior secondary schools. *J. Emerg. Trends Educ. Res. Pol. Stud.* **2012**, *3*, 99.
13. Paik, S.H.; Kim, S.; Kim, K. Suggestion of a viewpoint change for the classification criteria of redox reactions. *J. Chem. Educ.* **2017**, *94*, 563–568. [CrossRef]
14. Schmidt, H.J.; Volke, D. Shift of meaning and students' alternative concepts. *Int. J. Sci. Educ.* **2003**, *25*, 1409–1424. [CrossRef]
15. De Jong, O.; Treagust, D.F. The teaching and learning of electrochemistry. In *Chemical Education: Towards Research-Based Practice*; Gilbert, J.K., De Jong, O., Justi, R., Treagust, D.F., Van Driel, J.H., Eds.; Springer: Dordrecht, The Netherlands, 2002; pp. 317–337.
16. Shibley, I.A., Jr.; Amaral, K.E.; Aurentz, D.J.; McCaully, R.J. Oxidation and reduction reactions in organic chemistry. *J. Chem. Educ.* **2010**, *87*, 1351–1354. [CrossRef]
17. Osman, K.; Lee, T.T. Impact of interactive multimedia module with pedagogical agents on students' understanding and motivation in the learning of electrochemistry. *Int. J. Sci. Math. Educ.* **2014**, *12*, 395–421. [CrossRef]
18. Eilks, I.; Witteck, T.; Pietzner, V. The role and potential dangers of visualisation when learning about sub-microscopic explanations in chemistry education. *Cent. Educ. Policy Stud. J.* **2012**, *2*, 125–145.
19. Ramnarain, U.; Joseph, A. Learning difficulties experienced by grade 12 South African students in the chemical representation of phenomena. *Chem. Educ. Res. Pract.* **2012**, *13*, 462–470. [CrossRef]
20. Valanides, N.; Nicolaidou, A.; Eilks, I. Twelfth grade students' understanding of oxidation and combustion: Using action research to improve teachers' practical knowledge and teaching practice. *Res. Sci. Tech. Educ.* **2003**, *21*, 159–175. [CrossRef]
21. Gilbert, J.K. On the nature of "context" in chemical education. *Int. J. Sci. Educ.* **2006**, *28*, 957–976. [CrossRef]
22. Pintó, R.; Ametller, J. Students' difficulties in reading images. Comparing results from four national research groups. *Int. J. Sci. Educ.* **2002**, *24*, 333–341. [CrossRef]
23. Dimopoulos, K.; Koulaidis, V.; Sklaveniti, S. Towards an analysis of visual images in school science textbooks and press articles about science and technology. *Res. Sci. Educ.* **2003**, *33*, 189–216. [CrossRef]
24. Eilks, I. Experiences and reflections about teaching atomic structure in a jigsaw classroom in lower secondary school chemistry lesson. *J. Chem. Educ.* **2005**, *82*, 313. [CrossRef]
25. Gkitzia, V.; Salta, K.; Tzougraki, C. Development and application of suitable criteria for the evaluation of chemical representations in school textbooks. *Chem. Educ. Res. Pract.* **2011**, *12*, 5–14. [CrossRef]
26. Stylianidou, F. Analysis of science textbook pictures about energy and pupils' readings of them. *Int. J. Sci. Educ.* **2002**, *24*, 257–283. [CrossRef]
27. Eilks, I. Teacher pathways through the particulate nature of matter in lower secondary school chemistry: Continuous switching between different models or a coherent conceptual structure? In *Concepts of Matter in Science Education*; Tsaparlis, G., Sevian, H., Eds.; Springer: Dordrecht, The Netherlands, 2013; pp. 213–230.

28. Stuckey, M.; Hofstein, A.; Mamlok-Naaman, R.; Eilks, I. The meaning of 'relevance' in science education and its implications for the science curriculum. *Stud. Sci. Educ.* **2013**, *49*, 1–34. [CrossRef]
29. Holman, J. Resources or courses? Contrasting approaches to the introduction of industry and technology to the secondary curriculum. *Sch. Sci. Rev.* **1987**, *68*, 432–438.
30. Raved, L.; Assarafs, O.B.Z. Attitudes towards science learning among 10th-Grade students: A qualitative look. *Int. J. Sci. Educ.* **2011**, *33*, 1219–1243. [CrossRef]
31. Wu, S.P.W.; Rau, M.A. Effectiveness and efficiency of adding drawing prompts to an interactive educational technology when learning with visual representations. *Learn. Instr.* **2018**, *55*, 93–104. [CrossRef]
32. Ainsworth, S. DeFT: A conceptual framework for considering learning with multiple representations. *Learn. Instr.* **2006**, *16*, 183–198. [CrossRef]
33. Rau, M.A.; Bowman, H.E.; Moore, J.W. An adaptive collaboration script for learning with multiple visual representations in chemistry. *Comput. Educ.* **2017**, *109*, 38–55. [CrossRef]
34. Eilks, I.; Rauch, F.; Ralle, B.; Hofstein, A. How to allocate the chemistry curriculum between science and society. In *Teaching Chemistry—A Studybook*; Eilks, I., Hofstein, A., Eds.; Sense Publisher: Rotterdam, The Netherlands, 2013; pp. 1–36.
35. Martinez-Gracia, M.V.; Gil-Quylez, M.J.; Osada, J. Genetic engineering: A matter that requires further refinement in Spanish secondary school textbooks. *Int. J. Sci. Educ.* **2003**, *25*, 1147–1168. [CrossRef]
36. Devetak, I.; Vogrinc, J. The criteria for evaluating the quality of the science textbooks. In *Critical Analysis of Science Textbooks: Evaluating Instructional Effectiveness*; Khine, M.S., Ed.; Springer: Dordrecht, The Netherlands, 2013; pp. 3–15.
37. Souza, K.A.F.D.; Porto, P.A. Chemistry and chemical education through text and image: Analysis of twentieth century textbooks used in Brazilian context. *Sci. Educ.* **2012**, *21*, 705–727. [CrossRef]
38. Cheng, K.L.; Wong, S.L. Nature of science as portrayed in the physics official curricula and textbooks in Hong Kong and on the mainland of the People's Republic of China. In *Topics and Trends in Current Science Education*; Bruguière, C., Tiberghien, A., Clément, P., Eds.; Springer: Dordrecht, The Netherlands, 2014; pp. 519–534.
39. Wang, L.; Tang, J.J.; Zhang, R.H.; Hu, J.H.; Zhi, Y.; Wei, R. Investigation of the use of new chemistry textbooks of senior high school and the influential factors. *J. Educ. Stud.* **2015**, *11*, 77–86.
40. Dagher, Z.R.; Erduran, S. Reconceptualizing the nature of science for science education. *Sci. Educ.* **2016**, *25*, 147–164. [CrossRef]
41. Van Den Akker, J. The science curriculum: Between ideals and outcomes. In *International Handbook of Science Education*; Fraser, B.J., Tobin, K.G., Eds.; Springer: Dordrecht, The Netherlands, 1998; pp. 421–447.
42. Lee, V.R. Adaptations and continuities in the use and design of visual representations in US middle school science textbooks. *Int. J. Sci. Educ.* **2010**, *32*, 1099–1126. [CrossRef]
43. Khaddoor, R.; Al-Amoush, S.; Eilks, I. A comparative analysis of the intended curriculum and its presentation in 10th grade chemistry textbooks from seven Arabic countries. *Chem. Educ. Res. Pract.* **2017**, *18*, 375–385. [CrossRef]
44. Calado, F.M.; Scharfenberg, F.-J.; Bogner, F.X. To what extent do biology textbooks contribute to scientific literacy? Criteria for analysing science-technology-society-environment issues. *Educ. Sci.* **2015**, *5*, 255–280. [CrossRef]
45. Livni-Alcasid, G.; Haskel-Ittah, M.; Yarden, A. As symbol as that: Inconsistencies in symbol systems of alleles in textbooks, and students' justifications for them. *Educ. Sci.* **2018**, *8*, 110. [CrossRef]
46. Department of Statistics Malaysia. Current Population Estimates, Malaysia, 2016–2017. Available online: www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=155&bul_id=a1d1UTFZazd5ajJiRWFHNDduOXFFQT09&menu_id=L0pheU43NWJwRWVSZklWdzQ4TlhUUT09 (accessed on 5 January 2018).
47. Liu, H. Retrospect and prospect of university entrance examination. *Educ. Res.* **2007**, *11*, 19–24.
48. Hong Kong Education Bureau, Recommended Textbook List. Available online: https://cd.edb.gov.hk/rtl/search.asp (accessed on 3 January 2019).
49. National Academy for Educational Research, Project of the Implementation of 12-Year Basic Education. Available online: www.naer.edu.tw/files/15-1000-7944,c639-1.php?Lang=zh-tw (accessed on 5 December 2017).

50. Dong Zong, The background of Dong Zong's Establishment. Available online: www.dongzong.my/aboutus.php (accessed on 5 January 2018).
51. Carney, R.N.; Levin, J.R. Pictorial illustrations still improve students' learning from text. *Educ. Psych. Rev.* **2002**, *14*, 5–26. [CrossRef]
52. Nyachwaya, J.M.; Gillaspie, M. Features of representations in general chemistry textbooks: A peek through the lens of the cognitive load theory. *Chem. Educ. Res. Pract.* **2015**, *17*, 58–71. [CrossRef]
53. Roseman, J.E.; Stern, L.; Koppal, M. A method for analyzing the coherence of high school biology textbooks. *J. Res. Sci. Teach.* **2010**, *47*, 47–70. [CrossRef]
54. Treagust, D.F.; Chittleborough, G.; Mamiala, T. The role of submicroscopic and symbolic representations in chemical explanations. *Int. J. Sci. Educ.* **2003**, *25*, 1353–1368. [CrossRef]
55. Berliner, D.C. The development of expertise in pedagogy. Charles W. Hunt Memorial Lecture presented at the annual meeting of the American Association of Colleges for Teacher Education, New Orleans, LA, USA, 17–20 February 1988.
56. Kozma, R.; Russell, J. Multimedia and understanding: Expert and novice responses to different representations of chemical phenomena. *J. Res. Sci. Teach.* **1997**, *34*, 949–968. [CrossRef]
57. Mahaffy, P. The human element: Chemistry education's contribution to our global future. In *Chemistry Education*; García-Martínez, J., Serrano-Torregrosas, E., Eds.; Wiley-VCH: Darmstadt, Germany, 2011; pp. 131–157.
58. Cuban, L. The lure of curricular reform and its pitiful history. *Phi Delta Kappan* **1993**, *75*, 182–185.
59. Russell, J.W.; Kozma, R.B.; Jones, T.; Wykof, J.; Marx, N.; Davis, J. Use of simultaneous-synchronised macroscopic, microscopic and symbolic representations to enhance the teaching and learning of chemical concepts. *J. Chem. Educ.* **1997**, *74*, 330–334. [CrossRef]
60. Eilks, I.; Hofstein, A. *Teaching Chemistry—A Studybook*; Sense Publisher: Rotterdam, The Netherlands, 2013.
61. Chiappetta, E.L.; Fillman, D.A. Analysis of five high school biology textbooks used in the United States for inclusion of the nature of science. *Int. J. Sci. Educ.* **2007**, *29*, 1847–1868. [CrossRef]
62. Lavonen, J. Commentary: What we can learn from science education in Asian countries? In *Science Education Research and Practice in Asia*; Chiu, M.-H., Ed.; Springer: Singapore, 2016; pp. 215–221.
63. Yore, L.D.; Shymansky, J.A.; Treagust, D.F. An international perspective on the people and events shaping science education in Taiwan—past, present, and future. In *Science Education Research and Practices in Taiwan*; Chiu, M.-H., Ed.; Springer: Singapore, 2016; pp. 397–419.
64. De Jong, O. Comments on section 4: Thoughts on science curriculum reform and teacher learning in western countries and Taiwan. In *Science Education Research and Practices in Taiwan*; Chiu, M.-H., Ed.; Springer: Singapore, 2016; pp. 387–394.
65. Nurul-Awanis, A.; Hazlina, A.; Yoke-Ma, L.; Zariyawati, M. Malaysian education system reform: Educationists' perspectives. In Proceedings of the International Conference on Social Science, Economics and Art 2011, Kuala Lumpur, Malaysia, 14–15 January 2011.