Myint Swe Khine *Editor*

Critical Analysis of Science Textbooks

Evaluating instructional effectiveness

Springer

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Contents

Part I Introduction

1 The Criteria for Evaluating the Quality of the Science Textbooks 3
Iztok Devetak and Janez Vogrinc

2 Development of the Graphical Analysis Protocol (GAP) for Eliciting the Graphical Demands of Science Textbooks 17
Scott W. Slough and Erin McTigue

Part II Textual and Language Analysis of Science Textbooks

3 Understanding the Disciplines of Science: Analysing the Language of Science Textbooks 33
Sandy Muspratt and Peter Freebody

4 Towards a More Epistemologically Valid Image of School Science: Revealing the Textuality of School Science Textbooks 61
Kostas Dimopoulos and Christina Karamanidou

5 How Effective Is the Use of Analogies in Science Textbooks? 79
MaryKay Orgill

6 Textual Features and Language Demands of Primary Grade Science Textbooks: The Call for More Informational Texts in Primary Grades 101
Nadine Bryce

Part III Content Analysis of Science Textbooks

7 **A Review of the Earth Science Content of Science Textbooks in England and Wales** 123
Chris King

8 **A Content Analysis of Science in Nineteenth-Century US Readers: Early American Science Education** 161
Peter Rillero

9 **Educational Approach to Environmental Complexity in Life Sciences School Manuals: An Analysis Across Countries** 173
Silvia Caravita and Adriana Valente

10 **Analysis of Turkish General Chemistry Textbooks Based on a History and Philosophy of Science Perspective** 199
Mansoor Niaz and Bayram Coştu

11 **An Analysis of Standards-Based High School Physics Textbooks of Finland and the United States** 219
Do-Yong Park and Jari Lavonen

12 **A Qualitative Method to Determine How Textbooks Portray Scientific Methodology** 239
Ian C. Binns

13 **Science and Science Teaching** 259
Nicos Valanides, Maria Papageorgiou, and Pavlos Rigas

14 **Content Analysis of Diagrams in Secondary School Science Textbooks** 287
Yang Liu and David F. Treagust

Part IV Conclusion

15 **Analysis of Science Textbooks for Instructional Effectiveness** 303
Myint Swe Khine

Index 311

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Part I
Introduction

Chapter 1
The Criteria for Evaluating the Quality of the Science Textbooks

Iztok Devetak and Janez Vogrinc

Introduction

Textbooks are primary teaching aids, sources from which students obtain knowledge. The concept of teaching aid comprises all objects that are specially designed for using in the classroom according to the teachers' selection. Textbooks should be a part of the students' individual activities, and the teacher can implement it in all stages of the learning process and to those learning methods, which entail working with text. Valverde, Bianchi, Wolfe, Schmidt, and Houang (2002) stated that "Textbooks help define school subjects as students experience them. They represent school disciplines to students" (p. 1). It is important to be aware that the inadequate and inconsistent scientific knowledge presented in science textbooks will negatively affect students' ideas (Irez, 2009), and as Clifford (2002) pointed out, some concern has been expressed that information in textbooks is not always found to be accurate. Textbooks also facilitate topic selection by teachers and provide an orientation in the way these topics are taught (Martínez-Gracia, Gil-Quílez, & Osada, 2006). Many teachers also rely on the textbook in deciding what and how to teach, especially when they are teaching outside their area of expertise (Stern & Roseman, 2004). It is also important to emphasise that teachers, as facilitators of learning, should be aware of the problems and limitations of the textbook their students are using (Haggarty & Pepin, 2002). Textbook authors have freedom to develop their own approach to the delivery of national curricula and examination specifications, and so textbooks represent a considerable diversity (Martínez-Gracia et al., 2006). Textbooks also describe links between real world phenomena and scientific theories (Ahtineva, 2005) and determine the content to be taught as well as basic guidelines for teaching procedures. Trends in International Mathematics and Science Study (TIMSS 2007)

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showed that in average about 40 % of teaching time is used by teachers to teach by textbooks almost every lesson. In Slovenian context, this percentage is in average lower for at least 15 %, as it was shown by the TIMSS 2007 study (Svetlik, Japelj Pavešić, Kozina, Rožman, & Šteblaj, 2008).

The focus of this chapter is to illustrate the possible criteria that teachers (as textbook users), authors and editors (as textbooks producers) can follow in forming adequate learning material for students. These criteria should be included in the good textbook if it is to foster quality learning and teaching.

Textbooks in Science Teaching and Learning

Learning science and students' acquired knowledge of science concepts is the most important aspect of school science teaching. We all struggle for our students to learn more and better, and we try to develop teaching strategies that can lead students to adequately scientifically literate individuals. But research in the last 30 years has shown that it is common for students to have misconceptions or other learning difficulties with different science concepts at all levels of education, from primary to university level. Students' misconceptions can have different sources, e.g. teachers' inadequate teaching, students' low attention while following the educational process, students' superficial individual learning of the material from personal notes, students' inaccurate reading of the textbooks and also poorly prepared textbooks by the author(s).

We know that textbooks have and should have an impact on student's learning. Irez (2009), for this matter, argues that uniformed ideas presented in a textbook could affect students' learning in a direct or indirect way.

According to the cognitive theory of multimedia learning developed by Mayer (1997), it is suggested that in multimedia learning, the learner engages in three important cognitive processes: (1) selecting – the incoming verbal information ought to yield a text base, and the incoming visual information should yield an image base; (2) organising – the word base creates a verbally based model of the to-be-explained system, and the image base creates a visually based model of the to-be-explained system; both processes should be emphasises during learners' textbook using; and (3) integrating – the learner builds connections between corresponding events (or states or parts) in the verbally based and the visually based model. This theory suggests that it is better to present an explanation in words and pictures together than solely in words. This is also confirmed by different studies (Levie & Lentz, 1982; Vasu & Howe, 1989) that emphasise a combination of both visual and verbal elements in teaching aids as being ideal, even before Mayers' cognitive theory of multimedia learning was established. Visual-verbal learning allows students to reconcile the two modes and compare carefully the information available in the picture with the explanation in the text (Reid, Briggs, & Beveridge, 1983).

As emphasised above, two specific elements of the teaching aids as textbooks are important. The first one is textual, and the second one is visual (pictorial) material. The visual aspect of learning becomes even more important in science learning, because science comprises abstract concepts that sometimes do not have visual and tangible examples of these concepts in reality. Science deals with complex phenomena with numerous variables that should be taken into account when trying to understand it. In chemistry, specifically, concepts could be presented at three levels, macroscopic (phenomena observations), submicroscopic (phenomena explanations at particulate level) and symbolic (phenomena presented by specific symbols). These levels pose a great amount of mental efforts for students to understand, and without visual elements supporting these efforts, an effective learning does not occur. Research in the last three decades (Adadan & Savasci, 2011; Bunce & Gabel, 2002; Davidowitz, Chittleborough, & Murray, 2010; de Berg, 2012; Devetak, 2005; Devetak, Vogrinc, & Glažar, 2009; Johnstone, 1982; Kelly & Jones, 2008; Papageorgiou & Johnson, 2005; Williamson & Abraham, 1995) shows that only when adequately merged can these representations help students to develop a conceptual understanding of chemical phenomena. All these facts indicate that science is hard to learn, is not easy to understand and is not simple to use in new situations.

As mentioned above, an adequate relation between textual and pictorial material in the textbooks should be assured if the science textbook is considered to be a good textbook. Firstly, the pictorial material will be discussed, and secondly, the textual aspects of textbooks will be mentioned. These two information modes (textual and illustrative) can be combined in the science textbooks and as adequately are integrated to each other as effective a science textbook can be.

Illustrations are the basis of visual learning in the science classroom and include representations found in typical science textbooks, such as photographs, diagrams, charts, graphs, drawings and tables (Cook, 2008). Cook suggested that because illustrations are a large part of science textbooks, more attention must be focused on understanding the impact visual images have on students and their learning. Ametller and Pinto (2002) discussed that visual aids in learning materials play an important role in the communication of science concepts. Research also shows that around 90 % of students learn science using some form of text, but important conclusions are that science texts do not significantly contribute to quality learning in science education (Peacock & Gates, 2000). Science textbooks demand that the learner integrates quite complicated science concepts, together with language abilities (scientific vocabulary and syntax and also capability of reading, writing and oral communicating), visualisation materials (different images, symbols, comic-strip style, etc.) and format in the science text.

Research also shows (Dimopoulos, Koulaidis, & Sklaveniti, 2003) that images contribute to the higher level of meaning of the text presented in the textbook. The authors also concluded that modern textbooks integrate more images in the text than did textbooks in the past. This indicates the influence of modern technologies that facilitate the application of different visualisation materials to present science and technology through media. Visualisation material is often a quite transparent and unproblematic method to represent reality and communicate science and technology. The analysis of Korean chemistry textbooks' pictorial elements (pictures of macroscopic and submicroscopic level) accompanied by the text explaining the pictures (Han & Roth, 2005) shows that difficulty in understanding the particulate nature of matter may result from the different processes of interpretation and meaning – making between inscriptions depicting the macroscopic and models based on the submicroscopic level.

On the other hand, Stylianidou, Ormerod and Ogborn (2002) summarised that images could present additional problems for students' understanding the message of the specific topic explained in the textbook, so they emphasise that more attention should be paid to the constructing of the pictorial representations for textbooks (see criteria for pictorial material Table 1.3).

The Analysis of the Science Textbooks

It is recommended that the learning goals stated in the national curriculum should lead the content analysis of the educational material (Kesidou & Roseman, 2002). The analysis of the textbooks should be conducted on three levels: (1) general structure, (2) textual material and (3) pictorial material.

The first one (general structure) consists of the general information of the textbook as number of pages, chapters, the length of the chapters, the percentage of textual and pictorial material in the specific chapter and the whole textbook.

The second level of the textbook analysis (textual material) comprises different attributes of textual material that can be classified into two categories. Category I represents different types of the textual material, and category II comprises the content/concepts part of the analysis. Category I comprises different elements of the textbooks' text, e.g. giving explanations, stimulating discourse, stimulating observations of the phenomena, proposals for teachers' demonstrations of a specific science phenomena, giving guidelines for individual students' experimentations, giving instructions for other practical work (i.e. project work and field work), emphasising problem solving strategies and summarising the important concepts at the end of the chapters and tasks (items, problems) in the middle or at the end of the chapter for students to repeat the content of the chapter (identifying type of items like open-ended of optional, items' cognitive level). Category II of the textual material analysis is more subject or scientific field driven and should be performed following the exact framework that was developed according to the reached agreement between subject area experts. As in the first category, or even more, also in this category comes forward the objectivity and reliability of the analysis. Wang (1998) discussed a series of published research studies analysing the instrumentation used in the data gathering process and also evaluated the criteria for selecting the amount of textbook material for analysis and the problems with its reliability. To reach the most objective level of analysis, two or better three analysts should analyse the text according to the frameworks, and the highest and the most harmonised level of agreement with the categorisation according to the framework should be reached. Conceptual or content analysis can be performed by identifying key concepts and connections between them according to the national curriculum recommendations – learning goals. Such analysis can be performed following the central idea of Weber's (1995) content analysis directive: content analysis in classifying words of a text into a smaller number of content categories (cited in Wang, 1998). The data gathering techniques and instruments which are used in the qualitative research (Bogdan & Biklen, 2003; Carvalho, Silva, & Clément, 2005; Dimopoulos et al., 2003; Vogrinc, 2005) can give specific guidelines to develop adequate criteria for the text analysis of the science textbooks. During the process of content analysis, the researchers examine the frequency and the placement of a certain category within the text. As in the content analysis a highly structured form of the text analysis is presupposed, it is crucial for the categories to be utterly precise and undoubtedly defined, as only in this case it is possible for various researchers analysing the same text to get the same and comparable results. The content analysis thus meets the demands of the main characteristic features of the quantity research, the basic goal of which is to obtain valid, reliable and verifiable results. Within the scope of the quality research, the content analysis is a very useful tool to acquire the descriptive data on the examined topic and information, describing the examined topic. It is applicable to develop topics (the main ideas) and facilitates logical organisation of a large amount of descriptive data. It is also suitable for examining the findings of other researchers and the findings, respectively, that were reached with applying other data gathering techniques (observation, interview). However, the content analysis is very rarely used as an independent data collection technique. The researchers focusing on quality research (Atkinson, 1992; Silverman, 2001) perceive the content analysis to be an imperfect form of analysing written documents, as they believe the application of the list of categories, given in advance limits the researchers in their work of analysing written materials. Researchers indulged in quality research prefer to focus on shorter texts and analyse a smaller number of documents, whereby they are not only interested in the frequency of the presence of a certain category; moreover, they try to predominantly understand this category and establish the application mode of various categories in concrete activities (e.g. curriculum vitae, narrations, assessments); thus, they are interested in the manner of identification of each category by its users.

The third level of textbook analysis refers to the pictorial material presented in the textbook to visually support the textual material. It is meant for all, but especially for more visual type of learning strategy students. Pictorial material can be classified in science and especially in chemistry textbooks into category I and category II. Category I includes the following: (1) realistic images that present reality according to the human optical perception, e.g. photograph or drawing; (2) conventional images that are graphs, diagrams, maps, molecular structures, etc. constructed according to the techno-scientific consensus in the most condensed way; and (3) hybrid images that combine the realistic and conventional ones (Dimopoulos et al., 2003). In category II, two types of images can be classified: (1) macroscopic images presenting experimental of other natural phenomena at the sensory level and (2) submicroscopic images that visualise particulate level (atoms, ions, molecules) of chemical concepts (Devetak, Vogrinc, & Glažar, 2010;

Johnstone, 1982). Research shows that students differently recognise the objects depicted in the illustrations presented in textbooks (Constable, Campbell, & Brown, 1988) and that many illustrations in textbooks depicting science processes assume prior knowledge on the part of the student (Cook, 2008). Cook stated that teachers often anticipate that most students understand the visual images presented in science textbooks, but Billings and Klanderman (2000) pointed out that student misconceptions can be generated in the process of interpreting illustrations and many stem from the lack of prior experience with the subject in their daily lives (Wu, Krajcik, & Soloway, 2001). Teachers must help students develop the basic skills of visual communication, specifically by teaching them to critically evaluate the form and content of visual communication (Cook, 2008). Students need to be taught how to read illustrations in order to avoid potential causes of confusion (Stylianidou et al., 2002), and teachers need to be aware of students' difficulties when reading images (Ametller & Pinto, 2002).

Teachers and Textbooks in Science Classroom

An important aspect in the broader context of the textbooks (or educational material) analysis is also the teachers' ability to critically evaluate textbooks, because the teacher should have the authority and resources to select the most appropriate materials and to take the decision about when, where and how to make them useful for his/her teaching (Wang, 1998). About the criteria for selecting a quality textbook are reasonable to think especially when teachers have professional autonomy and responsibility that of the textbooks offered on the market, they choose one that they consider most effective. An important condition for them to choose the most effective textbook is their professional and didactic competence. Content and path towards learning goals and standards of knowledge contained in the curriculum, the fact may be different, since the government does not examine fully the content of the textbooks but rather only its consistency with the learning goals and standards and examples of content that are proposed in the curriculum. Teaching methods, teaching content and textbooks are thus left to teachers' decision in the specific school (Kovač, Kovač Šebart, Krek, Štefanc, & Vidmar, 2005).

Textbooks' Quality Criteria

In formulating the criteria for evaluating textbooks, didactic principles can be taken into account. In this respect, the quality textbook should incorporate in its content and form in the most efficient manner didactic principles.

Didactic principles that are important from this chapter's focus are (Kovač et al., 2005) as follows: (1) content of the textbook (textbook should be written to take into account the principle of representation, real-logical correctness, structure and systematic), (2) the relationship to the student (textbook development should respect the principles of proximity, individualisation, education), (3) principle of students' action and problem solving (textbook shall be designed in a way that does not bring all the knowledge to the student, but it puts him/her in a situation where student has to work according to his/her initiative to obtain the knowledge. Students should therefore be encouraged to perform activities and to solve problems related to the learning content. The background of this requirement is the assumption that knowledge to which students are encouraged to come alone, with their research activities, is stronger and more stable than knowledge obtained by the mere memorising) and (4) principle of the organisation of the learning process (textbooks should be organised in a way that the learning process leading by the textbook should be economic and rational).

A quality textbook is supposed to be the one which in its content and form involves all didactic principles in the most efficient manner. The problem that arises regarding these aspects is the fact that some of these didactic principles are at least partly in an exclusive relationship; e.g. time used for teaching process is a limiting factor when the principle of students' action and problem solving and principle of the organisation of the learning process (economy and rationality) is considered.

Class instruction is a process that requires rationalisation at both planning and implementation levels. Quality textbook should in its content and structure, in addition to promoting research activities and problem solving and suggesting the use of other sources of information, maintain its functionality in communicating and presenting learning content. This means that it must provide to the students a clear insight into the basic content, structure and systematic of the science subject and thereby helping to provide rational and economic instruction (Kovač et al., 2005; Kovač & Kovač Šebart, 2004).

The most important criteria for a good science textbook is probably the fact that it should take into account the level of development of students, their level of understanding and experience with science concepts at previous schooling levels. The use of appropriate language with minimal foreign words, clear explanations and short sentences is important. The text should be broken down to the topics, subtopics and notes in the margins so that transparency of the text can increase. Various ways should be taken into account to promote reading comprehension and higher cognitive activities such as appropriate tasks and questions, summaries, tables, graphs and schemata, and for older students, each chapter should begin with a cognitive framework, and list of important concepts with explanations should be written at the end of each chapter and/or at the end of the textbook. Authors should pay much attention to pictorial presentations in the text (e.g. charts, drawings, visual material).

Nine general criteria for quality science textbooks can be identified (Table 1.1). Authors of science textbooks should be aware of these criteria and should consider them while preparing a new textbook. Some of these general criteria can be applied also specifically to textual and pictorial material of the textbook. But on the other hand, also some specific criteria for these two textbooks' elements can be identified (see Tables 1.2 and 1.3).

Table 1.1 General quality criteria for the science textbooks and other educational material (Adapted by CPI Quality criteria for teaching materials)

General criteria	Description
1. The structure is clear and transparent	Students can easily find themselves in the textbook; this means that the title and the usefulness of the textbook clearly written (e.g. study programme, subject and competencies that are covered by the material); textbook should have a table of contents; the objectives of individual learning unit within the textbook are indicated; the contents are logically arranged in the textbook, following the subjects' concepts development; as a conclusion or summary of the specific learning unit in the textbook, some activities to summarise the content of the unit should be offered; and references that were followed by the authors should be consistently listed
2. Technical guidance is considered	Cover and colophon comprise all necessary components, technical guidelines for the textbook design are taken into account and copyrights are governed
3. The content is consistent with the learning objectives/aims/goals	The textbook at each chapter clearly states the operational learning objectives/aims/goals presented in the national curriculum for a specific science subject. Also, competences that students should develop using the specific textbook chapter can be stated
4. The content is a learning-goals based	Textbooks' content is derived from the learning goals stated in the national curriculum for the specific science subject, but not from the structure of learning material. Textbook helps in achieving the learning goals and allows the students to achieve competences, both generic and science subject-specific
5. Textbook extents a coherent learning material in the framework of the specific educational programme	The textbook covers a full and comprehensive subjects' area, it contains a uniform terminology, contents relate to one another and also some links to additional resources and activities should be added as well
6. The inductive approach is used	The textbooks' content should be developed from general to specific. Specific chapter is started with the practical problem to which the appropriate theoretical and general knowledge is attached. Theoretical knowledge is linked with its practical application that gives meaning and ensures its durability
7. The content is correct	The content of the textbook must be correct according to the actual knowledge of the specific science subject area. It must be reviewed by two reviewers, and one of them must have a Ph.D. from the science area that textbook is for. Science textbooks usually comprise the most important concepts, facts, principles and rules, laws and methods, procedures and tools that are proven and have longer value. Excessive details, abundance of new information at once, the most recent and not yet proven science subjects' knowledge and content that is changing rapidly should not be part of the textbooks. Textbooks ought to direct students to the appropriate current references and ought to encourage them to be able to find additional information by themselves

(continued)

Table 1.1 (continued)

General criteria	Description
8. The content is didactically adequate	The content of the textbook must be adapted to the needs of target group students. The content is tailored to the complexity and level of educational programme. The learning material should allow individualisation and differentiation of content and should take into account students' different learning styles
9. Suggestions for cross-curricular integration	The textbooks' content should offer cross-curricular links, and these are included where and when they make sense and bring additional quality to the materials

Table 1.2 Textual material quality criteria for the science textbooks and other educational material (Adapted by CPI Quality criteria for teaching materials)

Textual criteria	Description
1. Text is linguistically correct and appropriate	The text must be proofread. Writing style is clear (sentence and text structure is understandable; the unknown and difficult words are explained) and close to the language of everyday life
2. Text contains motivational elements	Elements that encourage interest/motivation for learning can be presented learning goals in the introduction, interesting facts form nature, industry research institutes, cases form individuals' lives, links to other references, problem solving, etc.
3. Text encourages active learning	The student reading the text in the textbook should be at all times encouraged to participate in an active learning process in response to the presented content. The text should constantly offer various activities such as exercises, questions that stimulate thinking, problems to be solved and proposals for laboratory work, observations of the natural phenomena and field and project work. Instructions for activities/exercises/questions/tasks/problems are clear and allow students' individual work. All activities must be feasible. Where possible, the solutions are desired, so that after solving the task, the student can check the solution and learn from possible mistakes and gets conformation for good work
4. Text contains activities at different cognitive levels	Textbook should contain texts that stimulate students' higher-order thinking skills by activity engaging them into tasks at higher cognitive levels. Some of the text and exercises/questions should be also at lower cognitive level (reproduction, understanding, using) for lower achievers. The cognitive differentiation of the text is imperative, for higher achievers in science. This means that some text and exercises/questions/problems should be at higher cognitive levels (analysis, synthesis, evaluation) which encourage students' creativity in solving problems

Table 1.3 Pictorial material quality criteria for the science textbooks and other educational material (Adapted by CPI Quality criteria for teaching materials; Stylianidou et al., 2002; Cook, 2008)

Pictorial criteria	Description of the criteria
1. Visuals are of high quality	Multimedia elements (pictures, images, photos, schemata, animations, multimedia, etc.) are clear enough to serve its purpose – to illustrate the textual content. It is also important that the colours used in illustrations must be carefully selected, since many students interpret differently the colours representing different features in the picture
2. Visuals contain motivational elements	Elements that encourage motivation for learning should be presented in illustrations, graphs, photos of interesting natural phenomena, experiments, research, etc. Usually there are icons for students' easier orientation in the textbook. Funny illustrations (caricature, comics, etc.) can be used to stimulate interest for reading the content
3. Visuals stimulate recall	Pictorial material must include information to elicit students' prior knowledge, so that new information can foster comprehension of new concepts presented in a textbooks' textual or pictorial material
4. Integration of visuals and text	Pictorial material must be explained with textual elements. Constructing and placing of the verbal elements in the image must be clear, and students should read the visuals together with text so that correct understanding of the visuals can be developed. Without the corresponding text, visuals can foster misconceptions
5. Different types of visuals	Textbooks should use realistic images that present reality according to the human optical perception, e.g. photograph or drawing, conventional images that are graphs, diagrams, maps and molecular structures constructed according to the techno-scientific consensus in the most condensed way, and also an adequate proportion of the hybrid images that combine the realistic and conventional ones, mixing the symbolic and real entities in an image. Conventional and hybrid visuals can stimulate higher-order cognitive processes while learning science concepts
6. Multipresentational aspect of the visual	Highlighting some elements of the image; encoding different meanings of similar symbols in different ways; and paying attention to the layout when one image is created by several pictures
7. Visuals in activities	Textbooks must foster students to use different visual material (realistic, conventional and hybrid) in answering questions and solving problems in the end of the specific chapter or while reading the content of the chapter. Students should read realistic, conventional and hybrid images or draw conventional visuals to illustrate their science concepts understanding

Four specific criteria for textbooks' textual elements must be followed when analysing the educational material and when writing the new textbook or editing or renewing already formed ones.

In Table 1.3, seven specific criteria for analysing the textbooks' pictorial elements are presented. Similar as for the textual elements, also these criteria need to be followed when preparing the education material. Quality visuals in science textbooks foster students' adequate and in-depth understanding of concepts, because it stimulates access of the material through different perception channels according to students' individual learning style.

Conclusion

Students' material should be adequately prepared at the text level and appropriately supported with different images. Author(s) of these educational materials, especially textbooks, can present the concepts in the form of text or different pictorial elements and can have an influence on developing students' understanding of these concepts. With textbooks, authors and publishers can also influence teachers as they use it for lesson planning. Following this aspect of the teaching and learning process, it can be estimated that textbooks also significantly influence on national (external) evaluation of the students' science knowledge, and also, guidelines of national evaluations can influence textbook writers. If the material is presented inadequately, it can cause the development of students' mental models incorporating misconceptions. Before using textbooks and also other science teaching and learning material, teachers should critically evaluate it. To do so, teachers should have criteria to evaluate the material, so that the textbook chosen for their practice is adjusted to their way of teaching, to students' cognitive development level, and the textbook should meet the learning aims determined in the national curriculum for the specific science subject. Criteria presented in this chapter can help teachers to evaluate the educational material before its application in the classroom, but it is also important to emphasise that authors and publishers should take into account, when developing educational material, these criteria and other science education research results, where prudent suggestions are made for teachers to overcome the students' possible science concepts learning problems. To reach this cooperation, new partnerships between the researchers and curriculum developers need to be established so that teachers and students would have access to the best-quality textbooks possible.

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Chapter 2
Development of the Graphical Analysis Protocol (GAP) for Eliciting the Graphical Demands of Science Textbooks

Scott W. Slough and Erin McTigue

School-based science textbooks have morphed in format and now mimic the layout of webpages and science trade books, with typical layouts including photographs, table, textboxes, flowcharts, drawings, and a myriad of other visual representations. Teachers report preference for these high visual-content books to traditionally formatted textbooks. While an increasing visual presence in science has been noted by many and explored in both middle and high school science textbooks, there is little information available about the graphical demands of science textbooks. Additionally, there is little research exploring the manner in which verbal and visual text work together. We discuss the development of a new instrument, the Graphical Analysis Protocol (GAP), based on four principles: (1) graphics should be considered by form and function, (2) graphics should help a viewer build a mental model of a system, (3) graphics and texts should be physically integrated, and (4) graphics and texts should be semantically integrated and discuss three research articles utilizing the GAP instrument for unique science textbooks.

Science and communication are linked because science progresses only when findings are disseminated and understood by other members of the field (American Association for Advancement of Science, 1994). The quantitative and technical nature of science compounds the challenges of communication, particularly with novices in the field (Best, Rowe, Ozuru, & McNamara, 2005; Bransford, Brown, & Cocking, 2000). Often, the curriculum has overlooked explicit connections to the communication of science (e.g., visual literacy, reading comprehension, and writing) in the science classroom (Cobb et al., 2004). Previously the *text* itself dominated the aptly named *textbooks*, while the pictures occupied a distant secondary role (McTigue & Slough, 2010). However, in recent years, textbooks offer a near-balanced display of verbal and visual information, with increasingly complicated graphics. This shift

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in visual dominance possesses endemic challenges for readers, particularly young readers with limited science experience. As textbooks continue to hold a prominent position in middle and high school science classes (Slough & Rupley, 2010), it is critical for content teachers to possess a sophisticated understanding of the current textbook design formats and the many factors which make them more and less accessible to learners. In addition, in order to have a more thorough understanding of how the textbooks worked holistically, and in recognition of the intertwined relationship of text and pictures (Kress & van Leeuwen, 2006; Sipe, 1998), the degree of integration between the text and graphics is critical. While readers often hold a misconception that reading comprehension is simply the process of knowing the meaning of all the individual words of a text, this view does not take into account the gestalt, including the intricacies of text and visual information (Pressley & Wharton-McDonald, 1997).

Science textbooks influence how science teachers organize the curriculum, and overreliance on textbooks can result in an overemphasis on terminology and vocabulary (Chiappetta & Fillman, 2007). Visual representations have been suggested as natural extensions of textual material (Mayer, 2001; McTigue & Slough, 2010; Paivio, 1991) and as critical in the communication of science concepts (Ametller & Pinto, 2002). Images of science exhibit an increasingly prominent role across multiple venues including the mass media of science reporting (Trumbo, 1999), authentic science inquiry (Bowen & Roth, 2002), and in school science textbooks (Martins, 2002; Walpole, 1998). Changes in publishing practices (Stern, Aprea, & Ebner, 2003), new technologies (Trumbo, 1999), and the prevalence of visual displays on the World Wide Web (Leu, 2000) contribute to this increase. Concepts are graphically represented in a variety of manners (Pozzer-Ardenghi & Roth, 2005), especially for displaying processes that are difficult to describe or contain multiple relationships (Cook, 2011). Current school science textbooks have morphed in format and now mimic the layout of webpages and science trade books (Walpole, 1998), with typical layouts including photographs, table, textboxes, flowcharts, drawings, and a myriad of other visual representations. Although limited research has been conducted on the effectiveness of such visually complex texts, teachers report preference for these high visual-content books (Carneiro & Freitas, cited in Freitas, 2007) to traditionally formatted textbooks. Textbooks are of interest to us because although there are multiple resources available to teachers, teachers tend to rely heavily on the textbooks (Kesidou & Roseman, 2002).

Research also needs to focus on the growing role of visual communications within textbooks because the inclusion of graphics adjuncts has increased rapidly in the past decade in both quantity and variety (Bransford et al., 2000; Kress & van Leeuwen, 2006; Martins, 2002; Walpole, 1999), but there is little information available about the graphical demands of science textbooks. Therefore, the purpose of this chapter is to discuss the development of a researcher-developed instrument, the Graphical Analysis Protocol (GAP) [see Appendix], that quantified the type and quality of the graphical representations and how they interacted with the textual material in science textbooks and to discuss three articles that used the instrument with a variety of science textbooks.

Guidelines for Evaluating the Graphics in Science Textbooks

In the following sections, a set of research-based principles regarding the analysis of instructional graphics for science learning and the integration of text and graphics are presented. These guidelines informed the development of the researcher-developed instrument.

Principle 1: Graphics should be considered by form and function.

Although often correlated, the form and function of graphical representations are two distinct descriptors, and as such, it is imperative to consider both aspects to quantify the use of graphics in science textbooks. Current classification systems of graphical types are, at best, disorganized (Vekiri, 2002). At the highest classification level, the overall terms of *visual displays*, *graphics*, *graphical displays*, and *graphical representations* are often used interchangeably in the literature, while other researchers prefer unique terms, including *scientific inscriptions* (Roth & McGinn, 1998) or *images* (Kress & van Leeuwen, 2006). This creates situations where researchers can use the same term with different meanings across studies (Vekiri, 2002). To further complicate matters, many graphical representations, such as a photograph with a labeled overlay, represent a hybrid of multiple forms and do not fit into current classification schemes (Atkinson et al., 1999).

Complex Categorization Systems: Accounting for Numerous Types

The following five systems of classification attempt to provide labels to a large field of graphical possibilities. Levin, Anglin and Carney (1987) approached this task through the function of the graphic. In contrast, Winn's (1987), Hegarty, Carpenter and Just's (1996), and Moline's (2011) systems relied on characteristics of the graphical form to define categories. Vekiri (2002) found some common overlap between the existing systems of function and form.

A Functional Classification Approach. Levin et al. (1987) used a functional classification approach in their meta-analysis of empirical validation for the function of pictures. Rather than grouping the illustrations by their defining structures, Levin and colleagues classified the illustrations as serving the following functions: (a) decoration, (b) representation, (c) organization, (d) interpretation, and (e) transformation. A *decorative* illustration adds an affective component but does not meaningfully support the text. *Representational* illustrations directly show what was in the text and thereby add an element of concreteness. *Organizational* illustrations add coherence by thematically organizing material. For example, an illustrated map would be used to depict geographical location of a text's subject, thus scaffolding a reader's organization. The function of *interpretation* goes beyond the organization function by adding information to support more difficult, unfamiliar concepts.

An example is a diagram that not only illustrates the heart but provides additional information about the direction of blood flow. Finally, emanating from Levin's personal interest in mnemonics, *transformational* illustrations attempt to recode the information into a form that is easier to remember.

Graphs, Charts, and Diagrams. Winn (1987) presented an organization scheme in which instructional graphics are divided into three categories: graphs, charts, and diagrams. According to Winn's tripartite taxonomy, *graphs* are defined as illustrating the relationship among variables with at least one variable being continuous. For example, in a graph comparing the Gross National Product (GNP) of various countries, the GNP variable is continuous, and the subject country is categorical. A *chart* presents relationships between categorical variables, as in a chart showing vitamins and their natural sources. *Diagrams* differ from charts and graphs in function, complexity, and visual nature. While charts and graphs illustrate simple relationships between variables, diagrams represent a whole process or structure and therefore often contain greater amounts of detail.

Subcategories of Diagrams Distinguished from Charts and Graphs. Hegarty et al. (1996) described three types of graphic representations in their taxonomy: (a) iconic diagrams, (b) schematic diagrams, and (c) charts and graphs. *Iconic diagrams* represent referent objects concretely and spatially; they most commonly take the form of a photograph or line drawing. *Schematic diagrams* depict abstract concepts and use conventions (e.g., an → can mean movement towards the right), rather than literal representations, to depict the components of the overall concept. Schematic diagrams may take the form of a representation of a pulley system or a graphic organizer such as a Venn diagram. *Charts and graphs* present related facts that are quantitative or can be shown in coordinate space. Examples of this category include line graphs and pie charts.

Teacher-Friendly Classification System

Specific implications for the school setting are also of interest. Moline's, 2011 text, *I See What You Mean*, was the only classification system developed specifically for teacher use. This text presents a guide to teaching visual literacy within the context of content-area classes. Moline grouped visual forms that are often used in school into the six categories of *simple diagrams* (picture glossary, scale diagram), *analytic diagrams* (cross section, cutaways), *synthetic diagrams* (flow diagrams, tree diagrams, web diagrams), *maps* (flow map, context map, bird's eye view map), *graphs* (bar graph, line graph), and *tables*.

An Attempt to Bring Order to Taxonomies. In her 2002 review of graphics, Vekiri attempted to bridge various classification schemes to make one system. She proposed dividing the field into the four most common types of graphics: diagrams, maps, graphs, and network charts. Vekiri explained that overlap exists between categories, and within each category, there exist descriptive ranges. For example, within the category of diagrams, there is a range in the level of realism, depending on whether the diagram is more iconic or schematic in design.

Simpler Classification Systems

Not all classification systems attempt to represent the complexity of illustrations. Some cast graphic differences in terms of binary distinctions. Two such systems are presented in the next section.

Redundant Versus Novel Information. Although graphical representations are often considered "*re*-presentations" of the textual information in a new form (Duke & Pearson, 2002), this is not always the case. Therefore, a functional method of classifying illustrations is based upon whether the diagrams accompanying text present redundant information or novel information (Hegarty et al., 1996). The text and diagrams can interact in various ways. For example, the text can provide information about the diagram itself, such as labeling the components of a diagram, or a diagram can present wholly new information that reinforces the information in the text (Winn, 1987). Even when the text and diagrams present redundant information (i.e., true *re*-presentations), the two types of information are processed differently, which may have a differential effect on performance (Bieger & Glock, 1986).

Static Versus Dynamic Representations. Even among printed, non-animated diagrams, an important distinction is whether the diagram is depicting a static object or a dynamic process. At the simplest level, arrows can be used to indicate movement. Unfortunately, these conventions can be ambiguous and therefore misinterpreted, because, for example, arrows have six distinct functional purposes within diagrams (Henderson, 1999). A more complex convention is to indicate movement through the use of multiple frames which shows movement as the change between each frame. For example, a series of frames can depict the path of the moon around the sun, in the manner of an old-fashioned flip book. However, it is difficult for learners, especially learners with low spatial skills, to take a static diagram and make a dynamic representation – a process that involves rotating or mentally animating the objects (Just & Carpenter, 1985).

In summary, researchers' categorization of graphical forms clearly reveals that the existing systems overlap, so that one graphic may belong to multiple categories. Until one system is accepted, it is advisable for all research with graphics to provide extensive description of the target graphic so the research can be compared and used to inform future research.

Principle 2: Graphics should help a viewer build a mental model of a system.

Salomon, Perkins and Globerson (1991) originally coined the term "mindful engagement" to describe the process in which students build conceptual knowledge (mental models) through the manipulation of multiple representations such as tables, graphs, simulations, and animations. Mental models have been described as the internal abstract representations of concepts and ideas that "store the spatial, physical, and conceptual features" … which are "useful for retrieval in the service of problem solving, inference generation, and decision making" (Rapp, 2005, p. 45). It has been suggested that mental models are in fact *imagistic* and not image-based (e.g., Pylyshyn, 2002). Imagistic representations retain the visual and physical features of an object or experience, but they are themselves not visual (Rapp, 2005). For instance, a mental model of a car would be much more complex than a mental picture of a car and might include abstractions about time and distance that a car could travel, internal working components that limit or enhance how the car performs, and memories of special road trips or vacations taken in a car. This imagistic nature of a mental model suggests that they are both useful and necessary for consideration of visual/spatial concepts or systems.

Diagrams have two main roles when illustrating a system: highlighting the parts (i.e., nouns) of a system and the processes (i.e., verbs) of the system. Within a static diagram, the parts are typically delineated by the use of labels, which are isolated words or phrases, and frequently are connected to the pictorial representation through an arrow or line to the featured component (Pappas, 2006). As described above, dynamic processes are challenging to illustrate within a print form and rely on the use of conventions.

Parts and Steps

To help students build a mental model of a system, Mayer and Gallini (1990) performed a series of experiments using expository passages with college students to explain how scientific devices (e.g., a braking system) worked. They concluded that both the devices' components and their respective actions should be illustrated and labeled. For each experiment, there were conditions of illustrations; these included (a) no illustrations/control, (b) illustrations with labels on the parts of the device (i.e., parts), (c) illustrations with labels on the major actions of the parts (i.e., steps), and (d) illustrations with both the parts and steps labeled. The "parts and steps" illustrations showed a series of multiple frames that illustrated the position of the system at various points during the operation of the system. Neither the "parts" condition nor the "steps" condition was effective in facilitating comprehension. In contrast, the "parts and steps" condition *was* effective. This finding indicates that to understand a dynamic system, skilled readers should have a visual support that delineates both the components of the system and the requisite processes. However, in a similar study with middle-grade readers (McTigue, 2009), the most complex parts and steps diagrams proved to be more challenging than beneficial for younger readers which indicates that such students may need extra guidance in how to understand complex displays of dynamic systems.

Principle 3: Graphics and texts should be physically integrated.

The proximity between the text and the illustration contributes to the effectiveness of illustrations. Mayer and colleagues have demonstrated that students perform better at transfer tasks when the texts and illustrations are placed in close proximity on a page, rather than separate from one another and deem this the *spatial-contiguity principle* (Mayer, 2001; Mayer & Sims, 1994). Eye-movement studies indicate that readers need to continually refer back and forth between the text and the illustrations (Hegarty et al., 1996), and placing the two sources of information next to each other can facilitate this switching of attention. Within the area of animated graphics for children, Rieber (1990) found a facilitative effect for animated lesson frames only when they were presented in chunks of textual and visual sequences, chunks being defined as a smaller subset of information. It has also been suggested that placing a picture before the text may work to activate background knowledge and existing schema (Peeck, 1993).

Principle 4: Graphics and texts should be semantically integrated.

Readers often need strong prompting to attend to illustrations (Levie & Lentz, 1982; Peeck, 1993). Holliday (1976) found that high school readers may judge certain diagrams too formidable to even approach and therefore receive no benefit from the diagram. Even when students do examine graphical illustrations, it can be a fleeting experience: Hannus and Hyona (1999) found attention to graphics accounted for only 6 % of children's total study time of a science text with multiple graphics.

Text-Diagram Integration

Cues in the verbal text which reference the graphical information is one possibility to signal the reader when to attend to the graphic and can guide the reader on how to integrate the two sources of information. Extended captions have been found to facilitate the learning of graphics (Bernard, 1990; Reinking, Hayes, & McEneaney, 1988). Cuing through labeling can make a difference as well. Mayer and Gallini (1990) observed that students learn more from illustrations in which both the elements of the diagram and the function of those elements are labeled. However, Peeck (1993), reviewing established research findings on pictorial representations, indicated that simply drawing students' attention to pictures does little to support processing of those representations. Given these findings, Peeck's advice was that instructors "tell the student to do something with the illustration" (p. 235) and suggested that related tasks yield an examinable product, such as having students label features in an illustration.

Questions and Directions. Holliday and Benson (1991) found that adjunct questions supporting a science chart had a powerful effect on learning the charted material. Adjuncts are defined as modifications or additions made to text to facilitate comprehension (Holliday & Benson). The questions worked to focus the students' attention in a selective fashion. In a similar fashion, Reinking et al. (1988) provided evidence that offering on-screen directions in integrating textual and animated graphical information makes the graphics more useful.

Implications for Textbooks. Based on their results with children, Hannus and Hyona (1999) recommended that textbook designers embed into the text more explicit cues on how the text and graphics are integrated. This would potentially increase the amount of time spent observing the illustrations and could make readers' attempts at integration more likely. Peeck's (1993) findings indicated that specific directives that explicitly direct the reader to an aspect of the diagram or demand active processing are more effective than general instructions to pay attention to the diagrams. Garner (1992) recommended that textbooks include directives explicitly informing the reader when a piece of information is critical.

Application and Discussion

GAP has been applied to sixth-grade science textbooks adopted in the state of Texas, USA (Slough, McTigue, Kim, & Jennings, 2010), a sixth-grade Turkish science textbook (Slough, Cavlazoglu, Erdogan, & Akgun, 2012), and a comparison of print and electronic high school physics textbooks in the State of Texas, USA (Anderson & Slough, 2012). In our original study comparing four sixth-grade science textbooks (Slough et al., 2010), we were able to use the GAP instrument for its intended purpose of identifying the interaction between text and graphical representations and thereby increasing text accessibility (McTigue & Slough, 2010). Also, the GAP instrument's emphasis on the key principles – (1) graphics should be considered by form and function, (2) graphics should help a viewer build a mental model of a system, (3) graphics and texts should be physically integrated, and (4) graphics and texts should be semantically integrated – provides a framework for future development of textbooks and for a more systematic textbook selection system for teachers and administrators. Publishers can utilize a more systematic approach to selecting and utilizing graphics as they continue to modify and improve texts by maximizing the interactions that they desire. Teachers and administrators can utilize a more systematic way to evaluate a text than a 10-min flip through the table of contents and looking at the pretty pictures. Further, it established differences by both publisher and content areas (physical science, life science, earth science, and introduction to science) and identified an overrepresentation of the least analytic forms of graphics;

over three-fourths were static representations, over one-third were not spatially connected to the representative text, over one-third were not indexically references, and almost one-fifth did not have captions.

In a follow-up comparison of Turkish sixth-grade science textbooks (Slough et al., 2012), it was noted how similar the comparison textbook was to the sixth-grade science textbooks from the United States (Slough et al., 2010), in that it has large numbers of high-quality graphics with mostly similar kinds of organization and connection. Some notable exceptions include the fact that the Turkish textbooks contained almost no captions; was much less likely to include unconnected, decorative photographs; routinely included very complicated hybrid graphics; typically had graphics which were more connected to the text that discussed the phenomena represented in the graphic; and introduced graphics that were designed solely as pedagogical tools (e.g., critical-thinking activity or computer-based activity). This results in an overall impression that the Turkish graphics are more pedagogically integrated, more complex, and more easily interpreted by the learner, overall showing how the GAP instrument could be used to compare textbooks across different nationalities.

The final application for the GAP instrument was a comparison of high school physics supplemental textbooks from the state of Texas (Anderson & Slough, 2012). These textbooks represent an early attempt to transition from a traditional to an electronic textbook (e-textbook). There was a great deal of variability from mostly PDF versions of a traditional textbook to one version that was closer to a piece of software or application for your smart phone. Even in this new environment, the GAP was applicable as it was able to identify that each publisher had large numbers of high-quality graphics that were generally integrated with the text in similar ways to traditional textbooks. In addition, the publisher who provided the software/application-styled version was able to provide a few new, more interactive graphical elements (e.g., animations and simulations). Interactive graphics seem especially important for science classes where concepts can often be very abstract in nature and difficult to depict in a two-dimensional illustration in a traditional textbook. The integration of animations and simulations, especially those in which the user is able to manipulate variables, could greatly impact student learning in science.

In combination, these studies have demonstrated that the GAP instrument is applicable across a range of applications, comprehensive in its treatment of both the text and the graphical elements that comprise a traditional textbook (McTigue & Slough, 2010), and flexible enough to at least introduce the discussion of more interactive graphical elements that will dominate the next generation of e-textbooks (Anderson & Slough, 2012; Slough et al., 2012). The next phase of development will be to expand the GAP instrument to include interactive graphical elements that will be certainly included in the next generation of e-textbooks for the multi-touch tablets (e.g., iPad, Kindle Fire) (Slough et al.).

Appendix

Graphical Analysis Protocol (GAP)

Working Definitions and Codes

Part I: Text (At This Point You Code at the Page Level)

Within one chapter, the text structure may show different structures and levels of interaction.

1. *Text Structure:*
   1. *L* Linear (the text moves from left to right and top to bottom)
   2. *NL* Non-Linear (the text direction is weblike or circular in organization, e.g., Space Encyclopedia)

2. *Text Reader Interaction:*
   Coded on a 1–4 scale.
   1. Informational/passive voice, transmission model.
   2. The text uses the second person (i.e., you) occasionally to sound as if it is speaking to the reader.
   3. The text encourages active reading by requesting that the participant makes predictions, have reactions, or poses questions.
   4. The text encourages the reader to actively participate (e.g., put your hand on your head).
3. *Format of the Page*
   1. *Single page*: the graphics were within the boundaries of one page.
   2. *Fol*io: the graphics spread across facing pages.
4. *Multimedia Proportion*
   (Looking at a two-page spread) the coders will determine if:
   1. Graphics > texts
   2. Graphics = text
   3. Texts > graphics

Part II: Graphics (Now You Code at the Individual Graphics)

Note About Numbering In the case of multiple graphics, each graphic will be given a page number and a letter (e.g., 4a, 4b, etc.). The numbering will start at the top left of the page and continue clockwise.

5. *Color:*

    1. COL color
    2. BW black & white

6. *Classification of Graphic*

    1. *Photograph.* (Only)
    2. *Naturalistic drawing* – All the features of the subject are depicted in detail.
    3. *Styliz*ed drawing – Graphics are delineated only with their outlines or in symbolic drawing.
    4. *Picture glossary* – Parts of the pictures are named with labels.
    5. *Scale diagram* – A scale is displayed beside the subject for indicating size, temp., distance, etc..
    6. *Flow chart* – cycle – Arrows or numbers are marked among stages in a circular process.
    7. *Flow chart* – sequence – Arrows or numbers are marked to indicate the stages in a linear process.
    8. *Cutaway/cross section* – Internal parts or process are marked with labels.
    9. *Maps* – Geographic features, like mountains or buildings, are marked to show spatial relation to others.
    10. *Tables* – Tables are composed of cells, which are the products of rows and columns.
    11. *Graphs/histograms* – Quantity information is recomposed in the format of relative graphs.
    12. *Hybrids* – Two or more graphics mentioned above are involved.

7. *Systematicity – (Consider the Words in Labels/Captions)*

    1. *Low* – the graphic depicts an isolated unit, not integrated into a larger system. For example, labels the parts of a machine but not how the parts move.
    2. *Medium* – the graphic depicts some aspect of the system. For example, there are arrows or labels that demonstrate movement, but there is not a "before" and "after."
    3. *High* – the graphic would help viewers build a mental model of a system. For example, the graphic shows three frames of a time series depicting how change occurs over time.

Part III: Integration

8. *Contiguity*

    1. *Unc*onnected
    2. *Distal* – on different pages
    3. *Facing* – on the same page spread but different pages
    4. *Direct* – the graphic and text are adjacent
    5. Pro*ximal* – on the same page

9. *Indexical Reference*

   1. Text does not reference the graphic
   2. Text references the graphics (e.g., see Figure 2.1)

10. *Captions*

    1. No captions.
    2. Caption identifies the target of the graphic but does not provide details.
    3. Caption provides a description of the graphic with details and associates the graphic to the main text.
    4. Caption actively engages viewer (e.g., asks a question, poses a task).

11. *Semantic Relations*
    How the information in the text and graphic are related:

    1. *DEC*=decorative – adds affective component, does not support text w/ meaning.
    2. *REP*=representational – directly shows what was in the text (add concreteness).
    3. *ORG*=organizational – adds coherence by putting the information within a greater scheme. (e.g., a scale diagram compares relative size).
       CONNECTION=represents the information in the text and adds new information. The reader may need to make connections to text. The reader may also need to use global information needed to make inference on how to interpret the image and link it to the text.

    4. *C-1*. An image with a score of 1 would be easy to interpret and add some additional information that would clearly link to the text.
    5. *C-2*. An image with a score of 2 would be relatively easy to interpret, but the link between the text and the new information would be less concrete. For example, the caption could use different verbiage.
    6. *C-3*. An image with a score of 3 would add new information, but the image would require background knowledge and scrutiny to derive its meaning.

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Part II
Textual and Language Analysis of Science Textbooks

Chapter 3
Understanding the Disciplines of Science: Analysing the Language of Science Textbooks

Sandy Muspratt and Peter Freebody

Introduction

Following some decades of empirical and theoretical attention on the acquisition of the generic skills of reading and writing, in particular as they are dealt with in the early years of schooling, significant interest has resurfaced in the ways in which each curriculum domain puts literacy to work in distinctive ways. Motivating this interest is a reaction to an apparent belief that explicit pedagogical work on the generic, content-free elements of reading and writing (decoding, encoding, comprehension and so on, as exemplified in the US National Reading Panel, 2000) is enough to prepare students adequately for the increasingly complex and specialised reading and writing demands of the secondary school's curriculum domains. Researchers, like teachers, have found that this belief amounts to a policy of leaving many students behind and a systematic misreading of literacy difficulties as a lack of aptitude or effort (Freebody, Chan, & Barton, in press; Moje, 2007).

It is important to recognise that extended research efforts beginning almost 40 years ago began to acknowledge the inextricable relationship between literacy capabilities and knowledge development across the curriculum domains. Awareness of the centrality of this relationship was exemplified by the creation of the US federally funded Center for the Study of Reading at the University of Illinois, which was charged with moving beyond generic literacy issues to engage with the particularities of knowledge domains in their theorisations of reading comprehension. The intervening years, however, have seen a policy- and thus funding-driven return to the more limited focus on early years' acquisition and generic notions of literacy and numeracy.

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In a range of contexts and from a range of perspectives, studies have shown the extent of curriculum-specific literacy demands and the need for systematic literacy instruction through the middle and secondary school years. Guided by developments in applied linguistics and cognitive science, Shanahan and Shanahan (2008), for example, constructed teams to explore, plan and execute curriculum-specific teaching strategies for disciplines of mathematics, chemistry and history. These teams comprised disciplinary experts (university specialists), teacher educators from each discipline, high school teachers who taught the discipline to students and literacy experts. Through these processes, the project found that the teams documented 'very different approaches to reading that drew on the ways these disciplines create, communicate, and evaluate knowledge' (p. 54) and showed how these differences could be used to plan and implement literacy teaching strategies within each of the curriculum areas.

From an ethnographic, anthropological approach, Lea and Street (2006) developed the perspective that literacy practices characterising differing academic disciplines are associated not just with institutionalised epistemologies, discourses and genres but also with different communities. The multiplicity of students' curricular experiences thus requires students to move between settings, both using appropriate literary practices in terms of styles and genres and negotiating the meanings and identities called upon in those various settings. Focusing on developing teaching staff and student interactions in two university programmes, they showed how the approach can generate deeper understandings about the knowledge-language-identity relationship and its significance for learning in academic institutions. It takes collaborative work, these researchers argued, to productively 'investigate the range of genres, mode shifts, transformations, representations, meaning-making processes and identities involved in academic learning within and across academic contexts' (p. 376). The urgency and complexity of these demands, which face students every day and often every hour, are only poorly reflected in the corpus of research on literacy education.

Christie and Derewianka (2008) (see Martin & Veel, 1998) have conducted one of the most extensive and detailed studies of reading and writing across the school years in science as part of a larger study of the textual and grammatical formations characterising the materials read and demanded of students from Kindergarten to Year 12 in science, history and English. Overall, they found evidence for a four-stage progression:

(i) Simple commonsense knowledge expressed in largely spoken language forms with simple attitudinal/evaluative expressions in the early childhood years.
(ii) Commonsense knowledge becomes elaborated as language resources expand and grammatical metaphor emerges with expanded attitudinal/evaluative expression in mid-childhood to early adolescence.
(iii) Knowledge becomes more 'uncommonsense', grammtical metaphor with expanded attitudinal/evaluative expression extended in mid-adolescence.
(iv) 'Uncommonsense' knowledge is expressed in noncongruent language, abstraction, generalisation, judgments and opinions in late adolescence.

Christie and Derewianka also concluded that a significant number of students do not maintain their writing progress across levels (ii) and (iii). This transition usually happens around the beginning of high school, at which time the need to read, interpret, use and make texts that are more specifically tailored to their content areas emerges.

The analyses reported here can be seen as part of a broader, ongoing effort to explore the details of textual formations in various discipline areas. One potential by-product of such analyses is that they provide teachers with usable information and researchers with conceptual and methodological grounds for further inquiries into curriculum-specific literacy demands, capabilities and practices.

The Study

This chapter reports on the patterns of language use in science textbooks produced for use in the early-middle secondary school years. It offers answers to three related questions:

- How do textbook authors deploy linguistic resources in representing scientific knowledge?
- Do textbook authors deploy linguistic resources differently across the disciplines of science and for younger and older readers?
- Can variation in the deployment of linguistic resources be meaningfully interpreted in terms of the processes and mechanisms for establishing reliable and valid scientific knowledge?

Five series of textbooks in use in Queensland high schools comprised the corpus. Each of the five series consisted of three separate books, one for each year level. The materials are referenced separately at the end of this chapter. These are henceforth referred to as AJ, CP, CW, SW and WW. A numeric code – 1, 2, or 3 – indicates the year level of each book. An additional numeric code indicates the chapter within each book. For instance, AJ109 refers to Chap. 9 in the first book in the *Elements of Science* series. Each chapter was coded according to the textbook series to which it belonged and the year level for which it was intended. Each chapter was also categorised according to the discipline (Biology, Geology, Chemistry or Physics) to which the topics of discussion belong. There was a fifth category, 'other', for chapters that did not fall neatly into one of the major discipline or for chapters that fell into groups too small to be categorised into a major discipline – such as chapters dealing with the solar system and measurement or chapters dealing with 'what is science' and the scientific method. Together, the texts comprising the corpus will be referred to as SC.

The analyses focus on:

- Vocabulary diversity – a set of measures that summarise the shape of the word frequency distributions
- Major structural relations – concerned with patterns of co-occurrence among those words that account for a large proportion of the running text

We employ multivariate analytic techniques that aim to reduce the dimensionality in the original data source, from a large set of variables or a large set of texts in the corpus to a more manageable and smaller set of variates. Highlighting the characteristics that are common to a given set of variables or a set of chapters can reveal the systematic variation in the ways in which the authors of the science textbooks deploy linguistic resources in representing scientific knowledge.

Vocabulary Diversity

This section is concerned with clustering the chapters of SC according to measures of vocabulary diversity. To begin, we introduce some terminology:

- Types and tokens: 'Type' refers to a type of word, for instance, the type *the*; 'Token' refers to the number of times that a type appears; for instance, the type *the* has 48,203 tokens in SC.
- N is the number of tokens, i.e. the size of the sample.
- V_N is the number of types, i.e. the size of the vocabulary in a sample of size N.
- V(i) is the number of types that occur *i* times in a sample; therefore, V(1) is the number of types that occur once only, often referred to as *hapax legomena*.

The ratio of types to tokens has been described as a measure of vocabulary diversity. It has an intuitive appeal: If the type/token ratio is large, then the larger number of types for a given sample size means the sample contains a large and thus more diverse vocabulary. However, many researchers (Chotlos, 1944; Kučera & Francis, 1967; Malvern & Richards, 2002; Richards, 1987; Tweedie & Baayen, 1997, 1998; Youmans, 1990) have cautioned against its use in comparing texts of different size because it is to some extent dependent on the sample size. This dependence has led to the development of alternatives, and while there is consensus concerning a group of measures that should not be used, there is debate concerning the appropriateness of the remaining measures. Following reviews by Tweedie and Baayen (1998) and Jarvis (2002) and Tweedie and Baayen's (1997) recommendation to employ a multivariate approach, we selected four measures:

- W: Brunet (cited in Baayen, van Halteren, & Tweedie, 1996) proposed a transformation to remove the dependence of the type/token ratio on sample size:

  $$W = N^{(V_N)^{-0.172}}$$

  It can be shown that as W increases, the type/token ratio (i.e. vocabulary diversity) decreases.
- H: Honoré (cited in Tweedie & Baayen, 1998) proposed the use of just one element from the frequency spectrum – the number of *hapax legomena*, V(1):

  $$H = \frac{100 \log N}{1 - \frac{V(1)}{V_N}}$$

H is cast in terms of the ratio of *hapax legomena* to vocabulary size, known as the growth rate. If the growth rate is large, then H is large, and vocabulary diversity tends to be large also.

- K: Yule's characteristic constant (cited in Tweedie & Baayen, 1998), a measure that uses all elements of the frequency spectrum, is given by

$$K = 10^4 \left[\sum_{i=1}^{i_{max}} V(i) \left(\frac{i}{N} \right)^2 - \frac{1}{N} \right]$$

K is a measure of the rate at which words are repeated and therefore can be considered as an inverse measure of vocabulary diversity (i.e. as K increases, vocabulary diversity decreases).

- D: Malvern and Richards' D (1997, 2002) relates type/token ratio (TTR) to sample size (N) and a parameter D:

$$TTR = \frac{2}{DN} \left[\sqrt{(1 + DN} - 1 \right]$$

It can be shown that D is in a direct relationship with the type/token ratio, and therefore, it is in a direct relationship with vocabulary diversity (i.e. as D increases, vocabulary diversity increases).

The four measures were calculated for each chapter in SC. The measures are on different scales, and so they were first standardised (i.e. each measure was rescaled to have a mean of 0 and a standard deviation of 1 across the chapters of SC). The standardised scores for K and W were reversed about zero so that large standardised scores for all diversity measures could be interpreted as indicating higher diversity.

The chapters were clustered using k-means cluster analysis. The aim of the cluster analysis was to find groups of chapters that were reasonably homogeneous with respect to their profiles across the four measures. The optimal number of groups was decided on the bases of the additional amount of variance accounted for when moving from k groups to k + 1 groups: If the increase in variance accounted for when moving between k groups to k + 1 groups is less than 0.05, then the k-group solution is taken to be optimal. That is, the more complex k + 1 group solution is not considered when it explains an additional 0.05 of the variance or less. Using this procedure, the 4-group solution, accounting for 63.8 % of the variance, was taken to be optimal. Figure 3.1 shows the standardised means for the four groups.

Groups 1 and 2 are readily interpretable. Group 1 has small standardised means for all measures and is interpreted as a low diversity group of chapters. In contrast, Group 2 has large standardised means for all measures and is interpreted as a high diversity group. Group 3 has small standardised means for H and W only. Both measures use relatively few elements of the frequency spectrum in their calculations, and H in particular is sensitive to changes at the low frequency end of the distributions. This cluster is interpreted as a group of chapters with low growth rates. Group 4 has small standardised means for D and K only. Both measures use a relatively large number of elements in their calculations, and K in particular is

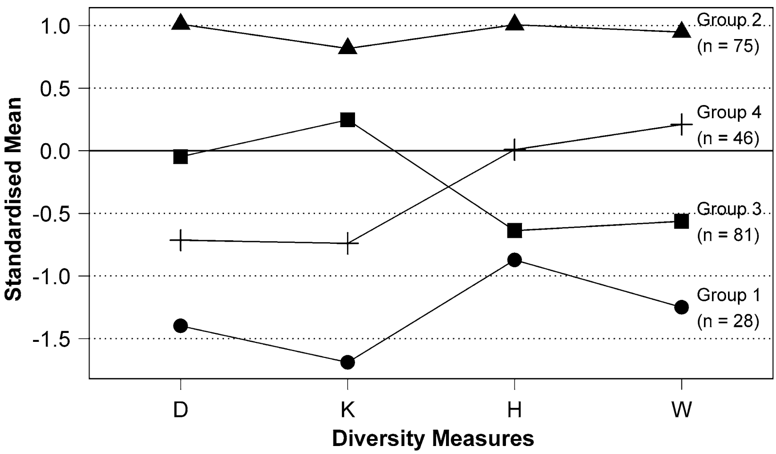

Fig. 3.1 Standardised means for the four vocabulary diversity groups

sensitive to changes at the high frequency end of the distributions. This group is interpreted as a group of chapters with high repeat rates.

Contrasting Low Diversity Chapters with High Diversity Chapters

We examined the text and word frequency lists for selected chapters drawn from across the distribution of diversities as measured by K and D in an attempt to highlight and differentiate the linguistic decisions of the textbook authors.

There are two chapters (CW112 and CP107) that deal with the geometric relationships between the sun, moon and earth. Both chapters discuss the spatial arrangements and movement of the earth relative to the sun and of the moon relative to the earth. They also discuss consequences that follow from these arrangements: night and day, length of day, seasons, phases of the moon, tides, eclipses and sundials.

Even though CW112 (containing 1,103 tokens) treats the content more economically than does CP107 (containing 3,771 tokens), they are both in the low diversity group, and their diversities do not differ markedly. The two chapters also exhibit markedly differing grammatical structures. CW112 is characterised by a sequence of simple sentences, whereas the grammatical structures in CP107 are much more complex. The similarity of their diversities despite their different grammatical structures suggests that grammatical complexity is not related in any simple or direct way to vocabulary diversity.

What is common to the two chapters is the high frequencies for the three words that signal the content of the chapters: *earth*, *moon* and *sun*. It is more usual to find function words (*the*, *of*, *and*, *is*, *in*, *to*, *a*, etc.) occupying the high frequency positions in the word lists. However, it is a feature of the low diversity group of chapters that there are content words (at least one, usually two or three, sometimes four) occupying the positions that are normally occupied by function words among the ten most frequent words. In contrast, the ten most frequent words for the high diversity chapters are all, with few exceptions, function words.

For the two chapters under consideration, the words *earth*, *moon* and *sun* provide links across the different concepts. Even though the concepts themselves are varied, they all depend on particular geometrical configurations for sun, moon and earth. The relative frequencies for the usual set of function words are not substantially reduced; rather, the three words *earth*, *moon* and *sun* are additional high frequency words. As a consequence, there is an even greater reliance on a small set of common words, resulting in lower diversity.

This demonstrates one way in which the structure of a chapter, rather than size or grammatical complexity, can result in low diversity. This structure is contrasted with the structures of another sequence of chapters whose diversity measures do vary. There are three chapters, taken from different year levels, that take simple machines as their content. One of these (CP119) is in the low diversity group. The chapter opens with a discussion of the concepts load and effort and how these are used to understand and calculate force advantage. This is followed by discussions of a number of simple machines (lever, pulley, wheel and axle, inclined plane and screw), and the chapter concludes with a discussion of efficiency. Each of these discussions draws on the concepts developed at the opening of the chapter (load, effort and force advantage). This set of words along with *machine* appears among the high frequency words. That is, among the high frequency words are content words that provide the links across the different sections of the chapter.

In another example (AJ304), a larger variety of machines is discussed, including hydraulic systems, and the discussion moves beyond machines to discuss stability, structures and beams. The sections dealing with simple machines are linked through the concepts of effort, load and force advantage, but the additional devices are not linked to these concepts. Instead, they depend on a different vocabulary and are presented in terms of pressure, centre of gravity and compression.

In yet another example (WW209), the authors present a discussion of simple machines in a similar way to that presented in CP119 and AJ304 (i.e. load, effort and force advantage provide the links among the versions of simple machines), but the authors embedded their discussion in a chapter that deals with force, work, energy and power.

The diversity measures for WW209 and AJ304 indicate that their vocabularies are more diverse than the vocabulary for CP119. AJ304 and WW209 are contained in the low growth rate and the high repeat rate groups respectively; both are low diversity groups but not as low as the low diversity group. There is greater opportunity in both WW209 and AJ304 for rarer words to be introduced because both chapters cover a larger range of topics. Also there is no central organising principle flowing through the chapters. AJ304 and WW209 do not contain the set of high frequency content words that are contained in CP119. The combination of these effects means that there is less repetition, and hence, vocabulary diversity increases.

These three chapters highlight one way in which the structuring of concepts in a chapter can affect vocabulary diversity. The three chapters contain a common set of concepts, but WW209 and AJ304 contain additional concepts. WW209 and AJ304 are longer than CP119, and the additional tokens are required to discuss the additional concepts. The diversity measures for WW209 and AJ304 indicate more diverse vocabularies than that contained in CP119. But it is not the case that higher diversities are a direct consequence of larger sample sizes. Rather, higher diversities are a consequence of the additional vocabularies required to present the additional concepts contained in WW209 and AJ304.

However, it is not always the case that greater diversity and variation in subject matter goes hand in hand with larger sample sizes. This can be demonstrated with another sequence of chapters dealing with matter. Each chapter presents a discussion of the states of matter, particle theory, how the particle theory explains properties of the states of matter and changing states of matter. For two of these chapters (CW102 and CP105), that set of concepts forms the content of the topic, and the diversity measures for these two chapters are low. A third chapter (AJ201), in addition to these concepts, presents a more elaborate version of the particle theory (kinetic theory) and, among properties, discusses density. The diversity measures for AJ201 are roughly at the medians. A fourth chapter (WW106) also presents the standard set of concepts but begins the discussion with a long introduction concerning different sorts of matter and how and why they are used. Also, among properties, this chapter presents discussions of density and solubility. Diversity measures for WW106 put it among chapters with the most diverse vocabularies.

With respect to the chapters dealing with simple machines, the size of the chapter increases with the number of concepts contained in the chapter. In contrast, the chapters dealing with matter do not follow this pattern. WW106, a high diversity chapter, is the second smallest in the sequence. That is, it is not always the case that additional concepts require a longer text. What is common to the two sets of examples is that vocabulary diversity increases with number of concepts.

Among high diversity chapters, there is a sequence that deals with environmental issues. Two of these chapters (AJ315 and AJ314) are at the upper end of the diversity spectrum. Both chapters treat environmental issues as a series of case studies, which depend on knowledge from a range of disciplines. Hence, there is no common group of words linking the case studies, and there is more opportunity within each case study for rarer words to be introduced that are not used in subsequent case studies. The result is that there is less repetition, and so vocabulary diversities are high. Other chapters dealing with environmental issues (WW311, CP312, CW312) treat the content in a similar way, and all five are in the high diversity group.

The high diversity chapters dealing with environmental issues were all classified as belonging to the discipline of Biology. But there are other chapters from a range of disciplines that also treat their content as a series of case studies: AJ308 (*Economic Geology*) presents case studies on particular mining ventures in Australia and SW313 (*Energy Alternatives*) and CW311 (*Energy in the Future*) present case studies describing energy alternatives. These chapters are all from the third book in each series, but high diversity chapters are also found in books intended for younger readers. For instance, WW111 is the second most diverse chapter in SC. Its title is *Food and Nutrition*, and in separate sections it deals with the major food groups and vitamins and minerals, as well as containing sections dealing with diet and storing and preparing food. As with the previous sequence of chapters, there is no common group of words to provide the links across the different sections in these chapters, and hence, vocabulary diversity increases.

The examples chosen for discussion in this section show the following:

- If texts deal with content by invoking the same or similar sets of concepts, then, irrespective of their length, their vocabulary diversities tend to be roughly equivalent.
- If texts deal with content by invoking additional concepts, then, irrespective of whether or not the additional concepts lead to longer texts, vocabulary diversities tend to increase.

These generalisations, though based on a small number of examples, can account for differences in average diversities among the textbook series. Chapters in the WW series tend to congregate in the high diversity group. Also, the WW series contain fewer but longer chapters. Assuming that all series cover roughly similar content, it follows that each WW chapter includes, on average, a broader range of concepts. If the argument holds that a broader range of concepts leads to increased vocabulary diversity, then it is the broader range of concepts contained in the WW chapters that contributes to their higher vocabulary diversities.

However, it is not likely that this explanation can account for the diversities among the disciplines. The discussion of the sequence of chapters dealing with simple machines showed that vocabulary diversity increased with an increasing range of concepts, but it is also noted that all chapters in this sequence are among low diversity chapters. This sequence of chapters belongs to the discipline of Physics, and as will be shown later, Physics chapters tend to belong to lower diversity groups. That is, even in those Physics chapters that include a larger range of concepts, there appears to be a counteracting influence that standardises and stabilises the vocabulary.

Major Structural Relations

This section is concerned with clustering the chapters of SC according to the frequencies of occurrence, adjusted to take account of the varying lengths of the chapters, for a small set of high frequency function words (see Table 3.1 below for a list drawn from SC). The patterns of co-occurrence of these words should highlight the major structural relationships among entities and processes. The analysis draws on authorship attribution studies (Baayen et al., 1996; Tweedie, Holmes, & Corns, 1998), which show how extended pieces of text can be distinguished on the basis of authors' preferences for high frequency function words. But unlike authorship attribution studies, where interest lies at the level of distinguishing the tests,

Table 3.1 Fifty most common function words (in order of frequency of occurrence in SC)

1. the	11. as	21. they	31. some	41. used
2. of	12. this	22. have	32. one	42. their
3. a	13. be	23. with	33. will	43. more
4. and	14. you	24. which	34. called	44. also
5. is	15. can	25. an	35. other	45. many
6. to	16. for	26. these	36. if	46. your
7. in	17. from	27. at	37. has	47. its
8. are	18. or	28. not	38. into	48. about
9. that	19. by	29. when	39. all	49. very
10. it	20. on	30. we	40. there	50. than

our study is in addition concerned with interpretation of the resulting dimensions and thus with highlighting the structural relations operating in SC.

The analysis proceeds in two stages. First, a dimension reduction procedure is applied to reduce the number of dimension from 50 (the number of function words in the analysis) to a more manageable set of underlying dimensions. We used Revelle's (1982) item clustering procedure, ICLUST. Revelle (1978) claimed that item cluster analysis is an appropriate alternative to the more common factor analysis when the number of items is large, when the correlations among the item are small or when sample sizes are small, characteristics of our data. ICLUST outputs include measures of reliability (Cronbach's α and β, an estimate of worst-case split-half reliability) so that psychometric principles can be used to determine whether or not clusters should be split. In general, α should be larger than 0.6, β should be larger than 0.5 and the difference between α and β should not be larger than 0.1; otherwise, the cluster contains at least two independent subsets of words.

For the second stage of the analysis, chapters' scores on each dimension were submitted to k-means cluster analyses, the same procedure that was applied to the diversity measures. The purpose again is to obtain homogeneous group of chapters with respect to their profiles across the dimensions.

Table 3.1 gives the 50 most frequent function words in SC. The word *your* was initially included in the list, but for more than half the chapters, its frequency was zero, and therefore, it was discarded. Table 3.1 contains the words *called* and *used*. They would not normally be categorised as function words, but their frequencies were large across all components, and therefore, they were included to determine whether or not they co-occur in meaningful ways with the more conventional function words.

Many of the function words have multiple functions, and they do not necessarily appear in each others' environments. The interpretations that follow result from an attempt to answer the question: What underlying dimensions could result in the co-occurrence patterns? Given the multifunctionality of the words, interpretation arose from an examination of the sets of words that comprise the clusters and groups and of the ways in which words are used in chapters that are typical of a given clustering or grouping pattern. The following sections present interpretations for, first, the clustering patterns and then for the grouping patterns.

Table 3.2 Clusters of high frequency function words

Cluster 1	Cluster 2	Cluster 3	Cluster 4
Partitioned entities vs generalised entities	Elaboration vs definition	Rules vs approximations	Application of entities vs existence of entities
$\alpha=0.82$, $\beta=0.74$	$\alpha=0.74$, $\beta=0.71$	$\alpha=0.64$, $\beta=0.56$	$\alpha=0.61$, $\beta=0.57$
Are	Their	A	Used
Many	And	An	By
Some	Which	Will	As
They		If	
These	- Is	Or	- There
Have	- It		
All		- About	
- The			

Patterns of Co-occurrence

ICLUST produced a 7-cluster solution, but Cronbach's reliability indicated that some clusters were not reliable, and the worst-case split-half reliability indicated that some clusters consisted of independent subsets. After discarding unreliable clusters and splitting independent subsets, a 4-cluster solution was obtained. Table 3.2 shows the words in each cluster, the α and β measures of reliability and a label. The labels for each dimension refer to two ends of a dimension. For instance, the underlying dimension for cluster 1 has a 'Partitioned entities' end and a 'Generalised entities' end. The words at the lower ends of a dimensions are distinguished from words at the upper end by using a – sign. The words at each end of a dimension work in opposite directions: high frequencies for words at the 'Partitioned Entities' end go with low frequencies for the word at the 'Generalised entities' end and vice versa.

Chapters' cluster scores were obtained by applying unit weights to the transformed frequencies for each word in each cluster and then calculating the mean of the transformed frequencies. Transformed frequencies for words at the lower end of each dimension were first inverted about their means. Thus, a chapter with a large cluster score generally contains higher frequencies for the words at the upper end of the dimension and lower frequencies for the words at the lower end of the dimension and vice versa.

Cluster 1

Word at the upper end of this dimension (*many*, *some*, *they*, *these*, *all*, *are*, *have*) usually make reference to entities or groups of entities. Some examples, taken from a chapter (WW104) that introduces readers to classification, are the following: *<u>all</u> living things move*; *<u>some</u> non-living things do not …*; *there are <u>many</u> further divisions within each group*; *you will study <u>some</u> of <u>these</u> …*; *<u>they</u> don't <u>all</u> do <u>these</u>*

things. The chapter distinguishes between living and nonliving things and between plants and animals and presents characteristics of the entities that fall into these categories. Other chapters with high scores on this dimension deal with the classification of various types of entities: animals with backbones, plants, types of cells, types of chemicals and types of fossils. As well as classifying concrete entities, there are chapters that deal with the classification of more abstract entities such as physical and chemical change, types of geological processes and steps in the scientific method. A common feature of all of these chapters is that they present an entity for the purpose of discussing ways in which that entity can be partitioned and of presenting characteristics of examples that fall into the partitioned entities. The words *are* and *have*, whether they are used as the main verb in a clause or as an auxiliary to a main verb, indicate plurality. They are contained in this cluster because the only way to refer to groups of entities is in their plural form.

The partitioning end of this cluster is contrasted with one word, *the*. If *the* was in contrast to the indefinite articles (*a* or *an*), then the cluster might have something to do with the topic-driven nature of the discourse. That is, the indefinite article (*a* or *an*) introduces an entity to the discourse, but subsequent mentions of the entity use the definite article (*the*), and so high frequencies for *the* would indicate fewer changes in topic. However, for chapters with low scores on this cluster (high frequencies for *the*), there are frequent changes in topic, and also, the indefinite articles (*a* and *an*) are located in a different cluster. The following example, typical of chapters that have low scores on this cluster, affords an alternative interpretation:

> Blood from <u>the</u> body enters <u>the</u> atria as they relax. <u>The</u> atria then contract, pumping blood down into <u>the</u> ventricles. Next <u>the</u> ventricles contract to pump blood out of <u>the</u> heart. Heart valves, between atrium and ventricle on each side, prevent <u>the</u> blood from flowing back into <u>the</u> atria when <u>the</u> ventricles contract. (CP310)

In the example, *the* precedes an entity that has to be interpreted as representing all instances of the entity. That is, *the* precedes a generalised entity. Therefore, cluster 1 is characterised as 'Partitioned entities versus generalised entities'.

Cluster 2

Three words, *their*, *and* and *which*, are located at the upper end of the dimension. The word *which* is used as the head of a nonrestrictive relative or 'adjectival' clause which provides additional information about a noun (e.g. *Under the leaves are tiny holes called stomata, <u>which</u> allow the plant to absorb carbon dioxide*). At times, *which* is used as the head of a restrictive or defining relative clause, and so the clause should not, strictly speaking, be interpreted as providing additional information. However, many of the defining clauses can be interpreted as providing a reminder or alerting readers to information presented earlier, for example:

> Thousands of spores are released from the mature spore plant and those spores <u>which</u> land on suitable ground may germinate.

A reader should already know that spores that do not land on suitable ground will not germinate. If it is important for the reader to distinguish between defining clauses and clauses that provide additional information, the authors usually do not leave it to chance that readers will distinguish between the two. If there is a need to restrict the range of entities, they generally use other structures to define the restriction.

The word *and* is a coordinating conjunction linking clauses, nouns, verbs and adjectives. Often, the element following *and* can be interpreted as providing additional information about a noun. In the example below, *and* provides additional information about water:

> Water is absorbed through the roots <u>and</u> is carried to the stems and leaves by tubes called xylem tubes.

The possessive pronoun *their* can be interpreted in a similar way. The first reference to an entity generally needs the noun. Subsequent reference, often appearing in grammatical structures that provide the additional information, needs only the pronoun (e.g. *Scientists use very specialised equipment or apparatus to conduct <u>their</u> experiments and to collect <u>their</u> data*). The three words at this end of the dimension are part of or are entailed in structures that elaborate on an entity introduced earlier to the discourse.

The words *it* and *is* appear at the other end of the dimension. The word *is* as the main verb in a clause and the combination *it is* signal defining relationships (e.g. *Kinetic energy <u>is</u> energy of motion*; *in glass, <u>it is</u> only 200,000 km/s*). Even when *is* is an auxiliary to the main verb, it is used to signify the present passive form of the verb (*Work <u>is measured</u> in units called joules*). In written text, the present tense has to be interpreted as denoting applicability at all times, that is, as the timeless present. If the statement is to be applicable at all times, then there is a defining element about it. Therefore, cluster 2 is characterised as 'Elaboration versus definition'.

Cluster 3

The co-occurrence of the five words at the upper end of this dimension, *a*, *an*, *will*, *if* and *or*, can be interpreted as indicating general rules. Mostly, *if* appears at the head of a conditional clause which indicates the general conditions under which the rule applies (e.g. *<u>If</u> over a period of years no test or experimental result disproves a hypothesis, it is called a theory*). The necessity modal, *will*, signals the necessity of an action (e.g. *A machine with a force advantage <u>will</u> move a large load much less distance than the effort moves*). Often, the necessity of an action is linked to the condition of a preceding action (e.g. *<u>If</u> a galena specimen is struck with a hammer, it <u>will</u> break to give cubes).*

The articles *a* and *an* refer to entities in an indefinite way. A statement that entails the entity has to be interpreted as being applicable to any instance of the entity. For instance, the statement, *<u>A</u> compound contains more than one type of element*, is applicable not to one particular compound but to all compounds. In chapters that receive high scores on this cluster, there are many of these rule-like statements. For example, in a chapter dealing with simple machines, the following are found: *A machine is a device which transfers …*; *A machine with a force advantage will move ….*

The word *or* is a coordinating conjunction linking nouns, verbs, adjectives, adverbs and clauses and offers the list of elements as alternatives. In chapters with high scores on this cluster, *or* links two or three elements, but there are two senses in which the two elements can be read as alternatives. First, the statement is applicable to two or three entities belonging to the same class of entity (e.g. *Compounds may be broken down by chemical* *or* *physical means*). Here, *or* can be interpreted as establishing a rule that is applicable to a number of entities. Second, and used less frequently, *or* separates alternative names for the same entity, but it is usually the case that one name is the preferred or scientific name (e.g. *Magma* *or* *molten rock forms when rock …*).

The other end of this dimension contains just one word, *about*. Of the two main meanings for *about*: concerning (*… to know something* *about* *all living things…*) and approximation (*It is* *about* *8 km thick under the oceans …*), most of the chapters with low scores on this cluster (high frequencies for *about*) use the approximation sense. Therefore, cluster 3 is characterised as ‘Rules versus approximation’.

Cluster 4

After reading chapters that receive high scores for this cluster, the three words at the upper end of the dimension, *used*, *by* and *as*, signify a number of relationships, including the following: in the capacity or manner of, how things are *used*, what things are like, specific instances of things and time functions. The word *used* is usually part of a passive voice structure indicating the manner, under what circumstances and how entities are used (e.g. *Solar panels are* *used* *to produce electricity and recharge batteries* *used* *on satellites*). The word *by* indicates primarily the method for performing an action (e.g. *Oxygen is made industrially* by *separating it from the air* *by* *fractional distillation*) or the agent of an action in passive voice structures (e.g. *Convection currents are movements in a liquid or gas caused* *by* *temperature differences*). The word *as* has many functions, but in the chapters with high scores on this cluster, there are four main functions: First, *as* indicates the role of an entity (e.g. *The wheel and axle can act* *as* *either a speed or a force multiplier*); second, *as* is used as the head word of a time clause (e.g. *As* *hydrogen bubbles are produced by the chemical reaction, they are converted to …*); third, *as* is used as the head word of a reason clause (e.g. *Nitrogen is important to living things* *as* *it is two important parts of proteins*); and fourth, *as* indicates examples of entities (e.g. *It is used in many everyday products such* *as* *soft drink cans and in alfoil wrappings*). Chapters with high scores on this cluster deal with applications of entities in one of two ways. First, they deal with multiple applications of a single entity. For instance, a chapter that takes oxygen as its subject discusses the extraction of oxygen, where and under what conditions oxygen is used and industrial applications. Second, they deal with the applications of multiple entities. For instance, a chapter that takes organic chemistry as its subject discusses, in addition to the chemistry of organic compounds, the applications for an array of organic compounds. This end of the cluster is interpreted as presenting the applications of entities.

At the other end of the dimension, the interpretation is clearer. Mostly, *there* is used as existential *there* (e.g. *There* *are two types of charge*; *there* *are two types of*

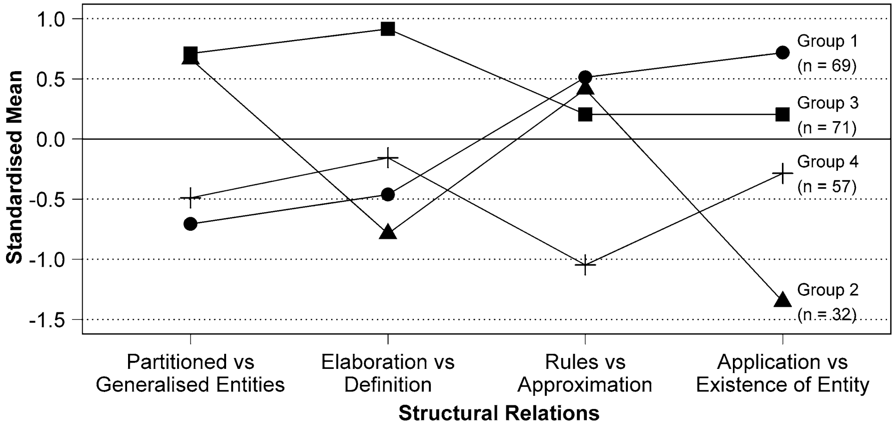

Fig. 3.2 Standardised means for four groups of chapters derived from four clusters of high frequency function words

white blood cell). This end of the dimension is interpreted as stating the existence of an entity. Therefore, cluster 4 is characterised as 'Application of entities versus existence of entities'.

In summary, on the basis of the frequencies of occurrence of the most frequent function words, four clusters, comprising 23 words out of the original set of 49, were identified. The four clusters represent four distinct underlying dimensions of variation among the chapters that comprise SC.

Grouping the Chapters

For the second stage of the analysis, standardised cluster scores were submitted to a series of k-means cluster analyses. As before, all solutions from the 2-group through to the 8-group solution were requested, and the optimal number of groups was decided on the basis of the additional amount of variance accounted for. The 5-group solution was taken to be optimal, accounting for 48.1 % of the variance. The solution produced a singleton. Chapter CW107, with a very large positive score for the 'Partitioned entities versus generalised entities' dimension and a large negative score for the 'Application of entities versus existence of entities' dimension, is the shortest chapter in SC (184 tokens). The chapter is taken to be an outlier and is not discussed further. Figure 3.2 shows the profiles of the other four groups across the four dimensions.

Group 1

This group tends to be at the generalised entity end of dimension 1 and at the definition end of dimension 2. Also, this group tends to be at the rules end of dimension 3 and at the application end of dimension 4.

This group uses rules to establish boundaries among alternatives. There are two ways in which a discussion of alternatives proceeds. First, the more common way is to present a range of alternatives all of which are considered as instances of a generalised instance. Close to the centre of this group are two Physics chapters (AJ206 & WW305) in which the alternatives electricity and magnetism, alternating and direct current and parallel and series circuits are part of a unified system.

The following examples taken from AJ206 show how conditional *if* clauses are used at various points throughout the chapter:

> If the circuit is broken on one of the pathways, then the others are not affected.
>
> If a north pole is placed near a south pole, then they are pulled towards each other.
>
> If a constant DC current is fed in, nothing happens. Only if the current is somehow turned on and off will the induction coil produce a spark.

The rules serve not only the purpose of categorising (for instance, circuits as series or parallel or magnetic forces as attractive or repulsive) but also the purpose of establishing the arrangements for or the uses of components within one of the alternatives. Examples of other chapters that treat their content in a similar way include SW309 which discusses the way in which lenses and mirrors and reflection and refraction are part of a unified optics system and CP317 which discusses the way in which conduction, convection and radiation are part of a unified system of heat transfer.

Second, a small number of chapters present alternatives, but only one of which can be considered viable or correct. Given the alternatives, the authors establish the preferred alternative by contrasting, comparing or stating the manner for the arrangement for or uses of entities. These chapters seem to be dealing with establishing appropriate ways of thinking about a concept. For instance, a chapter that takes the scientific method as its subject establishes a unique status for science by eliminating other systems of knowledge from the category scientific. Thus, Group 1 chapters are characterised as 'establish correct procedures and arrangements'.

Group 2

This group tends to be at the partitioned entities end of dimension 1 and at the rules end of dimension 3. Also, this group tends to be at the definition end of dimension 2 and at the existence of entities end of dimension 4.

These chapters seem to be dealing with the classification of entities. Typically, they deal with a number of entities and establish the existence of categories by defining the rules to be applied when determining how entities and processes are categorised. For instance, a chapter (AJ305) establishes the following classification with respect to chemical substances:

> Pure substances that can be broken down by chemical reactions are called compounds. Other pure substances that cannot be chemically broken down are called elements. Elements can be classified as either metals or non-metals. … these [compounds] can be easily classified into groups if they are dissolved in water. Soluble compounds form acidic, basic or neutral solutions … some are composed only of atoms of non-metals. These are called covalent compounds. Other compounds are composed of both metal and non-metal atoms. These are called ionic compounds.

Chapters often state the existence of a class of entities, and typically, existential *there* establishes the class of entities, as demonstrated by the following examples:

> There are millions of compounds around us.
>
> There are many possible things that can change.
>
> There are now known to be over a hundred of these subatomic particles.

The class of entities is then divided into a number of categories, and typically the boundaries between the categories are established by the use of conditional *if* clauses, as demonstrated by these examples:

> If an atom loses an electron or two, it has excess positive charge. Hence, it becomes a positive ion. If it gains an electron or two, it becomes a negative ion.
>
> If a large body of magma cools to a solid mass, it is called a pluton (if less than about 30 km diameter). If many of these gather together into a huge body, we call it a batholith.

These chapters are concerned with classes of entities that are categorised according to stated rules and the explicit naming of the categories. Group 2 chapters are characterised as 'establish classification'.

Group 3

This group tends to be at the partitioned entities end of dimension 1 and at the elaboration end of dimension 2. This group deals with the characteristics of entities that fall into categories of a given classification scheme. Among these chapters, there seems to be little need to establish a classification system or to justify the positioning of entities into a category. These are taken as given. Rather, entities are classified so that the discourse can elaborate on the characteristics of entities belonging to given categories. Most of the chapters that deal with the biological classification of living things are members of this group. The classification of living things is intuitive in that there are obvious differences between, say, a mammal and a fish. The categories mammal and fish are taken as being already established, and the discourse highlights the commonalities among members of each category.

A number of chapters dealing with processes appear in this group. Processes can be classified in two ways. First, a process can be broken down to a number of smaller steps; and second, the same general process can be achieved by a number of means. A chapter dealing with plant reproduction (AJ209) illustrates both. The process of plant reproduction is broken down into a number of steps: pollination, fertilisation, maturation of seeds, seed dispersal, germination and plant growth. The chapter provides a description of each process and of the parts of the plant that are the sites for these processes. Two of these processes, pollination and seed dispersal, are general processes which are classified according to how they are carried out. For example, pollination is described as being achieved by means of insect pollination or by means of wind pollination, and the chapter describes the anatomical structures of plants that undergo pollination by either of these means.

There is a large number of chapters dealing with other biological themes that are close to the centre of this group, including WW111 and SW113 dealing with food types, WW210 and WW208 dealing with systems in the human body and SW304 and CW319 dealing with diseases. Chapters from other discipline areas, however, are also close to the group centre: WW302 dealing with erosion; WW110 dealing with elements, compounds and mixtures; and CP208 and WW108 dealing with fossils. Group 3 chapters are characterised as 'elaborate on classified entities'.

Group 4

This group tends to be at the generalised entities end of dimension 1 and at the approximation end of dimension 3. These chapters deal with a range of content including the solar system (AJ112, CP218, WW203), the night sky (AJ111), internal structure of the earth (CW314) and renewable and nonrenewable resources (SW312). A point of connection among these chapters is that the phenomena under discussion are positioned on a spatial, temporal or numeric scale, but it is not necessary to know the exact position on a scale in order to know the phenomena:

> About 530 million years ago, lava poured out of very large fissures … Initially the lava covered an area of about 300 000 km^2. Erosion has reduced it to about 35 000 km^2.

Many of the chapters in this group make reference to concrete entities. For instance, a chapter that takes objects in the solar system as its topic (CP218) makes repeated reference to *the sun*, *the moon* and *the earth* when describing each. It also provides descriptive accounts of a number of exploration missions, and so there is reference to *the Apollo missions*, *the Mariner Mission* and *the Voyager missions*. The chapter contains a large number of measurements, but most are approximations concerning counts (*It contains about 100 billion stars*), distances (*The average distance is about 150 million kilometres*), temperatures (*The temperature of this region is about 6,000 °C*), angles (*Pluto's orbit lies at about 17° to this plane*), proportions (*The force of gravity on the moon is about one-sixth that on Earth*) and times (*It will take about another 400,000 years to pass near another star*).

The quantitative details are there to provide a context and are part of the descriptive accounts. There is generally no explicit categorising of entities. Instead, the discourse presents descriptions of entities that are only loosely connected. Examples of chapters that present their content in this way include CP320 and AJ308 which present accounts of various mining ventures in Australia and AJ310, CP202 and CP310 which present the functions and arrangements for the parts of the human reproduction system, the digestive system and the circulatory system. Group 4 chapters are characterised as 'provide descriptive accounts'.

In summary, it was possible to reduce the 230 chapters to four homogeneous groups of chapters (and a singleton) according to their profiles across the four underlying dimensions. The analysis produces two groups of chapters that tend to deal with classification: one where the classification scheme might be less familiar or less obvious to a reader with the result that the discourse establishes a classification scheme and one where the classification scheme is likely to be more obvious or more familiar to a reader, and so there is less need to establish a scheme and instead the discourse presents characteristics of entities that fall into the various categories of the scheme. The analysis also produces a group of chapters where the discourse establishes correct processes, procedures, uses and arrangements for entities and concepts that tend to be part of a unified system and a group of chapters where the discourse provides descriptive accounts of groups of loosely connected entities.

Contrasting Classification Systems

The four groupings of chapters obtained above can be discussed in terms of the level of sophistication they employ in the deployment and explication of relationships among the entities that are the topics of their chapters.

Beginning with the least sophisticated, Group 4 chapters (provide descriptive accounts) do not deal with a structuring of entities beyond a rudimentary level of providing labels for the entities. For some chapters, a scientific structuring of entities might not be readily available; for instance, two chapters (CP320 and AJ308) present descriptive accounts of various mining ventures in Australia: what is mined, output of the mine, estimates of reserves, location of the mine and so forth. However, other Group 4 chapters ignore available scientific taxonomies. For example, a number of chapters dealing with the solar system are members of this group. They provide descriptive accounts of the planets, moons, asteroids, comets, meteors and sun in terms of compositions, atmospheres, daytime and night-time temperatures, oddities and so forth. Two of the chapters structure the objects of the solar system in terms of the order in which they would encounter if one took an imaginary journey. However, such a structuring means that scientific principles and relationships, such as the distinctions between planets and moons, jovian and terrestrial planets, and planets, asteroids and comets, are not considered.

Group 3 chapters (elaborate on classified entities) are similar to Group 4 in that they provide descriptive accounts of entities, but they differ from Group 4 in that entities are explicitly classified. However, the resulting taxonomies tend to be simple in that they display little internal structure and typically do not proceed beyond one or two levels. Also, the rules for determining the development of the taxonomy and the positioning of entities into classes are generally not explained other than the positioning of entities according to detailed descriptive accounts. A large number of chapters (AJ104, AJ105, CP104, CP111, CP116, SW111 and WW204) that take classification of living things as their topic are members of this group. They generally take a class of entities (for instance, the vertebrates or invertebrates or plants) and present descriptive accounts of the classes of entities at the next level. They provide few guidelines for determining how the taxonomy might fit into a more complete taxonomy or for determining the relationships among the classified entities. Whether they are dealing with foods, diseases, rocks, minerals, cells or steps in the scientific method, they typically name of the subordinate categories, but their content is generally descriptive.

Group 1 and 2 chapters present more sophisticated taxonomies in that they provide the decision making rules for positioning entities at various levels in the taxonomy. For instance, a chapter (AJ305) that takes elements and compounds as its topic shows how to distinguish between compounds and elements according to whether or not chemical substances can be chemically broken down or how to distinguish between covalent and ionic compounds according to whether or not compounds contain metal atoms. Another set of chapters dealing with simple machines show how to distinguish between first order, second order and third order levers according to the positions of the fulcrum, load and effort. That is, a common characteristic of Group 1 and 2 chapters is that they contain explicit statements of the relationships between the superordinate category (e.g. lever) and the subordinate categories (e.g. first, second and third order levers).

The chapters dealing with simple machines, however, are Group 1 chapters, and they take the development of taxonomies to another level. In addition to the explication of the relationships between superordinate and subordinate categories, Group 1 chapters deploy additional and often abstract entities that serve to explicate the relationships among the subordinate categories. For instance, CP119, dealing with simple machines, discusses how the pulley is like a lever but also how it is different from the lever. In this way, Group 1 chapters present a more systematic treatment of their content in the sense that the content is organised around a small number of generative ideas. It was shown earlier that load, effort and force advantage were invoked for each class of simple machine. They are the generative ideas that organise the content of these chapters. The machines themselves serve as practical examples for the different arrangements of load, effort and force advantage; and further, load, effort and force advantage serve to establish and maintain an order on a potentially vast array of practical examples of simple machines. Potentially, the generative ideas can be used to categorise almost any simple machine into the taxonomy. However, no such generative ideas are provided in most of the chapters dealing with the classification of living things.

Associations Among the Groupings

One way of investigating the associations among the *a priori* groupings of year level and discipline and the empirical groupings of vocabulary diversity and high frequency function words is via a series of crosstabulations. However, that would entail five crosstabulations, making interpretation of the associations across the crosstabulations difficult. Instead, we take a multivariate approach. The multivariate associations among the groupings were explored using a homogeneity analysis (in particular, the homals procedure in SPSS). The procedure plots variables' categories in a low dimensional space (here, a two-dimensional space) so that categories that are associated with each other are plotted close together. In this way the associations can be explored simultaneously.

In an initial homogeneity analysis with all the groupings (year level, discipline, vocabulary diversity groups and high frequency function word), year level was poorly discriminated in both dimensions (first dimension, 0.018; second dimension, 0.017), and so year level was dropped from the analysis.

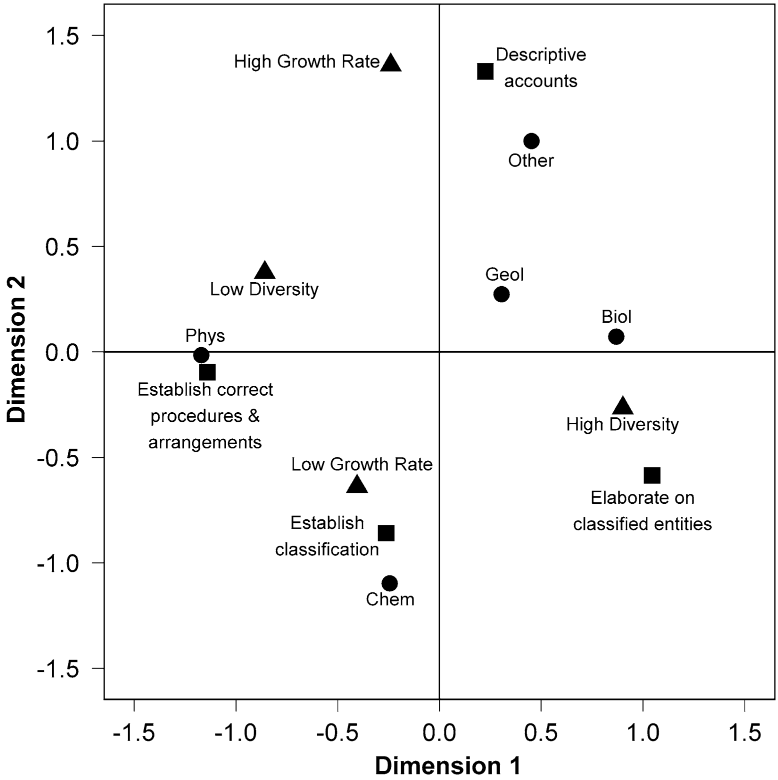

Fig. 3.3 Category quantifications for discipline, vocabulary diversity, and high frequency function word groups

A second homogeneity analysis was performed on the remaining groupings. The discrimination measures suggest that the categories for high frequency function word groups (first dimension, 0.75; second dimension, 0.65) were well discriminated in both dimensions, and the categories for vocabulary diversity groups (first dimension, 0.43; second dimension, 0.55) are moderately well discriminated on both dimensions. Categories for discipline (first dimension, 0.64; second dimension, 0.35) are discriminated better on the first dimension than on the second dimension. Figure 3.3 shows the category quantifications for the two-dimensional solution.

Dimension 1 in Fig. 3.3 shows a contrast between a set of low diversity chapters associated with the discipline of Physics and high diversity chapters associated with the discipline of Biology. Geology chapters tend to be located part way between the two extremes though more closely aligned with Biology and high diversity than the other extreme. On considering the high frequency function words groups, the figure shows the group displaying a sophisticated development of taxonomies, establish correct procedures and arrangements, and is located to the left (along with Physics and low diversity chapters), and the group displaying a somewhat less sophisticated development of taxonomies, elaborate on classified entities, is located to the right (along with Biology and high diversity chapters).

Dimension 2 separates the high repeat rate group from the low growth rate group. These are both low diversity groups, but the measures that determine these groupings are sensitive to changes in diversity at opposite ends of the word frequency distribution: The measures for the high repeat rate group are sensitive to changes at the high frequency end, while the measures for the low growth rate group are sensitive to changes at the low frequency end. Therefore, dimension 2 appears to be separating low function word diversity from low content word diversity. In addition, dimension 2 separates chapters that deal with unclassified or unclassifiable entities (provide descriptive accounts) at the upper end from chapters dealing with establishing classification schemes (establish classification) at the lower end. There is also the suggestion that dimension 2 separates Chemistry chapters from the chapters that fall into the ‘Other’ category. However, the discrimination for discipline is not strong along the second dimension, and so the indication is that there is some association but not a strong association for Chemistry and ‘Other’ chapters with the low growth rate and high repeat rate groups and with the establish classification and provide descriptive accounts groups.

These alignments can also be represented as in Fig. 3.4, showing a progression from the bottom to the top of the figure in terms of the level of sophistication in the development of taxonomies. Also shown in the figure are descriptors drawn from the discussion presented here (no taxonomic organisation versus organised taxonomies and no underlying concepts versus underlying concepts) and also descriptors drawn from Toulmin’s (1972), Schwab’s (1978) and Hempel’s (1965) considerations of the development of the disciplines.

Toulmin (1972) argued that disciplines can be distinguished along an axis differentiating between diffuse and compact disciplines. He described a compact discipline as one whose activities are directed towards a common and agreed set of standards that govern the criteria of adequacy for judging what constitute valid observations, interpretations, hypotheses and theories. When a discipline has developed these standards, researchers place increasing emphasis on the attainment of comprehensive accounts of, and generalised and theoretical explanations for, empirical observations. Diffuse disciplines lack these standards. They collect empirical findings but are more concerned with describing phenomena and developing simple empirical generalisations.

In a similar vein, Schwab (1978), discussing the structure of disciplinary knowledge, argued that knowledge is roughly of two kinds: ad hoc and systematic. He explained that ad hoc knowledge arises ‘as lore, as a collection of know-hows, as ad hoc solutions to problems which life with its wants and needs poses’ (p. 264). Ad hoc knowledge is practical and commonsense and serves an immediate need. In contrast, systematic knowledge arises when it is realised that practical needs might be better served ‘by being not quite so practical, so immediate, so ad hoc’ (p. 265). Instead of looking for separate solutions to different practical problems, systematic knowledge develops as people became aware of patterns that could be applied across separate practical solutions.

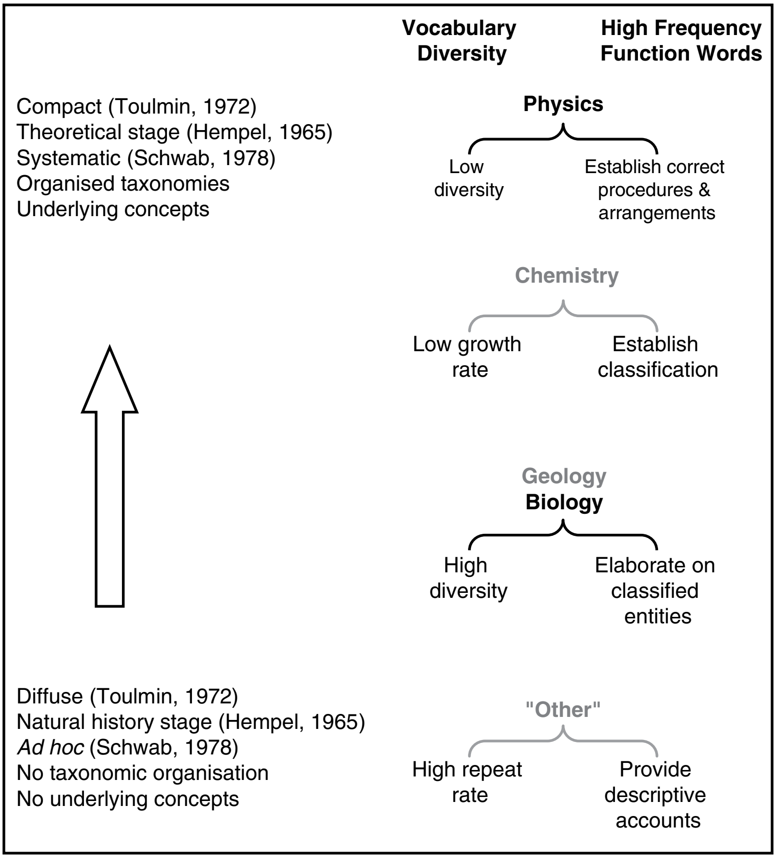

Fig. 3.4 Alignment of disciplines with linguistic configurations

Similarly, Hempel (1965) discussed the development of disciplines, drawing attention to issues of vocabulary. He argued that the vocabulary of science serves two main functions: first, 'to provide adequate descriptions of things and events … [that are] ascertainable fairly directly by observation' and, second, 'to permit the establishment of general laws and theories by means of which particular events may be explained and predicted'. The entities, their characteristics and the processes to which the laws and theories refer 'are more or less removed from the level of directly observable things and events' (pp. 139–140). Hempel argued that the development of a discipline often proceeds from a 'natural history stage' which emphasises the description of phenomena, through to more 'theoretical stages' (p. 140) which place increasing emphasis on theoretical accounts.

There is no claim here that among the disciplines themselves one or another have the characteristics of diffuseness, or that they are at the natural history stage or that they depend upon *ad hoc* knowledge systems. Rather, the claim is that there are groups of chapters in the corpus that are characterised by diffuseness, ad hoc knowledge systems and descriptive accounts, while other chapters are characterised by compactness, systematic knowledge systems and theoretical. Further, the Physics chapters tend to align with the latter, and the Biology chapters tend to align with the former.

As argued earlier, when Biology chapters and, to a less extent, Geology chapters provide descriptive accounts of phenomena, the phenomena exist or have existed in the world prior to the description. Similarly, when Biology and Geology chapters categorise phenomena, the existence of the categories does not need to be established. The categories might need appropriate labels, but the categories themselves are taken to be readily available to the senses. Their availability becomes evident once observable characteristics of phenomena have been documented, and generalisations concerning commonalities among the observations have been made. That is, the entities under discussion in Biology and Geology chapters and their taxonomies already exist, and, further, they exist independently of theoretical systems.

In one sense, the presentation of the content of Physics contrasts with the other disciplines. Many of the entities do not have experiential-world equivalents. These unifying and underlying concepts represent common points of reference and allow variations on common themes to be presented. But in another sense, the presentation of Physics has points in common with Biology and Geology: All are wedded to empiricism. Physics, for the authors of these textbooks, involves the labelling of theoretical phenomena, not for the purpose of working with the phenomena in a theoretical way, but rather, the purpose is often to interpret experiential-world phenomena in terms of a theoretical perspective. There is little discussion of the origins of theoretical entities, and instead the content draws on experiential-world phenomena to provide theories with empirical confirmation. Scientific knowledge is thereby presented in this corpus as valid and reliable to the extent that it corresponds with the experiential world.

The physical sciences are empirical sciences, but the physical sciences as disciplines have matured – their reasoning and knowledge systems no longer remain embedded in the empirical world. Ideas, things that are purely abstract and removed from the empirical world, play an important role in the development of the sciences. In contrast, the science that is presented in the textbooks is about observability and utility; science becomes centred on the experiential world, and science comes to be about experiences and their manipulation.

Conclusions

The corpus described here was collected some years ago and comprised textbooks used in one educational jurisdiction. In this sense, there is no claim that the corpus is generalisable to other secondary school systems or to other times. By the same token, it is not the case that major curricular reforms in secondary school science would lead to the suspicion that the materials in use in Queensland or other educational jurisdictions would be different in substantial ways. The generalisability of the main patterns discovered through these analyses is a matter of ongoing empirical inquiry.

The hope is that these findings, in that they take systematic account of the nonintuitive multicollinearities among language patterns, allow for much more grounded detailed qualitative analyses (e.g. by applied linguists or ethnographers interested in the use of these language patterns in classroom activities). They also provide, first, broadly based understanding of distinctive patterns of differences among subdomains within science and, second, some methodological guidance for uncovering the potentially more powerful differences among other curriculum domains outside of the sciences.

These patterns, along with the demonstrated associations among the patterns, can lead to more generalisable, portable knowledge and application by teachers, curriculum designers and textbook writers. What the texts embody is not one single form of 'scientific thought' or 'literacy of science' but rather a set of contrasting features. Critically, however, from a pedagogical point of view, the forms that these features take is not made evident or a topic of discussion, an object of pedagogy; there is no explicated problematic around the languages of the written forms of the sciences.

The increasing focus on curriculum-specific literacy demands in curriculum development, policy and eventually even literacy research is as well an increasing call for explicit language and literacy teaching (Deng & Luke, 2008; Freebody & Muspratt, 2007; Lemke, 2002) in the diverse, hybrid and portable 'new mainstream' classrooms (Enright, 2010) that characterise contemporary educational provision. Explicating what is known about the features of materials students need to read for school, and of the features they are expected to reflect in their writing, has substantial implications for equity through education:

> teaching with integrity involves developing secondary school subject-matter pedagogy that is socially just in its provision of opportunities to learn how to make sense of and produce the texts of different subject areas. (Moje, 2007, p. 37)

The findings reported here can make the usually unremarked details that students face each day more pedagogically available and the gifts of the knowledge those features embody more accessible.

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Chapter 4
Towards a More Epistemologically Valid Image of School Science: Revealing the Textuality of School Science Textbooks

Kostas Dimopoulos and Christina Karamanidou

School Science and Science in the Public Field

Science as a body of knowledge transported from the initial context of its production to other contexts, such as that of school or the public field, is subject to selective transformations which substantially changes its epistemological image so much so that we can essentially talk about two discrete bodies of knowledge rather than a modified body of knowledge (Tsatsaroni & Koulaidis, 2001).

Many years of research (e.g., Knain, 2001; Matthews, 1994; McComas, 1998) concerning the epistemological image of school science have resulted in certain basic conclusions. According to these conclusions, school science as presented in science textbooks is static and final. Also, in many cases, it is presented as ahistoric, beyond doubt, universally applied knowledge, discovered[1] by intelligent, individual scientists with no self-interest, after painful efforts, which are ultimately crowned with success.

As mentioned by Kuhn (1970), school textbooks present the 'paradigm' of each scientific area. In the majority of cases, using the concept categories that Masterman (1970) identified as attributable to the term "paradigm," what dominates is the philosophical paradigm, i.e., the basic ontological perceptions such as the certainty of the existence of fields, electrons, and other entities constituting the scientific universe.

Conversely, what seems to be absent from school textbooks is the notion of artifact paradigm, i.e., the paradigm corresponding to legitimate models of solving

[1]The term "discovery" is of great epistemological significance as it implies that scientific truths preexist and are waiting to be discovered. Conversely, terms such as "invention" or "results" openly imply the involvement and contribution of the scientific community and the construction of scientific knowledge.

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Table 4.1 The most important epistemological differences between school science and science in the public domain

School science	Science in the public domain
Static – final	Dynamic – in the making
Ahistorical	Evolutionary/innovative
Beyond doubt/above controversy	Under negotiation/controversial
Free from conflicts of interest/insulated from motives – a product of cognitive effort exclusively	Under the influence of interests
Universally applied	Locally applied/depending on the context
Linear – deterministic	Nonlinear – reflective
Generated by individual scientists	Generated by multidisciplinary teams of collaborating experts
Linear path to a successful conclusion	Regressions between successes and failures

scientific problems. This is due to the fact that scientific knowledge is presented as a "ready-made solution" rather than "an open question to be answered." Also absent is the sociological paradigm, i.e., the whole of commonly accepted rules of social negotiation of knowledge within the scientific community since as it has already been mentioned school science is presented as unquestionable.

In conclusion, the basic characteristic of school science is its transcendency and, consequently, the concealment of evidence which can corroborate the idea that it is a "construction" or a product resulting from processes taking place in the context of specific epistemic, cultural, political, financial, or other influences.

On the other hand, science in the public sphere is mainly presented due to its adhesion to other areas of human activity and culture such as politics, economy, and ethics or due to its innovative character (new scientific theories, technological innovations). Moreover, science usually enters the public domain due to controversies that occur both within the scientific community as well as between the scientific community and representatives of other social institutions or finally due to the challenge and/or the protection from modern risks (Dimopoulos, 2001).

The aforementioned reasons dictate the epistemological image of science in public. Science in public constitutes a complex, dynamic body of knowledge which is frequently in question, under constant social negotiation, dependent on the specific circumstances of its implementation framework and is formed based on the collaboration of multidisciplinary groups of specialists and a number of regressions between successes and a multitude of failures.

In the public domain, the influence on science of various interests coming from different actors or pressure groups, e.g., industry, governments, international organizations, citizens' societies (civil society organizations), and nongovernmental organizations, is more than evident.

In Table 4.1, the most important epistemological differences of school science with science in the public domain are presented.

The characteristics listed in the above table are possibly not the only ones, but they suffice to establish the view that school science and science in public constitute two discrete and divergent bodies of knowledge.

Based on the conclusions of a series of modern ethnomethodological studies deriving from the current sociology of scientific knowledge (SSK) (e.g., Knorr-Cetina, 1999; Latour & Woolgar, 1979; Pickering, 1984) and focusing on how the scientific community practices the formation of techno-scientific knowledge, it seems that the image of science in the public sphere is more representative of the way techno-scientific knowledge is really produced within the context of the current social conditions than the image of school science.

In order to further illustrate this point, the theory of Gibbons et al. (1994) concerning the contemporary way of production of techno-scientific knowledge should be mentioned. According to this theory, after the end of World War II, a dramatic change occurred in the way of production of techno-scientific knowledge. This change is described as a simple transition from Mode 1 to Mode 2 (the terms are introduced by Gibbons et al.). Mode 1 corresponds to what traditionally is called *academic science and technology*, the main characteristics of which are (Ziman, 2000):

- The search of universal laws in favor of the objective truth
- The handling of techno-scientific problems by individual expert scientists
- The restriction of techno-scientific work to academic-type institutions (e.g., universities, academies)
- The relative autonomy of techno-scientific research from its duty to be accountable to various social agents

Conversely, Mode 2 corresponds to what is called *post-academic science and technology* (Gibbons et al., 1994; Ziman, 2000) which refers to a new way of production of the equivalent knowledge. This way is gaining ground during the last decades against the *academic science and technology* to such an extent that currently it is considered dominant. The main characteristics of Mode 2 are:

- The search for practical solutions to real-life problems of limited scope
- The handling of problems by numerous scientific groups which are comprised by experts from various techno-scientific fields
- The conduct of techno-scientific work within the context of nonacademic organizations and especially organizations which relate to state and business interests
- The requirement of the techno-scientific research to handle available resources with effectiveness and be accountable for its results to various social agents (public, governments, private interests, etc.)

It is evident from the above analysis that the description of science in public (e.g., as presented in the mass media) is closer to the "post-academic" mode rather than the traditional academic one. Equivalently, school science (as it is presented in school science textbooks) seems to be more compatible with the "academic" mode.

This epistemological image in school science textbooks is constructed through the frequent use of certain rhetorical means. The term "rhetoric" in this case refers to the means of persuasion and building consensus which are used by school textbooks in order to establish the truth of the allegations projected through them (Gross, 1996).

The aforementioned are linguistic means used for the formation of equivalent concepts. Their effectiveness lies in the fact that through frequent use, the means are internalized by the students as the canonical language of natural sciences and are normalized, thus, making their "rhetoric" function invisible.

Consequently, a substantial move towards the direction of changing the epistemological image of school science so that it becomes more compatible with the nature of science in public would require the drastic refutation of this "rhetoric" and the adoption of alternatives in its place.

The Concealment of Textuality of School Science Textbooks

The image of the natural sciences in school, as described in the previous section, is constructed based on a series of "rhetoric" means which converge into an effort to present the relevant school texts as self-referential, a monologue which conceals its textuality and, thus, its constructed nature. These means enhance the absolutization of school knowledge and the conversion of the school textbook into a "symbol of knowledge."

The most important of these means are:

(a) The *concealment of the subjects of scientific action* via the frequent use of verbs in passive voice, in third person singular or in plural form, using physical entities or their relationships between them as subjects. Furthermore, declaratory statements as well as the lack of references to parallel texts, sources, or alternative views.

These means attempt to withdraw subjects' (e.g., scientists) actions from the scene and therefore the contribution of scientists in the process of formation of scientific knowledge.

Conversely, emphasis is put on the specific given, ahistorical, and realistic character of physical entities and the deterministic laws that govern their behavior. According to Woolgar (1988a, p. 69), the impression given is "as if scientists simply stumble upon eternally pre-existing truths which have until now not been discovered."

In fact, it is an attempt to form a belief of metaphysical realism, a belief according to which natural-scientific entities and laws correspond to entities and structures of the natural world.

For example, in the excerpt that follows, the impression that is given is that there is an anonymous narrator which can be identified in the minds of the reader as the "voice of the textbook" or "the voice of the whole scientific community" which describes the way in which the natural world works. The use of third person singular decisively contributes to this rhetoric result, which brings references to entities and the relationships described to the foreground (e.g., a planet which has potential energy, a revolving electron, a taut string which has potential energy, bodies regaining their original state), as well as the use of passive voice (e.g., exercised, subjected):

Example 1

A planet revolving around the sun has gravitational potential energy because of the gravitational force that the sun exercises on the planet. But an electron which revolves around the nucleus of an atom has electrical potential energy because of the pulling electrical force that the nucleus exercises on it.

Potential energy is also evident in a taut string, a compressed spring or a deformed ball. On all the above cases the deformation is elastic which means that the bodies fall back to their original condition when the force which deformed them is no longer exercised. Every body which has been subjected to elastic deformation has potential energy which depends on the extent of its deformation. *The potential energy of each body equals the work that resulted from the force that was exercised to deform them.*

Source: Antoniou, N., Demetriades, P., Kampouris, K., Papamichalis, K., Papatsimpa, L. (2007). Physics year 9, Athens OEDB, p. 94.

(b) *The reinforcement of faith in the objective realities of entities and laws of natural science* through the rhetoric of iconicity or experiential iconism (Enkvist, 1981), the use of the present tense, and the almost complete lack of modality of formalities. Iconicity or experiential iconism corresponds to figures of speech in accordance to which the structure of language has an isomorphic relationship with the structure of empirical reality. In other words, the order of textual data corresponds to the order of the incoming data of the sensory experience (temporal, spatial, causal, etc.).

For example, in the following excerpt from a chemistry school textbook, temporal determinations and actions are represented in an isomorphic manner evident by their linear order in the text:

Example 2

In the first test tube a white blur is formed, in the second a whitish-yellowish blur is formed and in the third a yellow blur is formed which is due to the formation of insoluble grains of chloride silver, bromide silver and iodide silver respectively. After some time the insoluble grains will sink to the bottom of the test tubes.

Source: Theodoropoulos, P., Theofanous, P., Sideri, F. (2007). Chemistry year 10, Athens, OEDB, p. 76.

Furthermore, the use of verbs in the present tense facilitates the emergence of scientific knowledge as timeless or "eternal truth" that has no specific time frame of validity.

(c) *The emphasis on scientific knowledge as a final product and the degradation of the scientific process* through the excessive use of reports and a lesser use of experimental and historical accounts (Koulaidis, Dimopoulos, Sklaveniti, & Christidou, 2002).

Firstly, "report" is a type of text that describes how things are, presents information by building up generalizations, classifies various entities, and explains processes in natural phenomena or explains how a technological artifact works.

"Experimental account" is a type of text that usually contains a series of sequenced steps, which show how a specific experimental task should be carried out, and/or presents the results of this task. Finally, "historical account" is a type of text that presents either episodes from the history of science and technology or biographical information about famous scientists and engineers.

According to Sklaveniti (2003) in the Greek school textbooks of the natural sciences of primary and secondary school, 80 % of text units can be classified as reports, 13.2 % as experiments, and 6.8 % as historical accounts.

Summarizing, the aforementioned three rhetorical strategies are complementary and work towards the common direction of consolidating and strengthening the objective nature of scientific knowledge, while attempting a systematic concealment of its fabricated nature from the reader's view.

In this manner, language as a means of representation, while shaping the epistemological image of science, tends to impose a certain kind of amnesia with regards to its own role (Serres, 2001).

It is attempted to convince student-readers that there is no effort of persuasion in the text. The written language is in this case internalized as an inert channel of an "objective" description of the natural world.

According to Collins and Pinch (1998), this mode of written language functions towards the "hardening of facts" and the hiding of the textuality of scientific knowledge. Furthermore, this becomes much more intense as the context of transmission becomes more remote (socially and/or time-wise) from the context of primary production.

A characteristic example of this trend is the evolution of wording used to describe the quark. In 1969, the Dutch physicist J. J. Kokkedee, one of the pioneers in research on the particle in question, talked about it in the following way: "At this moment the quark model should not be considered anything more than what it is: a trial or a simplistic expression of a still unclear underlying dynamic within the context of the world of hadrons" (as reported by Pickering, 1984, p. 91).

In 1974, only 5 years later, Feynman considers the quark as almost real reporting that: "There is a considerable body of evidence, and no experimental evidence against the idea that hadrons consist of quarks…let's assume then therefore that quarks exist in reality."

By 1982, the formalities had advanced further towards the objective existence of quarks. The renowned physicist George Zweig reported "The quark model admirably describes half of the natural world" (as reported by Pickering, 1984, pp. 114, 147). Thus, in less than a few decades, the quark from a convenient agreement of

Fig. 4.1 The splitting and inversion model

(1) The textual representation

(2) The textual representation → the entity of the natural world

(3) The textual representation ... the entity of the natural world

(4) The textual representation ← the entity of the natural world

(5) Denial (or concealment) of stages 1-3

theoretical physicists became a real entity which explains the causal structure of a large part of the natural world.

A similar course has been followed in the development of other scientific advances. A typical case is the introduction and establishment of the "Big Bang" theory which competes on an equal basis with two other theories with regard to the birth and evolution of the universe, namely, the "Steady State Universe"[2] proposed by Fred Hoyle, Thomas Gold, and Hermann Bondi and the "Inflationary Universe"[3] theory proposed by Alan Guth (Bucchi, 1998).

The supporters of the "Big Bang" theory using basic rhetorical means[4] tried and largely succeeded to establish this theory in education (today, in the vast majority of school textbooks, the "Big Bang" theory is undeniable) as well as in the public domain marginalizing the other two competing theories.

The trend of gradual concealment of the constructed and, thus, of the textual nature of scientific knowledge is described by the model of "splitting and inversion". This model attempts to shape the process of scientific knowledge production based on the case study of the discovery of pulsars by Hewish, Bell, and other three members of the amateur astronomy society in the late 1960s (Woolgar, 1988a). The model which foregrounds the textual and thus constructed nature of scientific knowledge includes the five stages presented in Fig. 4.1.

During the first phase, scientists handle textual data representations in the form of recording instruments (e.g., graphs as output of recording instruments), articles published in academic journals, and tables of empirical results of previous research efforts.

[2]According to the theory of the "Steady State Universe" which was introduced in 1948, the universe is always in a state of constant density as the constantly emerging new material is balanced out by the process of cosmic expansion.

[3]According to the theory of the "Inflationary Universe" introduced in 1981, the universe at the initial stage of its evolution spent a brief period of accelerated expansion during which the light had the opportunity to spread throughout the forming universe. This theory addresses the weakness of the "Big Bang" theory (which paradoxically is also its experimental confirmation) to explain the uniformity of the cosmic radiation background in the universe as according to the latter, the light did not have the time to spread across all the areas of the universe which were formed. The "Inflationary Universe" theory includes the additional theoretical difficulty of predicting the existence of negative gravity during the first phase of the accelerated expansion of the universe.

[4]In the context of this strategy came the publication of the Stephen Hawking's "Chronicles of Time," an avid supporter of this theory. The book attracted the public's interest in techno-scientific issues and revived editions of popularized scientific works and sold, according to Rodgers (1992), four and a half million copies worldwide.

During the second stage, scientists through an intense process of discussions and debates select or combine some of these textual representations in order to infer the existence of an entity of the natural world. Thus, at this stage, the textuality of scientific knowledge is very visible. During the third stage, a schism occurs between the entity and the textual representations from which it derived. In other words, the entity acquires status commencing its autonomous existence. During the fourth stage, the relationship between the entity and the textual representations is reversed. Thus, during this phase, an assumption is created that a text refers to an entity that has always existed. This phase corresponds to the phase of scientific publication during which the rhetoric goal is to convince peers for the truth of the allegations. However, at this stage, the rhetoric means and therefore the textual nature of scientific knowledge are still visible. Finally, a critical fifth stage follows which involves minimization, denial, and degradation of all the previous stages of the procedure. In this final stage, the story of the scientific discovery is rewritten so as to fully establish the objective ontological status of the scientific terms and relationships. According to our previous analysis, this phase corresponds to the image presented in school textbooks.

Towards a Proposal for the Disclosure of Textuality of Educational Materials for the Teaching of Natural Sciences

As it has been previously mentioned, a more realistic image of science corresponds to a form of knowledge which is being formulated. The problem that arises is the following: Which rhetorical means can be used to highlight the textual and therefore constructed nature of this knowledge as shown in the first four stages of its construction according to the "splitting and inversion" model?

After all, we should not forget the very etymology of the word "text" in the Latin version (the current English word comes from the Latin noun *textum* (verb *texo*) which means "textile" or "construction based on interwoven sections of wood" and refers to an artifact with complicated construction characteristics which is made from a combination of several components) (Lehtonen, 2000).

In a figurative level, we would say that the aim is the dismantling (tearing down) of the individual threads that make up this "construction" called *text* so as to highlight the formulation process, in other words its textuality. Such a process treats the textual representation of scientific knowledge more as a process rather than a final and static product (Barthes, 1986).

In this case, certain textual elements are required in order to bring to the foreground the following:

(a) The actors of the scientific process (scientists, authors of the school textbook, other stakeholders)
(b) The activities of these actors (claims, formulations of hypotheses, collection of experimental measurements)
(c) The antecedent conditions that lead to relevant activities (motives, interests, etc.) (Woolgar, 1988a)

Such elements, however, are necessary to put the validity of those rhetorical means through a critical test which in accordance with our previous analysis tend to increase belief in a metaphysical type of realism cultivated through school textbooks. The critical test of conventional rhetoric means, which tends to be used in the context of teaching of the natural sciences, arises from the effort to avoid a futile attempt to escape the constructed nature of every type of representation.

With regard to the question as to which are the most appropriate textual techniques to create the conditions to challenge the dominant rhetoric practice of hiding textuality of natural-scientific knowledge, the sociology of scientific knowledge (Ashmore, Myers, & Potter, 1995; Cooper, 1997; Woolgar, 1988b) in response has proposed all those forms of speech which, through their non-conventionality, highlight the mutual relationship between form and content (new literary forms).

These forms of speech are characterized by the celebration of heterogeneity, the introduction of textual instability, and the placement of the text construction procedure in the foreground, in other words the very idea of textuality.

Such texts, which make educational materials seem less self-referential and less like a monologue, tend to develop reflexivity and therefore control to the student-reader (Cooper, 1997). Lawson (1985, p. 363) characteristically states that: "the move toward reflexivity allows the text to indicate that there is something more than the meaning already mentioned."

The trend of moving towards texts which enhance reflexivity originates from the principle of symmetry (Bloor, 1976) according to which the various conflicting and controversial versions of natural-scientific knowledge (contemporary or previous historical phases) should be treated (even retrospectively if it concerns theories now established) as phases (1) and (2) of the "splitting and inversion" model.

The aim, therefore, of the use of non-conventional forms of discourse is to question tacit commitment to an orthodox epistemology governing natural-scientific texts in the field of education (perhaps not solely) while at the same time opening up to any type of challenge based on the claims made.

This can be achieved in two ways: firstly, by introducing textual types to the educational material which bring to the foreground multiple "voices" with regard to the same issue.

Secondly, the same literary effect can be produced with the creative use of figures of speech which through surprise and intensity of expression make the constructed nature of the text more visible while leaving the content open to interpretations on the part of the reader.[5]

Indeed, regarding the introduction of non-conventional figures of speech as a reinforcement of the reflexivity of the text, Gross (1996) reports that the avoidance of these figures of speech in standard scientific writing has as an aim to cultivate

[5] See the difference between "closed" i.e., stylized and formalistic, and "open," i.e., not as standardized in terms of expression texts according to Eco (1979), or the corresponding focus on form rather than content of abstract art which creates the conditions for more open-ended interpretations according to Gombrich (1960).

(or foster) the impression that science describes reality without the need to refer to the mediation of expressive means, in other words, a perception according to which scientific truth speaks for itself without the need for rhetoric tricks (décor).

Characteristic examples of the first of two types of functions (i.e., the introduction of multiple voices) are dialogue, plays, attribution of human voice to entities (real or imagined), diary, review of the literature, description of conditions behind the authorship of a text, and verbatim quotes from someone (i.e., quotations).

Examples of figures of speech, which, through the surprise they cause, contribute towards a more reflective attitude of the student-reader, are irony, paradox, hyperbole, rhetorical questions, and self-reference (Cooper, 1997) as well as enhanced modality formalities (Latour & Woolgar, 1979). Each of these forms will be analyzed in greater detail below.

Textual Types Revealing Textuality and Thus Enhancing Reflexivity

Dialogue

Dialogue is a textual type which allows the positions of the author to be questioned by those voicing alternative approaches to these positions. In other words, dialogue, as a text type, allows the introduction of "multiple voices" into the educational material. It is a simulation of a discussion or debate, and of course if the style is closer to spoken language, then it differs dramatically from the formal style of scientific writing in the sense that it invites the reflexivity on the part of the reader.

Apart from its direct form, dialogue can be introduced in the educational material indirectly as well by quoting opposing views in the format of a table or parallel texts. A typical example of such writing is the famous dialogue in which Galileo presents his views in his works primarily through the voices of Salviati and secondarily Sagredo while expressing the Aristotelian and counterargument to them through the voice of Simplicio.[6]

Theatrical Script (Play)

Apart from the dialogues included in theatrical writing, whose value has already been analyzed, there are also stage descriptions as well as description of the psychological state of the protagonists. These are elements which allow a viewer to reflect upon the

[6] According to Shamos (1987), the reasons which led Galileo to adopt this model of writing was his effort to appear attentive and less absolute in the formulation of his positions because of the expected response these would generate but also due to his admiration for the work of Plato (out of 36 works of Plato, all but "Apology" are written in dialogue).

context of the positions additionally to the positions themselves. A characteristic example of this case is the play Copenhagen by Michael Frayn. The play is about a meeting which takes place in September 1941 in Copenhagen, under German occupation at the time, between Heisenberg and Bohr, and uses as a background the construction of the atomic bomb.

Similar cases include the *Life of Galileo* by Brecht, *The Physicists* by Durrenmatt which addresses the issue of moral responsibility of scientists with regard to the use of their research findings, or the comedy *Picasso at the Lapin Agile* by Martin which describes a meeting between Picasso and Einstein in a coffee shop one afternoon in 1904, 1 year before the theory of relativity was formulated. Yoon (2004) indeed categorizes plays relating to the natural sciences into those that (a) describe (give, contain) content with regard to the natural sciences, (b) describe the lives of certain scientists, (c) relate to episodes (defining moments) in the history of science, (d) refer to the social dimensions of science, and (e) use natural sciences as a pretext in order to let the dramatic plot unfold.

The Attribution of Human Voice to Entities

This approach draws its inspiration from the Actor Network Theory by Latour (1987) according to which the formulation of scientific knowledge is a process which is characterized by the creation of networks comprising of heterogeneous elements such as texts, references, artifacts, technologies, people, and institutions. This position suggests that in order to study science in the making and the creation of these networks, we have to abandon all the a priori distinctions between human and nonhuman actors. A characteristic example of the way various researchers in the field of sociology of scientific knowledge have used the technique of attribution of a human voice to entities in order to handle the procedures of socio-technical systems is that of Mulkay (1991a) which gave a voice to dolphins and fetuses in the womb (Mulkay, 1991b) and that of Law (1992) who gave a voice to the text itself which conversed in dialogue with the author and other voices.

The attribution of human voice to entities in the form of animism can only be found in the educational material used in the first years of primary education. In this case, the reflective effect does not seem to be achieved. In older ages, the use of this technique could create the conditions required for reflexivity (e.g., see cases of voice attribution to the planet Earth or animal species in ecology texts).

The Diary

This genre allows the recording of the evolution of a scientist's thinking over time as well as the recording of the social and historical contexts within which this evolution takes place or at least as the scientist perceives them. This very description of the evolutionary process demonstrates in the eyes of the student-reader that the scientific thought goes through multiple stages of formulation and is influenced by many circumstances or even random incidents. Autobiography could also be included in this textual type. Typical examples of this kind are the autobiographical chronicle of the discovery of the double helix structure of DNA as presented by one of the two scientists who made the discovery, James Watson (the other scientist was Francis Crick), entitled *The Double Helix* (Watson, 1966), and extracts from the *Red Notebook* in which Darwin kept all the notes regarding his observations and his thoughts during the 55 months of voyage on the Beagle.

Review of the Literature

The use of references from and commentary of the existing literature on a certain scientific issue is an established practice in the scientific literature but usually absent from educational material. The adoption of such a textual practice in educational material would undermine the absolute nature of what is being said and thus would enhance reflexivity. Moreover, the very nature of this practice would indicate clearly that the formation of scientific knowledge is a result of social interaction within the scientific community and thus refers to its textual nature.

Description of Conditions Behind the Authorship of Educational Material Texts

This textual practice is quite often met in prologues to various texts whereby the authors adopt a style resembling a confession or an evaluation and describe the conditions under which they produced their text (Genette, 2001). In this way, student-readers can more easily understand the constructed nature of the text they are exposed to, as well as understand the special circumstances under which it was written (e.g., influence from peers, communicating with reviewers and editors, and psychological or emotional state of the author at the time).

Quotations

Citing verbatim quotes constitutes a crack in the usual monologue of natural sciences educational texts, as it allows the introduction of additional "voices" beyond the voice of the author. Indeed, the reflective function in this case is especially strengthened when the citations listed are in conflict with the main arguments of the material.

Figures of Speech

Irony

In this figure of speech, the author seems to say something, but actually, he means something else. In this way, this figure of speech contains contradictory meanings out of which the student-reader must choose the right one and thus becomes more reflective. The reflective function of irony is further enhanced by the fact that in order to communicate its meaning, it must refer to the common interpretative resources of the author transmitter and the student-reader. In this way, these two agents come into play, and the text is revealed as a product of the author's activity and is therefore constructed. According to Giannakoppulos (1991), irony constitutes an antiphrase. In other words, irony is a figure of speech "with which an expression of a concept or a judgment is made with words that mean exactly the opposite" (p. 517). Similar to the rhetorical function of irony are euphemism and humor. All these figures of speech are, by their very nature, attempts to undermine meaning delivered and thus represent a direct criticism of their objectivity.

Paradox

The paradox is a figure of speech which while at first glance appears not true and/or not feasible, a second reading can make it appear to the student-reader compatible with reality (e.g., the paradox of the Hare and Tortoise by Zeno and the paradox of Einstein's Gemini). One could say that the reflective nature of the paradox is the very fact that emphasizes that certain claims which initially seem to be untrue could under certain circumstances or conditions become true. A similar function to the paradox is also performed by the figure of speech "oxymoron."

Hyperbole

According to Pantidos (2008) in the figure of speech of hyperbole, formalities differ a lot from the usual (or mainstream) in order to cause a sensation. It is this deviation which invites the student-reader to consider the accuracy or otherwise of the claim and thus makes him/her more reflective.

Rhetorical Questions

These questions are put as a pretext with an aim to lead immediately after to their response. However, the mere fact that they are posed clearly suggests that scientific claims do not emerge directly from nature but constitute answers to questions posed by scientists. In this sense, a rhetorical question brings the scientific community to the forefront and helps scientists to be seen not as passive readers of the "book of nature" but as active actors who shape the actual scope of their quests. The technique of rhetorical questions has been used by Newton in his work *Optics*. Specifically in this work, Newton has included over 31 such questions, in order to refute the criticism of other scientists and specifically Hooke, with regard to the particle nature of light which he advocated (Gross, 1996).

Self-Reference

The voice of the author is expressed through the use of first person singular (or first person plural in the case of multiple authors). The corresponding formulations can concern either the epistemic (degree of effect, certainty, innovativeness, generality, compatibility, probability, possibility) or the emotional (usefulness, utility, elegance, morality, acceptability) or the evaluative attitude of the author in relation either to its own claims or the claims of others. The self-references in the educational material relativize the value of arguments presented, leaving the student-reader free to agree or disagree with the explicit position of the author.

Reinforcing the Modality of Formalities

The epistemic attitude of the author is possible to be delivered indirectly through the modality of formalities used. The modality in this case refers to the degree of certainty attached to each formality. Moreover, the modality of expression constitutes "one of the most important means of showing the attitude of the transmitter towards the content of an utterance" (Lekka, 2005 p. 77). Adding expressions that indicate modality (e.g., may, under certain circumstances it may apply, scientist X argues that) results in gradual devaluation or degradation of the objectivity of the claims raised.

Latour and Woolgar (1979) distinguish five levels of modality of scientific formulations.

Claims that appear to be certain and obvious within a scientific field belong to level 5. Claims that are presented as unquestionable however are accompanied by detailed explanations belong to level 4. The claims of the educational material used for natural sciences in the school usually belong to these two levels. Claims that belong to levels 3 and 2 include expressions of reservations, restrictions, and conditions which suggest that the meaning of the claim is not undisputed. Claims that belong to level 3 are especially hard to distinguish (e.g., citation of a bibliographic reference weakens the certainty of a claim since support external to the text is needed). At level 2, the expressions of modality are a lot more powerful, and formalities indicate the availability or lack of evidence which enhance truth. Finally, the formalities of level 1 are openly and frankly speculative and incorporate assumptions concerning the lack of sufficient evidence with regard to the truth. As formalities included in the educational material move from levels 5 and 4 towards levels 3, 2, and 1, their modality is increased, and therefore, it is possible that the reflexivity of the student-reader is also increased in terms of power.

A final word of caution regarding the textual types and figures of speech which highlight the textuality of the educational material would be that these elements of speech are commonly used in two communication fields of scientific knowledge, namely, in peer-reviewed publications in scientific journals as well as popularized publications in the public domain.

In both fields, the choice of the emergence of textuality is supported by the need to make skeptic readers more reflective and thus convince them. In the case of scientific publications, relevant texts are produced very near to the front of the primary construction of natural-scientific knowledge and therefore need to appear as reflective as possible in relation to the accuracy of their claims so as to overcome the test of organized skepticism of peer readers according to Merton. On the other hand, texts in the public domain are addressed to nonspecialists who do not have any epistemic commitment to science but, at the same time, function in a climate of growing skepticism about the results of techno-science and are in need of being convinced, especially in modern conditions where, according to Giddens (2001), knowledge and social practices feed into each other in a dialectical way.

Synopsis

This chapter stems from the observation that the epistemological images of the school science and science in the public domain, or at least how they are reflected in the texts of each field, are considerably diversified. This differentiation constitutes a fundamental barrier for the adoption of approaches aiming to teach natural sciences for citizenship. An important part of this image of school science is shaped by the rhetorical means used in school textbooks. The common denominator of these means is the concealment of textbook textuality and the associated absolutization of scientific knowledge for the sake of metaphysical realism.

In order to rebut this image of science, it is proposed to include unconventional textual types and figures of speech in school science textbooks which reveal their textuality, and therefore, the constructed and negotiable nature of science will be revealed, as it is presented in the public domain. The inclusion of such textual elements could potentially enhance the reflexivity of the student-reader and therefore help him/her to adopt a more realistic view of the conditions of formation and change of scientific knowledge.

In an era where the presence of techno-science is increasingly in the spotlight of the public life, only reflectivity and the healthy skepticism it creates can help students dealing with both a blind allegiance to an occult science (scientism) as well as the antiscientific, pseudoscientific, and anti-rational trends of postmodernity.

Postscriptum

If by now the reader of this chapter has not seen the glaring contradiction between our proposal with regard to the need of using textual types and figures of speech that enhance reflexivity and how this proposal is expressed (complete lack of such evidence in this chapter), then this means that resorting to the usual conventions of scientific writing has achieved its aim to hide the textuality of this chapter, namely, that it is merely a contrived position of the authors. "Exactly what had to be proven was proven."[7]

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[7]This postscriptum is the only reflective type reference in a text that otherwise takes position in favor of integrating reflectivity as a process in the educational material.

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Chapter 5
How Effective Is the Use of Analogies in Science Textbooks?

MaryKay Orgill

Introduction

Both scientists and science educators use analogies, in either written or oral form, to convey information to others: to their colleagues, to the media, to their friends, and to their students. Simply put, an analogy is a comparison between two domains of knowledge – one familiar and one less familiar. In the literature, the familiar domain is referred to as the "vehicle," "base," "source," or "analog" domain, and the less familiar domain, or the domain to be learned, is referred to as the "target" domain. For the purposes of this chapter, I will refer to the two domains as the "analog" and "target" domains, respectively.

To say that an analogy is a comparison may be an oversimplification. An analogy is not just a comparison between different domains: it is a special kind of comparison that is defined by its purpose and by the type of information it relates. "An analogy," according to Gentner (1989), "is a mapping of knowledge from one domain (the base) into another (the target), which conveys that a system of relations that holds among the base objects also holds among the target objects" (p. 201). The purpose of an analogy is the transfer of relational structure from a known, or familiar, domain to a less known domain (Mason & Sorzio, 1996). Thus, the strength of an analogy lies less in the number of features the analog and target domains have in common than in the relational structure overlap between the two domains and the system of connected information that it conveys (Gentner, 1983).

Analogies are often used in educational settings to help students develop an understanding about topics that are unfamiliar or abstract by comparing them to information that is already familiar to the students (Beall, 1999). They can be particularly

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helpful in science education, where many concepts are not only new and, thus, unfamiliar but also abstract. However, the potential of analogies to help students develop understandings of scientific concepts is not always achieved. Both research and experience indicate that not all analogies are good analogies and that an analogy that is useful for one person may not be useful for another person.

Although the ultimate focus of this chapter will be on the effectiveness of analogy use in scientific textbooks, it will be useful to first briefly review some of the roles that analogies can play in promoting meaningful learning, some of the challenges and difficulties associated with using analogies in educational settings, and what research says about effective classroom analogy use.

Potential Roles of Analogies in Promoting Meaningful Learning

There are three main roles that analogies can play in promoting meaningful learning (Venville & Treagust, 1997): they can help students develop an *understanding* of new information, they can help students *visualize* new or abstract information, and they can *motivate* students to learn meaningfully.

First, analogies may help learners develop an *understanding* of new information, particularly when students lack sufficient background in a content area (Thiele & Treagust, 1992). Analogies can help students connect new information to already understood, already developed concepts (Thiele & Treagust, 1995), a process that is essential for meaningful learning (Glynn & Duit, 1995), by arranging existing memory to prepare it for new information. They can also give structure to information being learned by drawing attention to significant features of the target domain (Simons, 1984) or to particular differences between the analog and target domains (Gentner & Markman, 1997). In some cases, analogies can be used to support the development of conceptual models (Iding, 1997) or even serve as initial mental models (Glynn & Takahashi, 1998).

Second, analogies may help students *visualize* abstract concepts or phenomena that cannot be observed or experienced directly (Curtis & Reigeluth, 1984; Dagher, 1995a; Harrison & Treagust, 1993; Iding, 1997; Simons, 1984; Thiele & Treagust, 1994a; Venville & Treagust, 1997). Analogies may also provide a concrete reference that students can use when thinking about challenging, abstract information (Brown, 1993; Simons, 1984).

Finally, analogies can play a *motivational* role in meaningful learning (Bean, Searles, & Cowen, 1990; Dagher, 1995a; Glynn & Takahashi, 1998; Thiele & Treagust, 1994a). Analogies' connection of unfamiliar, abstract information to students' real-world experiences and analogies' familiar language can motivate students to learn new information meaningfully (Thiele & Treagust, 1994a). Lemke (1990) asserts that students are three to four times more likely to pay attention to an analogy than to a "scientific" explanation of a concept, perhaps because the language of an analogy is more familiar and accessible than scientific language. In fact, Dagher (1995a) says that the language of analogies can demystify scientific language and reports that the use of narrative analogies tends to result in higher student motivation and engagement.

Challenges and Difficulties Associated with Using Analogies in a Classroom Setting

While analogies can help students understand new information, visualize abstract concepts, or be motivated to learn, the effects of analogy use are not always positive. In the best-case scenario, students can ignore or not use the analogies provided to them by their teachers. In other cases, students may resort to mechanical use of an analogy, with no thought of the target concept which the analogy was meant to convey. In the worst-case scenario, an analogy can promote the formation of misconceptions about a topic. Some of these negative effects can be avoided if teachers follow certain guidelines in their teaching with analogies practices (see the following section), but at least some of these negative effects are possible even when teachers follow those guidelines.

There are multiple situations in which students might ignore or not use an analogy. When students do not understand what analogies are or how analogies can be used as instructional tools, students may not use analogies or may transfer only the surface features of the analog concept to the target concept instead of focusing on the transfer of a system of relationships from the analog concept to the target concept (Raviolo & Garritz, 2009; Thiele & Treagust, 1992; Venville & Treagust, 1997). Additionally, although, in theory, analogies are meant to convey new information about a target concept by relating it to a familiar analog concept, it may be that an analog concept that is familiar to an instructor is not familiar to the students. When the analog concept is not familiar to students, the analogy is not understandable and may be ignored (Venville & Treagust, 1997).

Even if students understand the analogies presented by their instructors, they may not use them – or may not use them as their instructors intend. For example, although both teacher and student may consider a particular analogy useful for learning new information, the analogy might be superfluous information if the student already has an understanding of the target concept being taught (Thiele & Treagust, 1992; Venville & Treagust, 1997). Additionally, if there is an algorithm that students can use to solve a problem, the students will most likely not pay attention to an analogy that has been presented with the goal of helping the student solve the problem (Friedel, Gabel, & Samuel, 1990).

Alternatively, a student could resort to using the analogy mechanically, without considering the meaning the analogy was meant to convey about the target concept (Arber, 1964; Gentner & Gentner, 1983; Venville & Treagust, 1997). Part of the mechanical use of analogy may be due to the students' not being willing to invest time to learn a concept if they can simply remember a familiar analogy for that concept.

The mechanical use of an analogy may also be due to a student's inability to differentiate the analogy from reality (Thiele & Treagust, 1995). No analogy is perfect because an analog concept, though *similar* to a target concept, is not the *same* as the target concept. In other words, each analogy has limitations. Unfortunately, students often do not know enough about the target concept to understand or identify the limitations of a given analogy (where an analogy "breaks down") – particularly when those limitations are not explicitly identified by their instructor.

When students inappropriately apply irrelevant concepts from the analog domain to the target domain, they can develop misconceptions about the target domain (Brown & Clement, 1989; Clement, 1993; Duit, 1991; Glynn, 1995; Kaufman, Patel, & Magder, 1996; Thagard, 1992; Venville & Treagust, 1997; Zook, 1991; Zook & DiVesta, 1991; Zook & Maier, 1994). For example, an analogy that is often used in biology courses compares a cell to a factory and the different organelles to parts of the factory. Students who know a lot about factories but little about the cell might mistakenly assume that the cell, like the factory, has a limited number of entrances. The misconceptions that are developed as the result of an analogy can be difficult to remedy.

Finally, and ironically, although one of the purposes of an analogy is to help students learn a concept meaningfully by relating that concept to the students' prior knowledge, the use of a single analogy may limit a student's ability to develop a deep understanding of that concept (Brown, 1989; Dagher, 1995b; Spiro, Feltovich, Coulson, & Anderson, 1989). When only one analogy is used to convey information about a particular topic, students may accept their teacher's analogical explanation as the only possible or necessary explanation for a given topic.

For example, Spiro et al. (1989) found that medical students were kept from a full understanding of concepts associated with myocardial failure because of analogies they had learned. They noted:

> […], although simple analogies rarely if ever form the basis for a full understanding of a newly encountered concept, there is nevertheless a powerful tendency for learners to continue to limit their understanding to just those aspects of the new concept covered by its mapping from the old one. Analogies seduce learners into reducing complex concepts to a simpler and more familiar analogical core. (Spiro et al., 1989, p. 498)

It may simply be more convenient for students to think of a concept as being explained by one familiar analogy than to invest the time to learn a new explanation for or develop a complete understanding of that concept. Spiro et al. (1989) do indicate, however, that the tendency for a single analogy to limit students' ability to develop deep understandings of concepts can be overcome through the use of multiple analogies because of the different perspectives that these analogies can provide about a given topic.

What Does Research Tell Us About How Analogies Should Be Used?

While some research indicates the positive effects of analogy use (Beveridge & Parkins, 1987; Brown & Clement, 1989; Cardinale, 1993; Clement, 1993; Donnelly & McDaniel, 1993; Fast, 1999; Glynn & Takahashi, 1998; Harrison & Treagust, 1993; Hayes & Tierney, 1982; Holyoak & Koh, 1987; Simons, 1984; Solomon, 1994; Treagust, Harrison, & Venville, 1996), other studies indicate that the use of analogies results in either mixed, neutral, or negative results (Bean, Searles, & Cowen, 1990; Friedel et al., 1990; Gilbert, 1989). Fortunately, there are several strategies that can be used to increase the probability of an analogy's having a positive effect on students' learning (to promote "analogical transfer").

Training in Analogy Use. The first strategy that can be used to help students learn from analogies is to teach students how to use analogies and to help them recognize the role that analogies can play in learning (Goswami, 1993; Harrison & Treagust, 2000; Iding, 1997; Klauer, 1989; Venville, Bryer, & Treagust, 1994; Venville & Treagust, 1997). The lack of such instruction in textbooks or in classrooms implies that textbook authors and teachers believe that their students are capable of both recognizing and applying analogies in order to learn. However, this assumption may not be warranted. The lack of spontaneous transfer of analogies demonstrated in the literature indicates that students are not familiar with the use of analogies as a learning tool.

Venville et al. (1994) assert that students must be familiar with the process of analogical thinking in order for their learning with analogies to be effective. They divided a class of 9th grade students at a Catholic secondary school into two groups. One group of students was trained in analogy use; the other group was not. An analogy (how a bookcase is like the shells of an atom) was presented to the whole class, and students were interviewed a day later. Immediately following the interviews, all students in the class completed an exam. The students in the analogy group had a better understanding of the word "analogy" and of the educational purpose of an analogy than their peers. There was little difference between the two groups in their ability to map out the similarities between the bookcase and the atom. The trained students, however, were more aware of and able to point out the limitations of the analogy than the other group. The ability of the trained students to recognize the limitations of the analogy may keep those students from developing analogy-based misconceptions.

Analog Explanation. Even when students understand what an analogy is and how to use it to learn, they may struggle with applying the analogy when they do not understand the analog concept. For this reason, several researchers suggest that instructors provide at least a brief explanation of the analog concept when using an analogy (Curtis & Reigeluth, 1984; Hayes & Tierney, 1982; Iding, 1997; Venville & Treagust, 1997). Such an explanation can be brief and should necessarily highlight transferable features and relationships in the analog concept but would ensure that all students in the class start with the same understanding of the analog concept.

The explanation of an analog concept could also be given in the form of a figure. Thiele and Treagust (1992) indicate that the use of a picture decreases the likelihood that a student is unfamiliar with an analog concept; other studies show increased understanding and retention of target concepts when analogies are accompanied by pictorial representations. Bean, Searles, Singer, and Cowen (1990) presented the analogy of a cell with a factory to high school students. Some of the students were presented with pictorial representations of the analogy. Others were not.

The students that received the pictorial instruction did significantly better than their peers on a comprehension/retention test. A study by Beveridge and Parkins (1987) suggests that visual representations of analogies are particularly useful in promoting meaningful learning when those representations highlight features or relationships in the analog concept that are to be transferred to the target concept.

Providing Hints. Another strategy that can promote analogical transfer is providing a hint to students that the analog and the target share similarities or that features of the analog can be used to solve a target problem (Anolli, Antonietti, Crisafulli, & Cantoia, 2001; Gick & Holyoak, 1980; Goswami, 1993; Spencer & Weisberg, 1986). In essence, "providing a hint" is equivalent to notifying the student that there is a connection between the analog and target concepts and implying that the student should look for that connection. Providing a hint is especially important in promoting analogical transfer when analog and target concepts are presented at different times or in different contexts (Spencer & Weisberg, 1986).

Explicit Mapping of Shared Attributes and Identification of Analogy Limitations. Beyond providing a hint, a teacher should promote analogical transfer by explicitly stating the similarities between the analog and target concepts and by stating the limitations of the analogy (Harrison & Treagust, 1996). Analogies are often used to make new information intelligible by drawing comparisons between it and knowledge the students already have. Students do not know which aspects of the analog apply to the new information and which do not. If teachers explicitly identify these similarities and limitations, students will be less likely to incorrectly apply the attributes of the analog to the target and more likely to apply the appropriate attributes.

Textbook Analogies

Analogies are often included in textbooks because some students require alternative presentations of different concepts in order to learn them meaningfully (Thiele, Venville, & Treagust, 1995) or because they make the text more "friendly" to students (Bean, Searles, & Cowen, 1990). In science textbooks, analogies may also serve the purpose of introducing students to the scientific style of writing. Unsworth (2001) found that in science textbooks, many events are "nominalized." In other words, events and generalizations are grammaticalized as "things." An example is using the words "his departure" (a noun) instead of "he departed" (an event). Analogies can be bridges between "regular" or "common" and "nominalized" text/grammar. In fact, analogies are often preparatory for the introduction of nominalized language in educational scientific texts.

Even though there are potential advantages of using analogies in textbooks, as implied by the fact that most textbooks, and particularly physical science textbooks, contain analogies (Duit, 1991), there are also potential problems associated with the use of analogies in textbooks. Textual analogies are very different from oral analogies because they offer no mechanism for immediate feedback or modification for individual students or for the correction of misconceptions that students might develop from the printed analogies. For these reasons, text analogies must be presented in such a way that their explanations are very clear in order to be effective (Curtis & Reigeluth, 1984).

Analogies, however, are not often presented as effectively as they could be in science textbooks. In the next two sections, I will focus on the somewhat limited literature base about the use of analogies in science textbooks. The focus will be twofold: (1) research about the effects of textual analogies about science concepts on student learning and (2) research about how – and how effectively – analogies are used and presented in science textbooks, when compared with the strategies that are known to promote analogical transfer.

Research About the Effects of Textual Analogies on Learning

The studies that have been done on the usefulness of textual analogies in science have been inconsistent; sometimes the analogies have aided learning; other times, they have not. For example, Bean, Searles, and Cowen (1990) gave high school students text passages about enzyme catalysis. Half of the students' passages contained a simple, unexplained analogy; the other half did not. After they read the prose, the students were asked to summarize and explain concepts about enzyme catalysis. The quality of the summaries and explanations given by the students who read the text containing the analogy was roughly equivalent to the quality of the summaries and explanations written by the students whose text did not include an analogy. The use of a written analogy did not improve learning under these conditions, perhaps, the authors state, because students do not take advantage of analogies unless they are specifically told to do so.

Gilbert (1989) followed a procedure similar to that of Bean, Searles, and Cowen (1990). He gave 9th and 10th grade Indiana high school students texts on either embryo and seed development or Mendelian genetics. Half of the readings were analogy enriched. The other half were literal. When students were tested for recall, retention, and attitude toward learning, no significant differences were found between the two groups. Gilbert concluded that there is no evidence that analogies should be used in text to promote either achievement or positive attitudes. The analogies used in this study, like those used in the Bean, Searles, and Cowen study, were fairly "simple," meaning that the presentation of the analogy did not include any explicit statements about the correlations (shared attributes) between the analog and target concepts or any explicit statements about the limitations (unshared attributes) of the analogy.

There have also been studies in which the use of textual analogies has produced mixed or positive results. The purpose of Simons's (1984) study was to examine the effects of written analogies on secondary students' understanding of scientific concepts. Two groups of students participated: an experimental/analogy group and a control group. Both groups were given readings about electricity. After they studied the material, the students were given comprehension and recall tests. Simons concluded that the students who scored high on operational learning and students who were visualizers (as opposed to verbalizers) performed better when they used texts that contained analogies.

Even though the analogy group outperformed the control group on both comprehension and recall tests in Simons's study, the analogy group took much more time to read and study the information than did the control group. When the reading and study time were controlled, the differences between the students disappeared. Simons interpreted this evidence to mean that analogies are effective reading aids only when there is sufficient time for students to compare analogies with target concepts.

In another experiment, Simons (1984) examined the kind of information that was transferred when students studied with analogy. In this experiment, it is important to know that the students in the control group were instructed in analogy use and asked questions throughout the text that should have helped them integrate the analogy and target concepts. The factual knowledge of the two groups was the same, but the experimental group had a better understanding of relations between concepts in the target domain. Simons's experiments indicate that textual analogies are beneficial under conditions of sufficient study time and that while analogies are particularly useful in conveying relational information to students, they may not convey any more factual information than more traditional means of instruction. Similar results were seen in studies by Hurt (1985, 1987) and Donnelly and McDaniel (1993), in which students who were provided with analogy-enriched text outperformed their peers on questions that required them to make inferences about a target concept while performing similarly to their peers on factual recall questions. Each of these studies suggests that the real educational power of a textual analogy is not in its ability to help students learn and recall factual information but in its ability to help students understand relationships within and make inferences about target concepts.

In another study, Cardinale (1993) explored the effects of textually embedded etymologies, causal relations, and analogies on the learning of information about the human heart. Her participants, undergraduate students in science education courses without much biology background, received either a control text or a text that contained an embedded explication of some kind. Two days after reading the text, students received a cued-recall test, an identification test, a definition test, and a comprehension test. Students who received either the analogy or causal relation texts scored significantly higher than the other groups of students on cued-recall and definition tests. Cardinale interprets the results to mean that both encoding and retrieval processes were enhanced by the analogy and causal relation explications and states her belief that textual analogies will particularly enhance learning in situations where vocabulary is unfamiliar or concepts are complex and abstract.

Glynn (1991) and Glynn and Takahashi (1998) assert that the inconsistency of the learning effects of textual analogies is the result of the inconsistency of the presentation of those analogies. In his 1991 study, Glynn examined 43 elementary, high school, and college science textbooks, looking for analogies in which there were explicit statements highlighting the relevant features of the analog concept, mapping concepts from the analog to the target concepts, and identifying the limitations of the analogies; but the presence of these "elaborate" analogies was rare. He proposed that students were more likely to learn from elaborate analogies than from simple analogies.

In 1998, Glynn and Takahashi (1998) examined the effects of an "elaborate" textual analogy on learning. In this study, 8th grade students read either an elaborate analogy-enhanced text or a "regular" text about the cell. They were asked to study the reading because they would be asked questions about the functions of the cell parts later. Students who studied with the analogies had higher recall scores that were maintained (factual retention) for at least 2 weeks. When younger students (6th grade) were examined under the same conditions, both the recall and retention advantages were maintained with the analogy group. The students were also asked to rate the concept they were studying in terms of importance, interest, and understandability. There was no significant difference in the importance ranking of the concept between the two groups. However, students in the analogy group ranked the concept of more interest and higher understandability than the control group.

Paris and Glynn (2004) used similar methods to examine undergraduate preservice elementary school teachers' learning about scientific concepts from elaborate analogy-enriched text. For each of three science topics – animal cells, the human eye, and electrical circuits – three text versions were prepared: one containing no analogies, one containing a simple analogy, and one containing an elaborate analogy. Each preservice teacher received a set of three texts to read – one text about each science concept, with the analogy conditions randomly assigned among the participant group. After they completed the readings, the preservice teachers were asked to respond to a questionnaire about their interest in, understanding of, and ability to explain (to a 5th grade student) each of the science concepts. The preservice teachers also completed a knowledge measures survey that included questions meant to examine the teachers' retention of knowledge about the target concepts, their ability to make inferences about the target concepts, and their metacognitive awareness (how well they believed they understood the concept or how correctly they felt they answered the question).

The preservice teachers ranked topics for which they had received the elaborate analogy-enriched text higher in interest, understandability, and explicability than topics for which they had received either the text with a simple analogy or the text with no analogies, regardless of the topic. All knowledge measures – retention, inference, and metacognitive awareness – were also higher for the science topic for which the teachers received elaborate analogy-enriched text. The preservice teachers indicated in subsequent interviews that they felt more confident explaining a science concept after learning it from an elaborate analogy-enriched text because the elaborate analogy explicitly compared the science concept with another concept with which they were already familiar. Paris and Glynn conclude that:

> The findings of the present study suggest that an elaborate analogy can help learners to make correct inferences by making the similarities between the analog and the target concept verbally and visually explicit. In addition, an elaborate analogy can remind learners that analogies are not perfect and provide examples of where the analogy breaks down, thereby reducing the likelihood that misconceptions will be formed. (Paris & Glynn, 2004, p. 242)

It is apparent from the literature that textual analogies may play a role in making scientific text more accessible to students and that they can be effective and useful learning tools if they are clearly thought out and effectively presented, if students have sufficient time to compare the analog concepts to the target concepts, and if the students know how to use textual analogies as learning tools. In fact, if used well, textual analogies can play an important role in the meaningful learning of scientific concepts. The question, then, is how effectively are analogies currently being used and presented in science textbooks?

How Effective Is Analogy Use in Science Textbooks?

There have been a limited number of published analyses of analogy use in science textbooks, and the majority of these are based on an analysis framework presented in a seminal work by Curtis and Reigeluth (1984), who examined analogy use in 26 elementary, secondary, and postsecondary science textbooks. Since the development of the initial analogy classification scheme by Curtis and Reigeluth, five additional studies have reported analyses of textbook analogies in science textbooks at various grade levels using this scheme or a modification of the scheme. Curtis (1988) used the original classification scheme to compare the use of analogies in science textbooks to that in social science textbooks. Thiele and Treagust (1992, 1994b, 1995) modified the scheme slightly to examine analogy use in high school chemistry textbooks, while Thiele et al. (1995) compared analogy use in high school chemistry textbooks with analogy use high school biology textbooks. Newton (2003) analyzed the use of analogies in 80 elementary science textbooks, and Orgill and Bodner (2006) used a slight modification of Thiele and Treagust's classification scheme to describe analogy use in college-level biochemistry textbooks.

Because each of the aforementioned analyses was done with Curtis and Reigeluth's classification scheme or with frameworks that contained slight modifications to that original scheme, I will first present the modified version of the analogy classification scheme used by Thiele and Treagust (1994b), Orgill (2003), and Orgill and Bodner (2006) before describing the results of the published analyses of analogy use in science textbooks.

Analogy Classification Framework. Curtis and Reigeluth's (1984) original analogy classification scheme was used to systematically analyze analogies according to features that are known to promote meaningful learning of scientific concepts. The slightly modified "Analogy Classification Framework" (Orgill, 2003; Orgill & Bodner, 2006; Thiele & Treagust, 1994b) categorizes analogies in the following areas:

1. *The content of the target concept* – Are there specific concepts that tend to be taught with analogies? Are there specific concepts that are not taught with analogies?
2. *The location of the analogy in the textbook* – Is the analogy found at the beginning of the textbook, in the middle of the textbook, or at the end of the textbook?

In both the Thiele and Treagust (1994b) and Orgill and Bodner (2006) studies, analogy location was determined by dividing the textbook into ten equal parts by page numbers and assigning an analogy to a particular tenth of the textbook.

3. *The analogical relationship between analog and target* – Do the analog and target concepts share similar "structure"? Similar "function"? Similar "structure-function"? Analogies in which the analog and target concepts share only similarities in external features or object attributes – and not in relational structures – are said to have similar "structure." Analogies for which the analog and target concepts share similar relational structures – in which the function or behavior of the analog and target concepts are the same – are said to have similar "function." Analogies for which the analog and target concepts share both similar relational structure and similarities in external features are said to have similar "structure-function."
4. *The presentation format* – Is the analogy presented verbally (in words) or is the analogy presented verbally and pictorially? Here the focus is not on a pictorial representation of the target concept, but on a pictorial representation of either the analog concept or of the analogy – a picture that compares the analog concept to the target concept.
5. *The level of abstraction of the analog and target concepts* – For a given analogy, is the analog concept abstract or concrete? Is the target concept abstract or concrete? In the study completed by Orgill and Bodner (2006), a concept was considered concrete if it was something that a student might see, hear, or touch with his eyes, ears, or fingers in the course of his daily activities. All other concepts were considered to be abstract.
6. *The position of the analog relative to the target* – Is the analog presented before the target concept as an "advanced organizer," with the target as an "embedded activator," or after the target, as a "post-synthesizer"? Orgill and Bodner (2006) considered an analogy to be an "embedded activator" if the analogy was presented in the main text of the chapter in which the primary discussion of the target concept was found. They considered the analogy to be an "advanced organizer" if was presented either in a chapter that preceded the primary discussion of the target concept or if it was presented in a chapter preface where the preface was separated from the main text of the chapter. They considered the analogy to be a "post-synthesizer" if it was presented after the main chapter discussing the target concept.
7. *The level of enrichment* – How much mapping is explicit? Is the analogy "simple," "enriched," or "extended"? While there is some disagreement in the literature about the features of an "extended" analogy, the difference between a "simple" analogy and an "enriched" analogy is clear. A simple analogy is a statement that an analog is similar to a target concept (i.e., "a cell is like a factory"). In an enriched analogy, the analogy statement is accompanied by explicit statements mapping the system of relations in the analog concept to the target concept. "Extended" analogies are either those for which there are multiple explicit mappings (Thiele & Treagust, 1994b) or those which are used multiple times in the same textbook (Orgill & Bodner, 2006).

8. *Analog explanation* – Is the analog concept explained in any detail – either verbally or pictorially?
9. *Indication of cognitive strategy* – Do the textbook authors indicate that they are using an analogy to explain a concept with the word "analogy"?
10. *The limitations of the analogy* – Do the authors state any limitations of the analogy?

Analysis of the Use of Analogies in Science Textbooks. Although the specific number of analogies varies from textbook to textbook, published analyses indicate that the use and presentation of analogies in science textbooks is fairly consistent and not as effective as it could or should be, regardless of the grade level or content focus of the book.

Number of Analogies in Science Textbooks. The number of analogies found in these textbooks was relatively small, seemed to increase with the grade level of the book, and may be correlated with the content focus of the book. In their original study, which included elementary, secondary, and postsecondary science textbooks, Curtis and Reigeluth (1984) found an average of 8.3 analogies per text, which is substantially higher than the number of analogies (2.7/book) found in social science texts (Curtis, 1988). However, studies with more narrow grade foci show an interesting trend. Newton (2003) examined 80 elementary science textbooks. Of these, 45 contained no analogies. In the remaining 35 books, there was an average of 2.6 analogies per book. In their analysis of high school chemistry books, Thiele and Treagust (1994b, 1995) found an average of eight to nine analogies per book. Orgill and Bodner (2006) analyzed college-level biochemistry textbooks, which had an average of approximately 20 analogies per book. It would appear, then, that, in general, more analogies are used in textbooks prepared for students at more advanced grade levels than in textbooks prepared for students at lower grade levels – with the number of analogies increasing, perhaps, with the number of abstract concepts presented in the text. However, this trend may only be true for books in a given content area. While Thiele and Treagust (1994b, 1995) found 8—9 analogies per high school chemistry book, Thiele et al. (1995) found an average of 43.5 analogies per high school biology book. It appears, then, that the number of analogies per science textbook may be a function of both the grade level of the book and the content focus of the book, although this assumption needs to be verified through future research. The number of analogies found in each textbook may also be a function of the individual preferences of the authors (Curtis & Reigeluth, 1984; Thiele & Treagust, 1992) or a function of the manner in which a subject has traditionally been taught.

The published data about the most common location of analogies in science textbooks is very limited. In both secondary chemistry and college-level biochemistry textbooks, more analogies were found toward the beginning of the text than toward the end (Orgill, 2003; Orgill & Bodner, 2006; Thiele & Treagust, 1994b). Common sense suggests that students may need analogies to familiar concepts to help them initially become acquainted with the new topics and words presented in the beginning of a science textbook. However, as students become familiar with the language and concepts of the discipline at the end of a semester or the end of a textbook, they may not require as many analogies to everyday objects and experiences help them understand new science concepts. Instead, they can reference new information to information they have learned previously in the course or in the textbook. Research about biochemistry analogies, however, indicates that the location of analogies in science textbooks may be related to the positioning of particular topics in the textbook (Orgill, 2003; Orgill & Bodner, 2006). For example, all biochemistry textbooks have analogies about enzyme/substrate complementarity, so the sections of the textbook that include the topic of enzymes contain analogies. On the other hand, there is not a single analogy about carbohydrates or lipids in any of the biochemistry textbooks examined by Orgill and Bodner (2006); accordingly, the sections of the book that cover these topics do not contain as many analogies, no matter where the chapter is placed in the textbook. Even so, the chapter layouts of biochemistry textbooks are very similar. Each textbook covers the main topics in roughly the same order, and the topics for which there tend to be analogies tend to be found closer to the beginning of the textbooks than to the end. Whether the placement of more analogies at the beginning of chemistry and biochemistry textbooks is a function of the topics typically covered at the beginning of these textbooks or a pedagogical choice on the part of the textbook authors is unclear. Indeed, it remains to be seen if analogies are more commonly located in the beginning than the end of all types of science textbooks.

Content Foci of Analogies in Science Textbooks. Based on their original, systematic analysis of analogies in science textbooks, Curtis and Reigeluth (1984) suggest that analogies are most effective for concepts that cannot be directly experienced. Duit (1991) noted that in physical science textbooks – which usually have the highest number of well-explained analogies – analogies are used to explain abstract or challenging information (Duit, 1991). This is consistent with the results of Thiele and Treagust (1994b), who found that analogies in chemistry textbooks were associated with concepts that are thought to be difficult or abstract for students, such as atomic structure, bonding, and energy – concepts that are also difficult for students to visualize. Analogies in biochemistry textbooks also tend to focus on abstract or hard to visualize topics, such as reaction energetics, the storage and transfer of genetic information, complementarity of enzymes and their substrates, the functions and behaviors of proteins, cell membrane structure, membrane transport, and the regulation of metabolism (Orgill, 2003; Orgill & Bodner, 2006).

Level of Abstraction of Analog and Target Concepts. The notion that analogies usually cover target material that is difficult or abstract is also supported by the relative levels of abstraction of the analog and target concepts. Overall, the majority of target concepts in science textbooks are abstract in nature, while the majority of analog concepts are concrete in nature (Curtis, 1988; Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele & Treagust, 1994b; Thiele et al., 1995). Generally, concrete concepts are thought to be easier for students to understand than abstract concepts. Therefore, a concrete analog should be used, and generally is used, to help students understand abstract target concepts (Curtis & Reigeluth, 1984). There is, however, another interesting exception in science textbooks written for elementary school students. In those books, concrete analog concepts are often used to explain concrete target concepts – particularly for biological concepts. This may be related to the type of content elementary students are expected to master (i.e., elementary school students might be expected to master science content that is more concrete than what a college student might be expected to master) or of the content focus (i.e., biological concepts may be more concrete overall than physical science concepts); however, this is another matter that will need to be confirmed through future research.

Analogical Relationship Between Analog and Target. Analogies are generally used to make the relational structure of the features of abstract target concepts more clear to students than they would have been after a direct explanation of the target concepts. This finding is demonstrated by the fact that, overall, the majority of science textbook analog/target pairs share similar "function" (Curtis, 1988; Curtis & Reigeluth, 1984; Thiele & Treagust, 1994b, 1995; Thiele et al., 1995). Again, however, the proportion of analog/target pairs sharing similar "function" (as opposed to similar "structure") increases with the grade level of the book (Curtis & Reigeluth, 1984; Newton, 2003; Orgill & Bodner, 2006). For example, the majority of analogies in elementary science textbooks could be considered "structural" analogies, focusing mainly on surface features of the analog and target concepts (Newton, 2003), while approximately 80 % of the analogies in college-level biochemistry textbooks could be considered "functional" because the analog and target concepts share similar functions or behaviors, but not similar surface features (Orgill, 2003; Orgill & Bodner, 2006). This trend may indicate that the expectation for students to learn more abstract or relational features about a target concept increases with grade level.

Level of Enrichment of Analogies in Science Textbooks. Although most analogies in textbooks for elementary schools students are "simple" (Newton, 2003), the majority of analogies in science textbooks for secondary or postsecondary students are explained ("enriched") to some extent (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele & Treagust, 1994b, 1995; Thiele et al., 1995). These analogies are not, however, completely explained. The fact that they are "enriched" to some extent only indicates that they contain at least one explicit mapping between features in the analog and target domains or one explicit indication of why the analog and target domains are being compared. Still, many textbook analogies could be considered "simple" or unexplained. This is particularly true in biology textbooks, which include many simple, unexplained analogies, such as "DNA is the powerhouse of the cell" or "ATP is cellular currency" (Thiele et al., 1995). Unexplained, simple analogies like these can result in misconceptions about scientific concepts (Orgill, 2003; Orgill & Bodner, 2006).

Ideally, analogies should be completely explained or enriched if they are to be understood (Curtis & Reigeluth, 1984; Glynn & Takahashi, 1998), but this is not the case for any of the analogies reported in the published analyses of science textbooks.

Presentation of Analogies in Science Textbooks. The last general set of findings about analogies in science textbooks concerns the manner in which the analogies are presented in the text: whether they are presented verbally or pictorially; whether analog concepts are presented alongside, before, or after target concepts; whether analog concepts are explained; whether analogies are identified as "analogies"; and whether the limitations of analogies are explicitly mentioned. Overall, the presentation of analogies in science textbooks is fairly consistent, regardless of the grade level or content focus of the book, and is not as effective as it could be.

Verbal or Pictorial Presentation? Most analogies in science textbooks are presented in writing or "verbally," to use the phrase from the Curtis and Reigeluth analogy classification scheme (Curtis & Reigeluth, 1984; Newton, 2003; Orgill & Bodner, 2006; Thiele & Treagust, 1994b, 1995; Thiele et al., 1995). Although biology textbooks contain more pictorial representations of analogies than chemistry textbooks (Thiele et al., 1995), none of the textbooks in the published analyses contains many pictorially represented analogies. Curtis and Reigeluth (1984) took the relative absence of pictorial representations of analogies to mean that a verbal presentation of an analogy may be sufficient to promote the educational purpose of the analogy, but those sentiments are not consistent with other published studies, which suggest that the presence of an pictorial representation of an analog concept can promote analogical transfer (Beveridge & Parkins, 1987; Bean, Searles, Singer, & Cowen, 1990). Given the potential importance of pictorial representations of analog concepts for promoting analogical transfer, it is unfortunate that many of the existing pictorial representations of analog concepts in science textbooks are printed in the text margins instead of being aligned with the main text (Thiele & Treagust, 1992, 1994b). Interviews with textbook authors suggest that this marginalization of pictorial representations of analogies is the result of pressure from textbook publishers to minimize the length of science textbooks (Thiele & Treagust, 1992, 1994b).

Relative Position of Analogies and the Main Presentation of Target Concepts. Analogies in science textbooks are typically presented along with (in the same chapter as) the target concept to which they are being compared as "embedded activators" of the target concept (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele & Treagust, 1994b). At times, analogies are presented as "advanced organizers" before the target concept is presented, but they are very rarely presented as "post-synthesizers" after the target concept has been presented. Curtis and Reigeluth (1984) suggest that this placement of analogies as either "advanced organizers" or "embedded activators" relative to target concepts indicates that the most effective position of analogies is either with or before the target concept; however, no published studies have examined the effects of analogy position (before, with, or after the target concept) on student learning.

Analogy Explanation. Finally, despite existing knowledge about factors that promote analogical transfer, analog concepts are rarely explained in science textbooks (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006), analogies are explicitly identified as "analogies" only ~15 % of the time (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele & Treagust, 1992, 1994b, 1995), and the limitations of analogies are infrequently mentioned (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele

& Treagust, 1995). Additionally, none of the science textbooks examined in the published analyses includes a general statement about analogy use or about how students should use analogies to learn (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele & Treagust, 1994b, 1995). By leaving out any explicit statements that indicate the presence of an analogy or explain how analogies are used to learn concepts, textbook authors have implicitly stated their beliefs that students should know how to identify and use analogies on their own. Such spontaneous recognition and use of analogies is not often reported in the literature (Anolli et al., 2001; Holyoak & Thagard, 1989).

Implications for the Future Use of Analogies in Science Textbooks

Science textbooks are important resources for both students and teachers (Newton, 2003), particularly when they are unfamiliar with a given topic. Textual analogies can play an important role in helping both students and teachers develop understandings of these unfamiliar topics, but current research shows that analogies are not used as effectively as they should be in science textbooks. None of the analogies in these books are completely explained, very few are identified as "analogies," and the limitations of the analogies are rarely mentioned. Textbook authors may assume that classroom instructors will explain the analogies that are present in their textbooks, but this is not the case (Orgill, 2003; Orgill & Bodner, 2006). Therefore, textbook authors must provide explanations of their analogies and their limitations if they want students (and teachers) to effectively use these analogies to learn science concepts.

As mentioned previously, the literature about the use of analogies in science textbooks is somewhat limited. The literature about specific pedagogical strategies for effectively presenting analogies in science textbooks is even more limited. However, several researchers have suggested models by which science analogies can be taught and presented effectively. Although the models have not been rigorously tested, they are consistent with the factors that promote analogical transfer. Some of these models were developed exclusively for use by classroom teachers, but their steps, strategies, and points of reflection should also be relevant for those wishing to present textual analogies as effectively as possible.

In the next two sections, I will present two of the teaching models from the analogy literature.

Teaching-With-Analogies Model

The teaching model cited most frequently in the literature is the Teaching-With-Analogies (TWA) model (Glynn, 1991, 1995, 1996). Glynn developed his guidelines for teaching with analogies by examining what he considered to be exceptional analogies from science textbooks. The Teaching-With-Analogies model outlines six steps that teachers and textbook authors should follow when using analogies as teaching tools. Each step is consistent with the factors that have been reported as having positive effects on correct analogical transfer:

1. Introduce the target concept.
2. Cue retrieval of the analog concept.
3. Identify the relevant features of the target and analog concepts.
4. Explicitly map the similarities between the target and analog concepts.
5. Indicate where the analogy breaks down.
6. Draw conclusions about the target concept based on the analog concept.

While these steps do not need to be followed in any certain order, teachers and textbook authors should include the features of each of the six steps outlined above in any discussions that include analogies. According to Glynn (1991), analogy-generated misconceptions can be avoided if teachers and textbook authors explain their analogies clearly by following the TWA model.

Although the TWA model is mentioned extensively in the analogy literature and is consistent with the pedagogical strategies known to promote analogical transfer, there are not many published studies that examine its effectiveness. Additionally, I am not aware of any situation in which a textbook author has used this model to present the analogies in a science textbook.

FAR (Focus, Action, Reflection) Model

Treagust and his colleagues (Treagust, 1993; Treagust, Harrison, & Venville, 1998) developed their FAR (Focus, Action, Reflection) model after observing five experienced teachers who used the TWA model with their favorite analogies. They found that although these experienced teachers did use each of the steps of the TWA model of teaching with analogies when they taught, they did not use the steps in any consistent order. Instead, they modified the order of the steps to meet the needs of their students and of the lesson they were teaching. Though not consistently, these experienced teachers also spent some time preparing their analogies before instruction and reflecting on the effects of using the analogy after instruction – actions that Treagust, Harrison, and Venville felt were necessary for the teachers' efficient use of analogies. Accordingly, the FAR guide integrates preparation and reflection stages into the actual instruction stage of using analogies.

The FAR guide is simpler than the TWA model and is so by design. The developers of the FAR guide felt that there were too many steps to remember in the TWA model, so they developed a guide for teaching with analogies that any teacher could remember easily (Treagust, 1993; Treagust et al., 1998). The steps of their FAR guide are found below (Treagust, 1993, p. 299). Although the FAR model for teaching with analogies was developed for use by classroom teachers, its focus and the questions it poses are relevant for anyone who wants to use textual analogies effectively.

F: FOCUS on the concept being taught and the analog to be used. Is it difficult, unfamiliar, or abstract? What do students know about the concept? Are students familiar with the analog?

A: ACTION. Explicitly connect the similarities between the analog and target concepts and discuss the limitations of the analogy.

R: REFLECTION. Evaluate how the analogy came across to the students and make improvements as needed.

Conclusions

There are a limited number of studies about the effects of textual analogies in science and about how analogies are currently being used in science textbooks. Clearly, more research needs to be done to determine how analogies can be used most effectively in science textbooks and how both students and teachers use analogies from science textbooks to learn. Once that research base has been established, the challenge will be to share this information with textbook authors and to help them find efficient, practical ways to invite investigation into scientific concepts through the effective use of analogies.

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Chapter 6
Textual Features and Language Demands of Primary Grade Science Textbooks: The Call for More Informational Texts in Primary Grades

Nadine Bryce

There is no surprise that intermediate and upper grade students in American schools predominantly read informational texts (Moss, 2005), but it may astound some that half of all reading materials for primary grade students should now be nonfiction. According to the recently adopted Common Core State Standards for English Language Arts and Literacy in History/Social Studies, Science, and Technical Subjects (CCSSO & NGA, 2011; corestandards.org), primary grade students are expected to use and learn from informational texts starting in first grade. In an earlier publication, Frey and Fisher similarly suggested that "…teaching students to read for information must begin with the primary grades" (2007, p. 3; see also, Duke, 2004; Duke & Bennett-Armistead, 2003). But in many schools, young children rarely use informational texts. In this current educational climate of increased technology and global competitiveness, the goal is to increase rigor in reading and writing instruction by increasing access to and production of expository texts, ensuring students are "college and career ready in literacy" when they graduate from high school. By the 12th grade, it is recommended that 70–80 % of the texts students read and write are informational. Thus, the learning standards call for curricular and pedagogical reform to include more informational texts at all grade levels, starting in the primary grades.

Textbooks are a main source of expository reading and remain a predominant instructional tool in all grades except kindergarten (Armbruster & Anderson, 1988; Camp, 2000; Chambliss & Calfee, 1989, 1998; Conderman & Elf, 2007; Moss, 1991, 2005; Palmer & Stewart, 1997; Sewall, 1988, 2005; Sosniak & Stodolsky, 1993). Textbooks dominate 75–90 % of content area instruction (Conderman & Elf, 2007; Moss, 1991). Because of their long-standing use, several educational researchers have articulated the importance of analyzing and evaluating the quality of textbooks to ensure children have access to informational texts they can read and understand.

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The Trouble with Textbooks

Commercially published science textbooks are designed to provide teachers with materials that are tailored to students' reading and interest levels (Frey & Fisher, 2007). Included are the teacher's edition, which contains all the information in the student's copy, plus instructional activities, assessment tips and tools, and suggested methods to differentiate for English language learners and children with disabilities. Also included are multimedia resources (e.g., CD-ROMs, websites), student workbooks, and reproducible worksheets to supplement the major texts.

Difficult to Read. Science textbooks have been rated as difficult to read because they are often written at levels that are too demanding for the intended readers (Daniels, 1996; Moss, 1991; Palmer & Stewart, 1997). In the 1950s, studies analyzing the difficulty of elementary science textbooks used readability formulas based on the complexity of language (as represented by sentence length) and difficulty of words (Mallinson, Sturm, & Patton, 1950; Spache, 1953). Later, readability formulas were reported outdated (Newport, 1965) because they used word lists that did not change with advancing technologies; therefore, newer words like "telephone" and "television" were considered hard because they were not included on the existing lists and made texts appear more difficult. But, readability formulas have been revised and are still used to evaluate text difficulty.

A recent readability study (Daniels, 1996) of secondary textbooks from Jamaica and Australia concluded grade-specific texts were appropriate for children whose knowledge of reading and English matched their grade levels. Some texts were written with simpler language and should have been easier to read, but many secondary students still struggled to comprehend. Daniels attributed the reading struggle to linguistic differences between children's home language and language used for instruction in school. Because many Jamaican and aboriginal Australian children were raised in homes where a language other than English (e.g., Creole) was spoken, learning through official science textbooks in school required learning in a new language.

Several other aspects of science textbooks were identified as problematic and are known to contribute to reading challenges. These textual features and elements of language function synergistically but are parceled apart for contemplation and analysis.

Difficult Vocabulary. Textbooks often use "…difficult technical vocabulary and abstract concepts" (Bryce, 2011, p. 474; see also Camp, 2000; Woodword, 1994; Yager, 1983). In a study of 25 of the most common K-12 science textbooks, Yager concluded that science terminology and specialized vocabulary were introduced at a faster rate than would be expected if readers were learning a foreign language. Introducing a large amount of vocabulary very quickly was a common trend in texts across all grade levels. Overemphasis on learning words and definitions was noted as one of the major contributing factors to the difficulties of learning science with textbooks. Camp (2000) similarly concurred in an article on pairing nonfiction trade books with fiction texts on the same topic to increase student enjoyment and understanding of content area information. She reported, "Students often struggle with content text material because of the density of facts and several vocabulary terms presented in a short amount of text" (Camp, 2000, p. 401). The effects of this struggle with vocabulary was noted in an earlier study of secondary science textbooks, as Woodward concluded, "…given the extensive number of concepts and vocabulary found in most commercial science texts, readers are likely to spend more time engaged in lower-level cognitive processes (e.g., decoding) at the expense of effective comprehension" (1994, p. 300).

Superficial View of Topics. Current textbooks, in social studies particularly, are likely to present a superficial view of topics without much controversy (Paxton, 1999; Sewall, 1988, 2005). Sewall (2005) identified political and market-driven pressures to reduce controversial content and promote sales of textbooks in as many states as possible. Publishing companies, editors, authors, educational consultants at the university level, and textbook adoption committees have been fingered as complicit in producing and promoting ahistoric biases in textbooks (Sewall, 2005; Tyson-Bernstein, 1988a). Abstract and objective writing abound, and content coverage drives the mission. Coverage is so broad in many textbooks that concepts and events are oversimplified, which results in a lack of deep understanding and reflection (Paxton, 1999). In addition, overuse of features (e.g., rich colorful photographs, charts, maps, sidebar text, thought questions, and other visual aids) breaks up the continuity of print and renders text dense and confusing. These findings may have similar implications for science textbooks.

Dry and Uninteresting Language. More explicit, vivid writing common to textbooks written during the twentieth century is reduced in favor of texts that are shortened in response to readability formulas. Complex sentences are broken up by removing syntactic and semantic features (e.g., modifiers, conjunctions, clauses) that contribute to coherence and support reader comprehension (Sewall, 1988; Tyson-Bernstein, 1988b). The resulting language is more abstract, less interesting "lifeless prose" (Paxton, 1999; Tyson-Bernstein, 1988b).

Lack of a User-Friendly Organization and Style. Textbooks often lack a user-friendly organization and employ styles that interfere with comprehension (Chambliss, 1994; Kantor, Anderson, & Armbruster, 1983; Moss, 2005; Tyson & Woodward, 1989). "Information that is poorly organized – that requires either domain expertise or substantial effort for comprehension – impedes learning for many students" (Woodward, 1994, p. 300). Poor text structure, lack of coherence, and questionable audience appropriateness are contributing factors that make texts inconsiderate (Armbruster & Anderson, 1988). In addition, structures that signal main ideas, key concepts, and difficult language (Moss, 1991) are needed to make texts more comprehensible. These elements have been compromised in many cases to meet readability requirements (Sewall, 1988, 2005; Tyson & Woodward, 1989) and make texts commercially viable.

Outdated and Filled with Errors. Many textbooks lack current information and contain errors (Sewall, 1988, 2005). Paxton (1999) noted that history textbooks omit important facts and points of view and some present information that is wrong. Tyson-Bernstein (1988b) presented the work of Lawrence Swan, a biology professor who examined science textbooks to find if they presented errors, inconsistencies, and critical omissions.

Since textbooks are so prevalent and systematically used to introduce content area information, they essentially determine content and pedagogy (Conderman & Elf, 2007; Moore, Moore, Cunningham, & Cunningham, 1986; Moss, 1991, 2005; Woodward & Elliot, 1990). Textbooks must be critically examined to ensure they are of high quality and appropriate for use with intended readers. Teachers can consider the common pitfalls and trouble spots often associated with textbook-based instruction and help students navigate the text through attention to vocabulary, language demands, coherence, breadth and depth of concepts, organization and style, and accuracy. Beyond bringing attention to the text itself, teachers must help children build background knowledge and engage in strategic reading to process the text, sustain meaning, and extend meaning beyond the text.

Systematic Analysis of Textual Features and Language Demands in Science Textbooks (and the Impact on Instruction)

Textbooks need not be judged as "good" or "bad"; instead, they can be viewed as important resources for content area instruction (Sosniak & Stodolsky, 1993). Teachers must consider the strengths and weaknesses of the particular textbook they are advised or mandated to use, to gain the most value pedagogically. The goal is to use textbooks thoughtfully to promote reading comprehension and student learning.

Thoughtful use of textbooks as resources for learning can be supported by a systematic examination of key features and language demands. The examples presented are gleaned from a primary grade textbook, entitled *Science: New York City Edition* (hereafter referred to as *"Science"*) (Harcourt, 2008).

Assess the Difficulty of the Text. The Flesch-Kincaid Grade Level Index uses the average number of words per sentence and the average number of syllables per word to establish a grade level index. I used it to determine the level of difficulty of the *Science* (Harcourt, 2008) textbook designed for children in second grade. As is customary, excerpts of the text were taken from the beginning (Chap. 1), middle (Chap. 4), and end (Chap. 6) of the book (Daniels, 1996). For consistency, I sampled the third and fourth pages in each of three chapters because they contained the most (four paragraphs) text. I did not include pictures and labels or focus skills questions located at the top and bottom of the page because each chapter contained a wide variation in the number of pictures and captions included. Chapter 1 had five pictures with captions, but Chaps. 2 and 3 had none. I also did not include "Insta-Lab" activities which were set off to the side; these practical tasks were found in Chaps. 4 and 6, but not Chap. 1. Table 6.1 summarizes the results of the readability scores established for excerpts from the three chapters.

The grade level index suggests, as is common for many textbooks, that the text is too difficult for the intended second grade students and may be best used with students

Table 6.1 Flesch-Kincaid Readability Grade Level Index for "Science: New York City Edition" (Harcourt, 2008)

Excerpts of chapters	Words	Sentences	Syllables	Grade level
1	133	13	188	5.0
4	95	14	131	3.3
6	100	11	120	3.1

in third–fifth grades. The most difficult excerpt is in the first chapter; it contains more complex text and more challenging words. The book appears to become easier to read as it progresses from start to finish, based on the grade level scores.

Proceed with Caution When Interpreting Readability Scores. Readability formulas do not consider many factors that affect the difficulty of a given text for particular readers. Characteristics such as reader background and familiarity with the topic, text structures and organization, coherence, or audience appropriateness can influence how challenged readers are by a given text. In this analysis of a second grade science textbook, it is possible that the Flesch-Kincaid Grade Level Index scores overestimated the difficulty of the text. In a study of nonfiction reading using science textbooks (Bryce, 2011), second grade teacher, Ms. Wallace, recognized the difficult language in the text (Harcourt, 2008) and used it for whole-class guided reading, with much success. Through read alouds, Ms. Wallace modeled fluent reading and pointed out text structures to guide and support comprehension. Individual children were selected to read the text interactively to the class, with teacher support if needed. Ms. Wallace initiated and led discussions that offered additional explanations, and she encouraged text-to-self connections. Further, she emphasized meaning through dramatization and prompted children to act out concepts. While reading about force, children were asked to dramatize how they used force to move their books and their chairs and kick an imaginary ball, which improved comprehension.

It is important for teachers to consider text difficulty in some systematic way before using it for instruction. If the measure of text difficulty indicates the grade level textbook may challenge current students, there are several efforts teachers can make to support successful nonfiction reading and content area learning.

Examine the Main Ideas, Key Concepts, and Vocabulary Signaled by Text Structures. Authors use structural cues, such as the table of contents and subject index, to organize and present the range of ideas and concepts in textbooks. It is helpful to preview them to get a sense of the topics presented and what additional information may be needed for enrichment. Chapter headings and subheadings show the order of ideas in each section. Margin notes, bulleted items, thought questions, diagrams, charts, and graphs, as well as photographs and captions, illustrate and expand ideas in the text. Visual aids serve as navigational tools and supplements to the text. They are purposeful for presenting, or analyzing and synthesizing information, but they also encourage the development of visual literacy – the "…decoding and comprehension of…[visual] elements to make sense of and interpret images" (Bryce, 2012, p. 181). Teaching children to recognize and familiarize themselves

Fossils

Dinosaurs were animals that lived millions of years ago on Earth. No dinosaurs live on Earth now. They have all become **extinct**, or died out. They were not able to survive in their environment.

Scientists have learned about dinosaurs from their fossils. A fossil is what is left of an animal or a plant that lived long ago. A **fossil** can be a footprint or an impression in rock. Fossils can also be shells, teeth, and bones that have turned to rock."

Fig. 6.1 Enlarged, bolded, highlighted fonts were common textual features used to signal key concepts and vocabulary in each chapter (Harcourt, 2008, p. 48)

with the structure and organization of the textbook increases their capacity to use it meaningfully (Burke, 2000). But more importantly, it prepares them for receiving new knowledge.

User-friendly texts are "considerate" (Armbruster & Anderson, 1988), have a clear and predictable framework for organization, and are easy to navigate. Frey and Fisher stated,

> Science textbooks are often organized using introductory thesis paragraphs, followed by supporting details in subsequent paragraphs. Vocabulary is essential to the field of science and is frequently introduced through a bolded word and an example. However, students may find this format frustrating because an explicit definition may not be found in the body of the text. Pictures, charts, not surprisingly, are used to illustrate phenomena and offer more details about the topic. Although many text structures may be used throughout the science book, cause and effect is the most common. (Frey & Fisher, 2007, p. 11)

Examine the Organization of Ideas in Small Sections of Text. In *Science* (Harcourt, 2008), major ideas and key concepts were similarly organized in each chapter. Each excerpt began with an introduction of three vocabulary words which were listed at the top of the page and subsequently explained in sentences within the body paragraphs (Fig. 6.1). The main heading was written in enlarged, bolded, colored font. Each vocabulary word was bolded, highlighted, and explained with an example.

To systematically review the textbook, teachers must look at the text within each chapter to see how information is organized and presented. Make note of specific textual features and language demands (e.g., headings, bolded and highlighted words with definitions) used to introduce and explain content and concepts. Children's understanding of expository structures, such as "main idea and details," develops from exposure to and explicit teaching of these predictable textual patterns. The *main idea and details* structure was quite common; almost always, the first sentence was the main idea, followed by details.

In Fig. 6.1, the key terms were highlighted in yellow and bolded. The definitions were set off by a comma (e.g., "They have all become **extinct**, or died out."). Definitions and examples also appear in separate sentences that follow (e.g., A fossil is what is left of an animal or a plant that lived long ago. A **fossil** can be a footprint or an impression in rock.). Teaching children to recognize language that is used to define terms (a fossil *is*…) or show examples (a fossil *can be*…) will improve comprehension and build schema important for understanding key concepts.

Table 6.2 Inquiry skills and science tools

Inquiry skills	Science tools
Observe	Hand lens
Compare	Magnifying box
Classify	Forceps
Sequence	Ruler
Measure	Tape measure
Make a model	Dropper
Hypothesize	Measuring cup
Infer	Balance
Draw conclusions	Thermometer
Predict	
Plan an investigation	
Communicate	

To build an effective conceptual framework for learning science from a science textbook, children need instruction in identifying text structures (e.g., main idea and details; cause and effect; sequence), as well as vocabulary and language used to teach key concepts (Moss, 2005).

Determine the Overall Text Structure and Preview the Content. In *Science* (Harcourt, 2008), there is one introductory unit on science literacy and three content units – Earth Materials, Forces and Motions, and Plant Diversity. An Enrichment Chapter on Weather and a References section are included at the end of the book.

Each chapter has three lessons and begins with a vivid two-page color photograph designed to appeal to young readers. The variety of images range from experiences children may have had (e.g., observing and making predictions using familiar objects, such as estimating the number of pennies it takes to fill a jar and then comparing the estimate to the actual amount) to experiences that are far less familiar (e.g., riding the waves at Cortes Bank, an undersea mountain range 100 miles from shores of Los Angeles, California). These striking images are quite engaging and directly relate to the concepts explored (e.g., learning about inquiry skills; learning about measuring ocean waves).

Inquiry skills and science tools (Table 6.2) are introduced in the first chapter and used to carry out "Insta-Lab" activities included in some lessons throughout the book. They are also used to carry out investigations at the start of each chapter.

Consider the Depth of Information Addressed. After each title page in every chapter, there is an "Investigation" that integrates hands-on activities with the topic of study to get children to learn through exploration and investigation. Review each chapter to examine the level of detail and thoroughness with which concepts and topics are addressed. Learn how the authors connect topics to exploratory learning experiences designed for the investigations, and consider what knowledge of science children may gain after completing them.

Investigations are fundamental to the learning experiences in this textbook and described in lesson 3 of the first chapter. Scientists use the inquiry cycle to develop scientific investigations (Harcourt, 2008, pp. 20–22):

1. Observe, and ask a question.
2. Form a hypothesis.
3. Plan a fair test.
4. Do the test.
5. Draw conclusions, and communicate results.
6. Investigate more.

In the chapter on Natural Resources, children explore “What Happens to Pollution?” For the investigation on pollution, children are instructed to add trash to a tray of soil, put it in a sunny place, and water it three times a week for 1 month. Throughout the month-long investigation, they communicate their observations and findings with classmates. Finally, they observe and record what happened to the objects when they uncover them at the end of the month. The inquiry skill emphasized in this activity was observation.

The investigation is connected to statements that relate to the chapter heading, “How Can People Harm Natural Resources?” and outlines the ideas explored in the chapter. On a whole-page image of a littered beach, a “Fast Fact” box states:

> Litter may harm birds and fish that try to eat it. You can observe pollution to find out what happens to some of it. (Harcourt, 2008, p. 72)

To make the connections more coherent, children must infer the connections between the picture on the title page and the “fast fact.” They should wonder what harm birds and fish face when they eat trash that does not belong in their natural environment, the beach. They must infer connections between trash on a beach and their investigation of what happens to trash after it starts to decay in wet soil after 1 month. The connections are made more explicitly in the chapter.

> Trash that people do not put in trash cans is called litter. Litter can harm plants and animals. Plants covered by litter cannot get the light they need to make food. Animals can get trapped by litter. If animals eat litter, they may get sick.” (p. 75)

Children can use the image of trash on the beach to interpret the paragraphs, and make connections beyond the context shown in the book, to their own experiences with trash in other natural environments.

The main idea is, “Putting trash in landfills keeps it from making water and land polluted” (p. 75). This is a true, but simple, statement. The purpose of landfills is to provide for waste disposal, which does keep land and water clean. But the US government’s Environmental Protection Agency (epa.gov) presents information on the harm landfills potentially cause to land, water, and air supplies. Waste material can contaminate adjacent bodies of water and land sites if landfills collapse or sink. Waste water from landfills can seep into underground water supplies. Methane and other gases from decomposing materials may be released into the atmosphere and contribute to greenhouse gases.

The limited presentation of information related to each topic (e.g., pollution) and the inferences needed to make coherent connections between the images and text

Table 6.3 Reading Focus Skill – Four Examples from Science: New York City Edition (Harcourt, 2008)

	Main idea and details	Cause and effect	Compare and contrast	Sequence
Before reading	Look for details about the inquiry skills that scientists use. (p. 4)	Look for the causes and effects of pollution. (p. 74)	Look for ways living and nonliving things are alike and different. (p. 132)	Look for the order of seasons and ways the weather changes from one season to the next. (p. 186)
After reading	*What are some inquiry skills? (p. 5)*	*What are some effects of air and water pollution? (p. 75)*	*How are the animals and plants alike? (p. 133)* *What living and nonliving things are in the picture below? How are they different? (p. 134)*	*How does the air change in spring? (p. 187)*

will impact readers' comprehension. The limited text may be age appropriate for second graders (remember, the readability scores indicate grade levels 3–5), but limited presentation of information and inferences needed for good understanding must be addressed. This suggests teachers need to consult a larger body of information for each unit to ensure the curriculum offerings are robust and accurate. They must also teach children to read critically, question the text, and consult other resources to gain multiple perspectives.

Learn About the Cognitive Demands Related to Expository Structures. Each chapter uses a "Reading Focus Skill" statement or question to help children activate their thinking skills and learn content. These "thought statements or questions" are addressed before and after reading extended sections of text, at the beginning, and end of each chapter (Table 6.3).

The pre- and post-reading focus skill statements and questions help readers set the expectations for learning before they read, and review what they learned after. This pre- and post-reading structure is common throughout all the chapters. Focus questions change in each lesson and chapter and are designed to help children learn content through awareness of expository text structures found in the book (Table 6.4).

An analysis of the frequency of expository text structures (Table 6.4) presented in *Science* (Harcourt, 2008) shows contradictory results with Frey and Fisher's (2007) findings. Instead of "cause and effect" (27.7 %), "main idea and details" (38.8 %) are the predominant expository structures addressed throughout the book (Table 6.5).

"Main idea and details" and "sequence" statements and questions emphasize literal comprehension, while "cause and effect" and "compare and contrast" statements and questions encourage literal comprehension, making connections and inferences.

Children benefit from awareness of these expository structures and how they are designed to support thinking about content. They should be encouraged to use these focus skill prompts as guides for their thinking before and after reading. They can talk with their peers to reflect on and review what they learned and then write a response to each question to support thinking and learning.

Table 6.4 Organization of main ideas and expository text structures

Chapters	Lessons	Expository text structures
1 Exploring Earth's Surface	1: What Changes Earth's Surface?	Cause and Effect
	2: What are Rocks, Sand, and Soil?	Compare and Contrast
	3: What can We Learn from Fossils?	Sequence
2 Natural Resources	1: How Can People Use Natural Resources?	Main Ideas and Details
	2: How Can People Harm Natural Resources?	Cause and Effect
	3: How Can People Protect Natural Resources?	Cause and Effect
3 Motion	1: What Are Ways Things Move?	Main Idea and Details
	2: What Makes Things Move?	Cause and Effect
	3: How Do Magnets Move Things?	Main Idea and Details
4 Living and Nonliving Things	1: What are Living and Nonliving Things?	Compare and Contrast
	2: What Do Animals Need?	Main Idea and Details
	3: What Do Plants Need?	Main Idea and Details
5 Plants	1: What Are the Parts of a Plant?	Main Idea and Details
	2: How Do Plants Differ?	Compare and Contrast
	3: What are Some Plant Life Cycles?	Sequence
6 Weather	1: How Does Weather Change?	Sequence
	2: Why Do We Measure Weather?	Main Idea and Details
	3: What Is The Water Cycle?	Cause and Effect

Table 6.5 Percentage of explicit expository structures in primary grade science textbook

	Percentage
Cause and effect	27.7
Compare and contrast	16.6
Main idea and details	38.8
Sequence	16.6

Evaluate How the Text Engages the Reader and Creates Interest. Pictures abound throughout the text, and as Frey and Fisher note, they illustrate and add details, contributing to elements that make this an interesting (versus uninteresting or "dull") text to read (Hidi & Baird, 1988).

Interest and engagement are deepened with the use of large, whole- or half-page, vividly colored photographs of objects, natural resources, and people. Images of children and adults are shown carrying out activities, observations, and experiments. A girl rollerblades to illustrate the concept of "speed"; a baseball player leaps high into the air to catch a ball; a woman boards a bus to show how she saves energy; a volcano erupts – hot lava spews from the top and runs down the sides of a mountain, turning everything to ash.

Throughout the book, images reflect pleasant-looking people with smiling faces, and those who appear to be concentrating deeply while interacting with materials and resources. Images of plants, animals, and natural resources are vivid and bright and presented with great detail. Images are commonly labeled, and larger pictures often have captions. Children should read and discuss the meaning conveyed in pictures and contemplate how these images add meaning to the text.

Stories about the practical use of technology (e.g., Canadian students who set a world record by driving a solar-powered car for 9,368 miles across Canada and the United States) and profiles of people (e.g., Nico Reyes and community members planting trees in celebration of Earth Day) are presented between chapters. Science projects for home and school are also shared in these chapters.

There is a "References" section at the back of the book. It includes a "Health Handbook" that includes diagrams and labels and pictures to illustrate the five senses and systems of the body (e.g., circulatory, respiratory, digestive), along with tips on how to care for the body. This section also includes explanations of the expository structures used throughout the book (e.g., identifying the main idea and details, compare and contrast, cause and effect, sequence, draw conclusions, and summarize (pp. R 14–R 19)). Also included are information on how to read visual texts (e.g., tables, charts, graphs, tallies and pictographs), linear and liquid measurements, and an illustrated glossary.

Throughout the textbook, the human-interest stories and activities are highly engaging. Visual texts add meaning to print (Bryce, 2012) by enlivening the content and providing concrete examples related to learning about the natural world and its resources. These attractive images may not result in learning greater amounts of scientific information but are important for keeping children interested in the text and potentially improving cognitive performance (Hidi & Baird, 1988). The reference section is rich and detailed and contains not only vocabulary terms but strategies for supporting better nonfiction reading. This section should be read early in the school year and reviewed several times to reinforce strategic reading.

Review and Understand Assessment Tools. At the end of each chapter is a "Reading Review" that instructs the reader to complete a task related to the expository text structure addressed in one or more lessons. Items include "fill-in" the blank to complete short sentences that reflect the concept and structural skills addressed. Answers can be found directly in the text.

1. *Main Idea and Details***.** Copy and complete this chart. Tell how people use natural resources.
   Main Idea and Details
   People use natural resources to meet their needs.

   A. People breathe _____.
   B. People use _____ to clean.
   C. People use _____ to get metal.
   D. People use _____ to make bricks to build with.
   E. People use _____ to make clothing and paper. (Harcourt, 2008, p. 71)

In addition, children are prompted to complete a "test prep" item, which familiarizes them with the multiple-choice format and assesses their understanding of key concepts. For example,

How can you tell it is spring?
A. Trees have no leaves.
B. Trees grow new leaves.
C. Some leaves change color.
D. Trees have lots of leaves. (Harcourt, 2008, p. 191)

Readers are prompted to use cognitive strategies and writing to learn (e.g., write a summary). Further, visual images are integrated into almost all assessment tools and can carry meaning. In several examples, children are asked to demonstrate knowledge of relevant vocabulary using text and pictures (e.g., "Use the term *natural resources* to tell about this picture" [p. 71]; "Use the terms *magnet, poles, attract*, and *repel* to tell about the picture" [p. 119]).

Additional post-lesson activities give children opportunities to write (e.g., draw and label, write a few facts) about the topic and capitalize on the social context to share ideas with classmates. Links and activities on the publisher's website (hspscience.com) provide additional resources for exploration; hence, literacy and technology are meaningfully integrated throughout the book.

Extension activities include art for learning, kinesthetic activities that encourage children to express meaning with their bodies, and applying observation and recording skills to math measurement activities. These activities go beyond the limited information provided in the chapters and encourage a more interactive, integrated approach that bridges content area knowledge with real-world experiences, visual and print literacies, technological literacies, and textbook-based instruction.

Judge the Accuracy of the Content. The recent publication date and current website information suggests the textbook (Harcourt, 2008) is up-to-date. Photo credits suggest a widely consulted body of information that supported the development of content for this book. But no major resources on science content were revealed. To judge the accuracy of the content, teachers ought to consult other resources and examine the textbook alongside other science texts for consistencies and inconsistencies. Kulm, Roseman, and Treistman (1999) evaluated middle school textbooks by examining how closely the content aligned to benchmark learning goals and science standards established by Project 2061, a "long-term science education reform initiative of the American Association for the Advancement of Science" (p. 147). Reviewers looked for the degree of alignment between the selected leaning goals and instructional support and materials for students and teachers. The results for science textbooks were not available at the time of publication, but the model suggested a viable option for reviewing curriculum materials in a systematic way. For teachers to ensure accuracy and go beyond a superficial presentation of topics, they will need to consult additional science texts to review the quality of ideas in the textbook and seek additional resources to enrich instruction, as needed.

Discussion

Currently, there is a dearth of nonfiction reading and use of informational texts in the primary grades. Expository texts are used for literacy instruction in elementary and middle schools at a low rate of 7–15 % (Moss & Newton, 2002; Yopp & Yopp, 2006). In her seminal study of 20 first grade classrooms in low- and high-income communities, Duke (2000) learned of the scarcity of informational texts, limited to 3.6 min a day, on average. Further, children from low-income communities in the participating schools spent even less time on informational reading and writing, as low as 1.9 min per day. Limited access to informational texts and material resources may explain why nonfiction reading and writing were infrequent in some classrooms in Duke's study. But for many others, limited or no use of informational texts in primary grades may be related to curriculum enactment and pedagogical practices that privilege narrative over expository texts.

Many educators and curriculum developers believe young children must first learn to read (stories) before they can *read to learn* (from informational texts). This view is challenged by current research on the use of informational texts in the early grades (Bryce, 2011; Moss, 2005; Pappas, 2006; Varelas & Pappas, 2006) which examine effective connections between content area learning and literacy.

Bryce (2011) examined the work of four primary grade teachers using science textbooks for nonfiction reading at an urban school in New York City. In all four classrooms, teachers taught and reinforced strategies for improved reading comprehension. The third grade special education teacher, Ms. Counts, taught students with reading disabilities to attend to difficult, technical vocabulary and abstract ideas (Yager, 1983) through discussion and guided reading, using an interactive whiteboard and individual copies of the textbook. The general education third grade teacher, Ms. Miah, supplemented the textbook with other reading materials and digital media resources to add depth of information that went beyond the superficial presentation of ideas in the textbook (e.g., Tyson-Bernstein, 1988a). The second grade teacher, Ms. Wallace, who used *Science* (Harcourt, 2008), breathed life and meaning into the text through oral reading, interpretation, discussion, and dramatization while acknowledging the tendency of textbooks to use "boring" and "uninteresting" language (Tyson & Woodward, 1989). The first grade teacher, Ms. Tsveer, encouraged children to keep in mind organizational and structural features (Chambliss, 1994; Kantor et al., 1983) to support their memory of topics they have heard read aloud and predict topics that will appear in the following chapter. These practices promoted deeper understanding of science concepts and offered young children opportunities to read (or listen to an oral reading of) science textbooks.

Informational trade books are being published at an alarming rate, but one primary source of nonfiction reading in the primary grade classrooms is still the science textbook (Bryce, 2011; Pappas, 2006). In this chapter, the systematic review of one science textbook, *Science* (Harcourt, 2008), provides an example of how teachers can approach the evaluation of science textbooks as tools for reading and content area learning.

Science textbooks may be written at levels that are too challenging for the intended readers. They often have difficult technical vocabulary that are introduced too quickly and sometimes without sufficient explanation. Children can spend more time decoding than trying to comprehend while they read. Science textbooks may also present a superficial view of topics, the information may be oversimplified and lack controversy and important details, or there may be omissions, outdated information, and other errors. There may be an overuse of visual features (e.g., charts, maps), which breaks up the continuity of print. The language may be obscure and abstract, and the writing dull and uninteresting. If the organization and structure are difficult to discern, it presents even more challenges. Science textbooks must be carefully evaluated before they are used for instruction, to mitigate these challenges, and prepare students to use them effectively for learning.

Teachers benefit from examining the difficulty of science textbooks, perhaps through readability index scores to establish the grade level of the text. Readability scores may indicate whether a text is too challenging for intended readers, but they provide only a partial perspective. Teachers must consider other factors of the reading context, such as children's backgrounds and familiarity with the topic, organization and structure of the text, and the text's coherence and appropriateness for their class before deciding if the text is too hard. Teachers ought to examine how the main ideas, key concepts, and important vocabulary are structurally arranged and presented using textual features (e.g., main idea and details, cause and effect; bolded, highlighted font). This suggests they should look at the organization of small sections of text within each chapter and the organization of the entire book. The depth and breadth of information and the levels of cognitive demand should be considered. Teachers should develop a clear sense of how expository text structures are used to organize and present information. Examining features that generate student interest and engage learners will provide teachers with tools for making connections to real-world experiences and promoting visual, print, and technological literacies. Supplemental sections of the text can be used to extend learning by providing other topics in science to study. In *Science* (Harcourt, 2008), supplemental sections also provided resources that supported nonfiction reading and explained the range of expository text structures used in the text. Evaluating the accuracy of the text may be more difficult if the authors and publishers did not provide references. In this case, teachers may need to consult state science standards and learning goals in their district to judge how effectively the science textbook may be for meeting these benchmarks for learning.

Instructional Implications

Content area instruction increases as children advance through the grades, and access to expository texts increase, often through textbooks (Sewall, 1988, 2005). There are efforts to enrich content area instruction with nonfiction trade books (Palmer & Stewart, 1997), but overwhelmingly, textbooks are the predominant instructional tool in the content areas, even for the youngest learners in the primary grades. Textbooks have been in use for centuries in the USA, but as they continue to evolve, they pose significant challenges to reading and comprehension for more experienced readers, and are especially difficult for very young readers.

This chapter addressed structural features and language and literacy demands of science textbooks used for primary grade children. Primary grade teachers who seek to improve their practice of teaching with informational text can benefit from a systematic approach to analyzing the textual features and language demands of current science textbooks to foster reader interest and improve comprehension.

Recommendations for Teaching with Science Textbooks

Reading Grade Level Texts. In general, primary grade students will be expected to read and learn from grade level texts during content area instruction. For many, this reading option does not present an overwhelming challenge, and for a few, reading the grade level text may be very easy. But some students will struggle. Using a challenging textbook with struggling students may frustrate them and lead to poor comprehension, even when they can effectively decode. This requires teachers to:

- Preview the content with the children before starting to read
- Teach vocabulary awareness and how to find definitions in the text
- Supplement the textbook with other print and nonprint resources
- Teach reading comprehension strategies explicitly
- Require children to write in response to reading
- Expose children to a wide variety of nonfiction texts, not just textbooks

Preview the Chapter and Set Expectations for Reading. Teaching children to preview the text to learn about the overall organization of ideas promotes understanding (Moss, 1991, 2005). Children should use the table of contents and subject index to scan the range of topics addressed and ask questions, as relevant. They should also look through the book, and into each chapter, to see if they can recognize structural and textual patterns that help them navigate the topics, key concepts, and vocabulary. Strategies for gaining meaning from print and visual texts should be taught. Children should be also taught to recognize and use structural signals in the text, including headings, subheadings, key concepts and highlighted vocabulary, photographs and captions, charts and graphs, and other visual displays (Chambliss & Calfee, 1989).

Teachers should set expectations for learning by previewing the headings and chapter questions. They should also provide children with opportunities to ask genuine questions and make connections to their prior experiences and background knowledge. It is important for children to unearth their assumptions and misconceptions about the content and develop the courage and capacity to question the text, so they can have fruitful discussions about what they know and understand and what they are unsure of and do not know. They should talk about concepts and ideas with peers and engage in buddy reading of the textbook to provide a social context for making meaning with informational science texts and improving decoding and fluency.

In this specific textbook, explicit instruction on expository text structures, such as those presented in the References section (Harcourt, 2008) at the back, will build a foundation for using the focus skills questions in each chapter to learn content and concepts in science. Also, addressing the differences between inquiry skills and inquiry tools will prepare readers to use materials (tools) to help them inquire (skills) or carry out an investigation about specific scientific phenomena explored in each chapter.

Teach Vocabulary Awareness. Teachers should introduce challenging vocabulary in grade level science textbooks. Read and review vocabulary with children and help them make connections to previous knowledge or experiences with those words (Camp, 2000; Woodward, 1994; Yager, 1983). Look in the book for textual features and language that support vocabulary development. Remind children that definitions are sometimes set off by commas, or illustrated by words in other sentences.

For example,

No dinosaurs live on Earth now. They have all become **extinct**, or died out. They were not able to survive in their environment.

Teachers must explicitly teach children to recognize textual features and patterns to support vocabulary awareness and development.

Supplement the Textbook with Other Print and Nonprint Sources. With content area learning, children should work towards developing rich and complex knowledge of a topic; therefore, they need to explore other print (Moss, 2005) and nonprint sources (Bryce, 2012) to deepen their understanding and go beyond the limited range and depth provided in the textbook.

Teach Reading Comprehension Strategies Explicitly. Teaching reading strategies for comprehending prose in domain-specific ways and increasing awareness of the process of making meaning with content area texts (Cook & Mayer, 1988) are essential for effective use of science textbooks. Teachers should help children learn to scan the text to preview each chapter before reading. They can also be introduced to the overall structure of the book. Awareness of textual structures can guide comprehension. It helps readers to gain conceptual understanding and a framework for learning and remembering what they read. It also helps readers build mental representations to develop a relevant schema, or network of ideas.

Teachers should concentrate on teaching students to (Cook & Mayer, 1988):

- Select what is most important in the textbook
- Connect new information to what is known
- Connect new information to one's own experiences and understanding
- Connect new information to what is learned in other texts, broader contexts, and events in the world

Teaching about textual features will include vocabulary awareness and concept development. Children should focus on the bolded, highlighted words and definitions and examine the explanations in the text. Review, discuss, and ask children to write a reflection and summary using the vocabulary terms.

Actively applying reading comprehension strategies help children to improve understanding. Teachers should model, guide, and provide independent practice as students engage in:

- Questioning
- Summarizing
- Inferring
- Self-monitoring
- Making connections
- Predicting
- Analyzing
- Evaluating ideas in the text

Awareness of the range of reading comprehension strategies to use while reading (e.g., what cognitive strategies are, when to use them, and why) builds metacognition and improves understanding. Before, during, and after reading, children can talk about which reading strategies might help them understand and remember what they read.

Children should also be taught to read science textbooks critically (Alvermann, Moon, & Hagood, 1999; Vasquez, 2004). Every source contains bias and specific points of view, and divergent perspectives should be sought. Therefore, teachers should model how to research and consult other sources for multiple viewpoints and supplement the textbooks with other nonfiction (and fiction) print and nonprint texts (Moss, 2005).

Require Children to Write in Response to Reading. In addition to discussing key concepts and vocabulary, writing reflective notes and questions in response to the text will support effective reading comprehension and content area learning (Angelillo, 2003). Writing clarifies thinking, improves expression, and supports comprehension. After reading, and in preparation for writing a summary, children can be encouraged to answer focus skills questions the author posed or develop their own questions from reading headings, subheadings, and highlighted vocabulary and recording what one wonders about them. For example, in *Science*, the authors asked a sequence question. "What happened to some plants and animals that lived long ago?" (Harcourt, 2008, p. 49). Readers can keep that question in mind but should be encouraged to wonder about the heading "Fossils." They should be encouraged to think and write questions, such as "What are fossils? Why are they important?" After reading, they should be encouraged to answer both the focus skills questions and the questions they developed on their own to support vocabulary development and deepen understanding.

Other suggested activities encourage writing and bridging science and social studies. For example, an extension activity encourages comparison and contrast of current and historic animals and plants.

> Observe fossils found in your state. Compare them with animals and plants that live today. Draw a picture of a fossil and a picture of a plant or animal that lives today. Tell how they are alike and how they are different. (Harcourt, 2008, p. 53)

Expose Children to a Wide Variety of Nonfiction Texts, Not Just Textbooks. It is pedagogically unwise to wait until children enter fourth grade before nonfiction texts become emphasized. Therefore, teachers must increase primary grade students' exposure and access to nonfiction (Duke, 2004). Familiarity with multiple genres, including text types and purposes, increases children's ability to navigate through the texts in order to learn from them. Teachers of young children need to consider more effective ways to help them build awareness, knowledge, and skills needed to read and comprehend informational texts.

Young children benefit greatly from using informational texts. With a wider array of nonfiction texts in multiple genres, children become exposed to a larger vocabulary, learn more about informational text structures and how to use them to learn from nonfiction texts, gain content area knowledge, and are motivated and interested to learn (Pentimonti, Zucker, Justice, & Kaderavek, 2010). Primary grade teachers must rethink their overload on narrative at the expense of informational texts and learn to value and prioritize nonfiction to promote academic rigor and enhance teaching and learning. Young children can simultaneously learn to read while reading to learn from informational texts.

Start in Preservice Education. Pre-service and beginning teachers sometimes experience tension between their perceptions of textbooks. On one hand, textbooks are "bad" because they reflect predetermined curriculum and strongly influence what is taught and how. On the other hand, the reality of many teachers suggests that textbooks are commonly mandated by districts and *have* to be implemented in classrooms. Preservice teachers are often taught that an effective teacher is one who plans her own lesson and develops her own curriculum. These newer teachers tend to distrust textbooks or feel stifled by them. But at the beginning of their careers, they often lack professional knowledge of subject matter, child development, and teaching to make other curricular choices. Ball and Feiman-Nemser (1988) reported that preservice teachers have great challenges keeping up with the demands of day-to-day instruction and life in the classroom, not to mention planning and developing lessons. Textbooks can be resources for planning, teaching, and evaluating learning. Teachers must learn how to justify their curriculum and planning choices, more about the subject matters they teach, and develop skills at supporting strategic, active reading. Finally, they must develop a strong sense of academic freedom and curricular independence to use textbooks as viable instructional resources.

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Part III
Content Analysis of Science Textbooks

Chapter 7
A Review of the Earth Science Content of Science Textbooks in England and Wales

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Background to the Review

Earth science has formed part of the National Curriculum for Science (NSC) since it was first instituted in England in 1989 to the present day. The amount of Earth science has varied through the different reviews, and if the amount of Earth science content at secondary-school level (high school, 11–16-year-olds) is judged by the percentage of Earth science content statements, it has averaged at about 7 %. The secondary NSC is subdivided into the content aimed at 11–14-year-olds (Key Stage 3, or KS3) and that aimed at 14–16-year-olds (KS4). All government-maintained schools in England and Wales are required to follow the National Curriculum, and it is assessed by national examinations; the national examination for KS4 students is the General Certificate in Secondary Education (GSCE).

Secondary (high school) science teachers teaching Earth science as part of the NSC in England and Wales were asked by questionnaire to provide information on the background to their Earth science teaching (King, 2001; 146 teachers, 57 % male, 43 % female). The survey showed that 63 % of the teachers had received no Earth science

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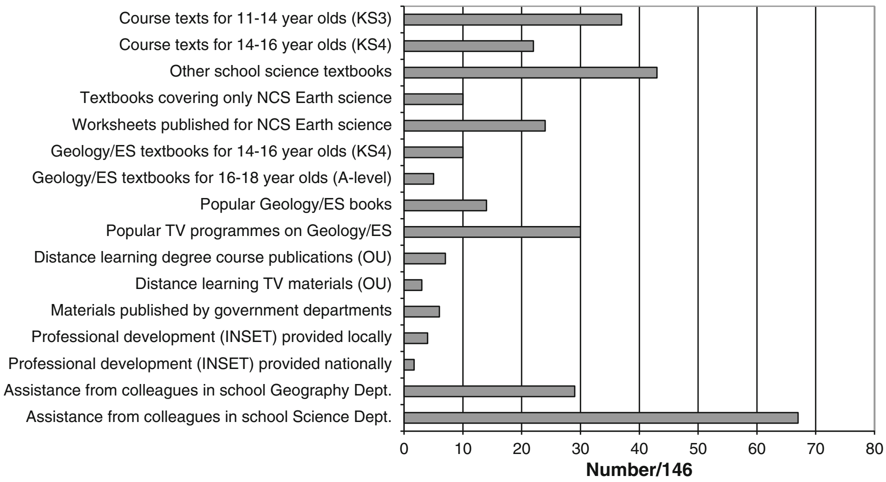

Fig. 7.1 Responses by science teachers of Earth science to the question: Which of the following have you found helpful in your Earth science teaching so far? ($n = 146$) (*INSET* in-service education and training, *NCS* National Curriculum for Science, *OU* Open University)

education themselves and an additional 19 % had only received some form of Earth science education when they were school students. Thus, they were largely untrained in Earth science and were very dependent on information derived from elsewhere. The sources of information they reported using in their teaching are shown in Fig. 7.1.

Figure 7.1 shows that most of the support for their Earth science teaching came from their colleagues (46 % from science teachers and 20 % from geography teachers) and from science textbooks (25 % textbooks for 11–14-year-olds, 15 % from books for 14–16-year-olds and 29 % from other science textbooks). These findings were supported by the government's Council for Science and Technology report published at a similar time (CST, 2000) which indicated that 89 % of the secondary science teachers surveyed ($n = 576$) used textbooks as sources of information 'often', whilst 39 % used their colleagues 'often'.

Further corroboration of the importance of textbooks to teachers came from beyond the UK. For example, Ball and Cohen (1996) quoted Goodlad (1984) in stating that

> commercially published curriculum materials dominate teaching practice in the United States. … Unlike frameworks, objectives, assessments and other mechanisms that seek to guide the curriculum, instructional materials are concrete and daily. They are the stuff of lessons and units, of what teachers and students do. That centrality affords curricular materials a uniquely intimate connection to teaching. (p. 6)

Meanwhile Good (1993) stated, 'most science teachers seem to use science textbooks most of the time …' (p. 619) and Abraham, Gryzybowski, Renner and Marek (1992) noted that 'In the experience of researchers, many junior high school teachers are much too dependent on textbooks' (p. 117). Wandershee, Mintzes and Noval (1994) commented, 'In the defence of teachers, the persistence of their alternative conceptions [misconceptions] may be an effect of poor college science textbook writing …' (p. 189)

Meanwhile there was abundant anecdotal evidence that the quality of the Earth science in UK science textbooks was poor, as maintained by Arthur in his article, 'Lies, damn lies and books on geology' (Arthur, 1996). Since this evidence suggested that science teachers, who were very dependent on science textbooks, were being misled by the content of those textbooks, and that misconceptions were being perpetrated through their use, it seemed beholden on the Earth science education community in the UK to review science textbooks for their Earth science content to provide a perspective on this issue.

Book Selection for the Review

There is no government control on the publication of school textbooks in the UK, so individual publishers are in competition with one another, and there is no external method to maintain quality control. In order that the textbook review of science textbooks for their Earth science content should be comprehensive, the reviewers visited the national Association for Science Education (ASE) meeting in January 2000 (the ASE meeting is the largest annual gathering of science teachers in the UK, attracting some 3,000 teachers per annum) to identify all the prominent publishers in the field. Following the meeting they mailed every publisher which had exhibited and asked them to submit their secondary science textbooks for review. This invitation was followed up by a personal invitation at the following ASE Annual Meeting in 2001. Most publishers readily submitted their books for review free of charge, and for those who were less willing, their books were purchased elsewhere. This meant that all widely used science textbooks, in print, which were being used in schools in England and Wales were covered by the review. In all 13 textbooks/series for 11–14-year-olds (KS3) from 10 publishers and 16 textbooks/series for 14–16-year-olds (KS4) from 9 publishers, a total of 51 texts were covered by the review.

Review Structure

The review was carried out by a team of five experienced Earth science educators. The team agreed the following process, as given in the internal report that resulted from the review (King, Fleming, Kennett, & Thompson, 2002):

- each textbook would be reviewed against a standard set of criteria taken from the National Curriculum for Science (2000 version, England; QCA, 1999);
- the reviews would be moderated across the evaluation team;
- the reviews would be compiled and a draft report prepared, based on them; this report would contain all the data collected, including details of each textbook, judgements of the Earth science coverage, and lists of materials included beyond the NCS and of errors and misconceptions;
- the draft report would be circulated to all the publishers involved for comment and correction of errors;

Table 7.1 Key Stage 3 (11–14-year-old) National Science Curriculum 2000 Earth science statements. Note: Sc1 covers 'How science works', Sc2 is mainly biology, Sc3 is mainly chemistry with some Earth science, and Sc4 is mainly physics

National Curriculum for Science (England) statements relating to KS4 Earth science	
Notes: 1. Where statements have been subdivided, this is indicated by i, ii, iii, etc.	
2. Items in square brackets are not statutory	
[Sc1 1aii]	[about the interplay between empirical questions, evidence and scientific explanations using historical and contemporary examples [for example … the possible causes of global warming]]
[Sc1 2dii]	[… how evidence may be collected in contexts [for example, fieldwork …] in which the variables cannot be readily controlled (- in an Earth science context)]
Sc2 5aii	about ways in which … the environment can be protected …
Sc2 5aiii	… the importance of sustainable development
[Sc3 1eii]	[how elements combine through chemical reactions to form compounds [for example … most minerals] with a definite composition]
Sc3 2d	how forces generated by expansion, contraction and the freezing of water can lead to the physical weathering of rocks
Sc3 2ei	about the formation of rocks by processes that take place over different timescales …
Sc3 2eii	… the mode of formation determines their texture and the minerals they contain
Sc3 2fi	how igneous rocks are formed by the cooling of magma …
Sc3 2fii	how … sedimentary rocks (are formed) by processes including the deposition of rock fragments or organic material, or as a result of evaporation …
Sc3 2fiii	how … metamorphic rocks (are formed) by the action of heat and pressure on existing rocks
Sc3 2i	about possible effects of burning fossil fuels on the environment and how these effects can be minimised
Sc3 3gii	how acids in the environment can lead to … chemical weathering of rock
Sc4 5ai	about the variety of energy resources, including oil, gas, coal … wind, waves …
Sc4 5aii	… the distinction between renewable and non-renewable resources
Sc4 5bi	about the Sun as the ultimate source of most of the Earth's energy resources …
Sc4 5bii	… to relate this (the Sun as the ultimate source of most energy) to how coal, oil and gas are formed
17 statements	

- a final report would be prepared as an internal publication by the Earth Science Education Unit, taking account of the publishers' comments and recommended corrections;
- the final report would sent to all the publishers involved and would be available to interested enquirers;
- reports based on the final internal report would be written for wide circulation, but would not include details of individual textbooks. (p. 2/3)

Each textbook was evaluated against a pro forma that included the National Curriculum for Science, Earth science criteria, subdivided as in Tables 7.1 and 7.2.

The pro forma used for the textbook survey was modelled on the pro forma used previously by a similar team to evaluate GCSE science syllabuses (specifications) (in King, Brooks, Gill, Rhodes, & Thompson, 1998, 1999).

Table 7.2 Key Stage 4 (14–16-year-old) National Science Curriculum 2000 Earth science statements. Note: See note on Sc1, Sc2, etc. in the caption of Table 7.1

National Curriculum for Science (England) statements relating to KS4 Earth science	
Notes: 1. Where statements have been subdivided, this is indicated by i, ii, iii, etc.	
2. Items in square brackets are not statutory	
[Sc1 1b]	[how scientific controversies can arise from different ways or interpreting empirical evidence [for example, Darwin's theory of evolution]]
[Sc1 2dii]	[… how evidence can be collected in contexts [for example, fieldwork …] in which the variables cannot be readily controlled]
Sc2 3i	that the fossil record is evidence for evolution
Sc2 3j	how variation and selection may lead to evolution or to extinction
Sc2 4bii	how the impact of humans on the environment depends on social and economic factors, including … industrial processes and levels of consumption and waste
Sc2 4c	about the importance of sustainable development
Sc3 2g	about the variety of useful substances [for example, chlorine, sodium hydroxide, glass, cement] that can be made from rocks and minerals
Sc3 2pi	how the Earth's atmosphere … (has) changed over time
Sc3 2pii	how the Earth's … oceans have changed over time
Sc3 2q	how the carbon cycle helps to maintain atmospheric conditions
Sc3 2ri	how the sequence of … rock formation and deformation is obtained from the rock record
Sc3 2rii	how the … evidence for rock formation (igneous rocks) … is obtained from the rock record
Sc3 2riii	how the … evidence for rock formation (sedimentary rocks) … is obtained from the rock record
Sc3 2riv	how the … evidence for rock formation (metamorphic rocks) … is obtained from the rock record
Sc3 2rv	how the … evidence for rock … deformation is obtained from the rock record
Sc4 3mi	that longitudinal and transverse waves are transmitted through the Earth …
Sc4 3mii	… how (the) travel times and paths (of earthquake waves) provide evidence for the Earth's layered structure
Sc4 3ni	that the Earth's outermost layer, the lithosphere, is composed of plates in relative motion …
Sc4 3nii	… that plate tectonic processes result in the formation … of rocks
Sc4 3niii	… that plate tectonic processes result in the … deformation … of rocks
Sc4 3niv	… that plate tectonic processes result in the … recycling of rocks
Sc4 6f	some uses of radioactivity including radioactive dating of rocks
22 statements	

Against each of the NCS Earth science statements, the content of each textbook was judged to be in one of the following categories:

- *Comprehensive* (going beyond the coverage implied by the NSC statement)
- *Basic* (meeting the coverage implied)
- *Less than basic* (not meeting the coverage implied)
- *None* (no coverage could be found in the obvious places in the textbook or through the index)

The total number of statements covered at each level was recorded.

Meanwhile each case of where the textbook contained material additional to that required by the NCS was recorded as an 'Extra' with the appropriate page numbers and the total number of 'Extras' was recorded.

For each error/oversimplification found, the erroneous quote was reproduced (or reference to the incorrect diagram, etc. given) and a correction was prepared, often with an explanation. The correction was written to illustrate to the author and publisher that a correct explanation could be given with a similar number of words and at the correct general reading level; the total number of errors/oversimplifications was recorded.

A tally was kept of the total number of pages relating to Earth science. This was used to calculate the percentage of Earth science in the book or series, by calculation against the total number of pages in the book/series. Where the book was not one of a series and did not purport to cover the whole of the NCS, this was noted. For example, a series of books at KS3 should cover 17 statements, but a 'biology' book at KS3 would be expected to cover only the Earth science-related statements in Attainment Target 1 (Sc1) and Attainment Target 2 (Sc2), a total of 4 statements. 'Chemistry' books at KS3 should cover Scs 1 and 3 with 11 statements, and KS3 'physics' texts should cover Scs1 and 4, with 6 statements. Similarly, at KS4, out of a possible 22 statements, 'biology' books should cover 6 statements, 'chemistry' books 11 statements and 'physics' books 9 statements.

Finally, each evaluator was invited to make a general comment on the textbook/series in the light of the evaluation experience.

An example of a completed survey pro forma is shown in Table 7.3. The KS4 pro forma was similar but based on KS4-related statements.

Moderation Process

Moderation across the team was carried out as described in the 2002 report (King et al., 2002):

> Moderation was carried out across the five team members involved as follows.
>
> - The proforma for evaluation, as described above, was agreed. …
> - A KS4 Chemistry textbook was photocopied and circulated to all members of the team, who were asked to evaluate the book using the pro forma.
> - A moderation meeting was held and standards of interpretation of the statements and criteria were agreed following discussion of the evaluation of the sample textbook.
> - Each book was evaluated by a team member and the evaluation submitted to the coordinator.
> - The coordinator checked and moderated each evaluation. A complete set of evaluations was compiled, to a standard format.
> - The complete set was circulated to all members of the team for checking.
> - The evaluations were amended in the light of comments from team members … [and were included in full in the final internal report]
> - Data from these moderated evaluations … [form] the basis of the discussions and conclusions of … [the] report. (p. 6/7)

Textbook Survey Results

The analysis (King et al., 2002) found that, on average, half the NCS Earth science were inadequately covered (10.7 of the 19.5 statements), that it was the geological statements that were particularly poorly covered, and that, in the poorest textbooks, nearly the whole of the Earth science component of the NCS was inadequately covered or was missing completely. This is despite the fact that the percentage of Earth science content averaged across all the textbooks of 9.4 % was creditably high, against a percentage of NCS Earth science content (as measured by the numbers of statements) of around 7 %.

The high level of error/oversimplification was also a serious issue, as summarised in the graph in Fig. 7.2.

Figure 7.2 shows that the mean error/oversimplification level across all the texts was one error per page. This finding is even worse when the worst cases are considered, with some textbooks having more than two errors per page and the worst of all having 66 errors in 26 pages. In all 453 cases of 'error/oversimplification' were found.

The review data allowed the books to be ranked on the basis of the following criteria:

- 'Least no. of the relevant NCS statements with "less than basic" or "none" coverage'
- 'Greatest % of Earth science'
- 'Least no. of errors/page'
- 'Greatest no. of "Extras"'.

A mean ranking was calculated from the data and used to produce a list of books in rank order. The overall rank order could have been calculated in different ways, by combining some or all of the categories listed above. However, calculating the ranking in these different ways did not make major changes to the order, particularly at the top and bottom of the lists. This allowed the team to identify the 'best' and 'worst' textbooks on the basis of the categories above.

Many provisos needed to be taken into account in considering this ranking, such as some textbooks being published prior to the publication of the latest NCS document and others being aimed at just part of the NCS (e.g. 'chemistry') rather than the whole NCS at that age range. Nevertheless, the ranking did provide a rough guide to those textbooks which provided the 'best' and 'worst' Earth science coverage.

The data also allowed a 'baseline' to be developed against which future textbooks could be judged, based on means in all the categories. The 'baseline' as published in the report (King et al., 2002, p. 12) is given as Table 7.4 below.

Table 7.4 shows that textbooks published in future that cover more than half the National Curriculum for Science Earth science statements adequately or better will be an improvement on these baseline findings, particularly if they reduce the error/oversimplification level to less than one error per page. This is, however, a very low baseline – and it is to be hoped that science textbooks published in future will by far exceed this low 'hurdle'.

Table 7.3 Textbook survey – KS3 recording sheet - a typical example of a completed KS3 proforma *(with the specific details of the series deleted). This landscape oriented sheet has been divided into two halves to be reproduced below*

Author(s)	Title	Publisher	Publication date	ISBN Nos
Deleted	*Textbook title deleted* 7, 8 and 9	*Deleted*	7 – 2000 8 – 1994 9 – 1995	*Deleted*
Publisher contact	Publisher details	No. in series	Teacher's Guide?	Pupil ability level?
Deleted	*Deleted*	3	Yes	Mixed

NCS reference	[Sc1 1aii]	[Sc1 2dii]	Sc2 5aii	Sc2 5aiii	[Sc3 1eii]	Sc3 2d	Sc3 2ei	Sc3 2eii	Sc3 2fi
National Curriculum for Science phrase	[about the interplay between empirical questions, evidence and scientific explanations using historical and contemporary examples [for example … the possible causes of global warming]]	[… how evidence may be collected in contexts [for example, fieldwork …] in which the variables cannot be readily controlled (– in an Earth science context)]	about ways in which … the environment can be protected …	… the importance of sustainable development	[how elements combine through chemical reactions to form compounds [for example … most minerals] with a definite composition]	how forces generated by expansion, contraction and the freezing of water can lead to the physical weathering of rocks	about the formation of rocks by processes that take place over different timescales …	… the mode of formation determines their texture and the minerals they contain	how igneous rocks are formed by the cooling of magma …
NCS reference	[Sc1 1aii]	[Sc1 2dii]	Sc2 5aii	Sc2 5aiii	[Sc3 1eii]	Sc3 2d	Sc3 2ei	Sc3 2eii	Sc3 2fi
Comprehensive coverage									
Basic coverage									
Less than basic coverage	B9, 17	B7, 20 – 21	B7, 30 – 31	B7, 30 – 31	B9, 38	B7, 138			B7, 137
		B7, 139	B9, 4 – 5			B9, 40 – 41			B9, 38
No coverage √?=not obvious							√	√	

(continued)

Table 7.3 (continued)

Author(s)	Title	Publisher	Publication date	ISBN Nos
Deleted	*Textbook title deleted* 7, 8 and 9	*Deleted*	7 – 2000 8 – 1994 9 – 1995	*Deleted*
Publisher contact	Publisher details	No. in series	Teacher's Guide?	Pupil ability level?
Deleted	*Deleted*	3	Yes	Mixed

NCS reference	Sc3 2fii	Sc3 2fiii	Sc3 2i	Sc3 3gii	Sc4 5ai	Sc4 5aii	Sc4 5bi	Sc4 5bii	
National Curriculum for Science phrase	how … sedimentary rocks (are formed) by processes including the deposition of rock fragments or organic material, or as a result of evaporation …	how … metamorphic rocks (are formed) by the action of heat and pressure on existing rocks	about possible effects of burning fossil fuels on the environment and how these effects can be minimised	how acids in the environment can lead to … chemical weathering of rock	about the variety of energy resources, including oil, gas, coal … wind, waves …	… the distinction between renewable and non-renewable resources	about the Sun as the ultimate source of most of the Earth's energy resources …	… to relate this (the Sun as the ultimate source of most energy) to how coal, oil and gas are formed	Totals
NCS reference	Sc3 2fii	Sc3 2fiii	Sc3 2i	Sc3 3gii	Sc4 5ai	Sc4 5aii	Sc4 5bi	Sc4 5bii	
Comprehensive coverage					B7, 42 – 43			B8, 104	2
					B8, 104 – 105; 108 – 109			B9, 18	
					B9, 18 – 19				
Basic coverage	B7, 137, 143, 144			B7, 77		B7, 42 – 43	B8, 102 – 105		4
	B8, 104			B8, 124		B8, 108–109	B9, 18		
	B9, 38			B9, 40		B9, 18			
Less than basic coverage		B7, 137	B7, 77 B8, 105						9
		B9, 38							
No coverage √?=not obvious									2
Approx. % of ES coverage	of book(s) covering whole PoS		6.8	of book covering only Sc2		of book covering only Sc3	of book covering only Sc4		Total 17
Extras	Suggested graveyard survey, B7, 139 Fossils as dead things that didn't decompose, B7, 133 Erosion and its effects B7, 140–141 Soil examination in the lab B7, 142 Fossils mentioned B7, 145 Geological time B7, 145 Water cycle B7, 89 – 97 Iron ore and limestone used to extract iron; other ores B8, 114 – 115 Seismic exploration B9, 69								Total 9

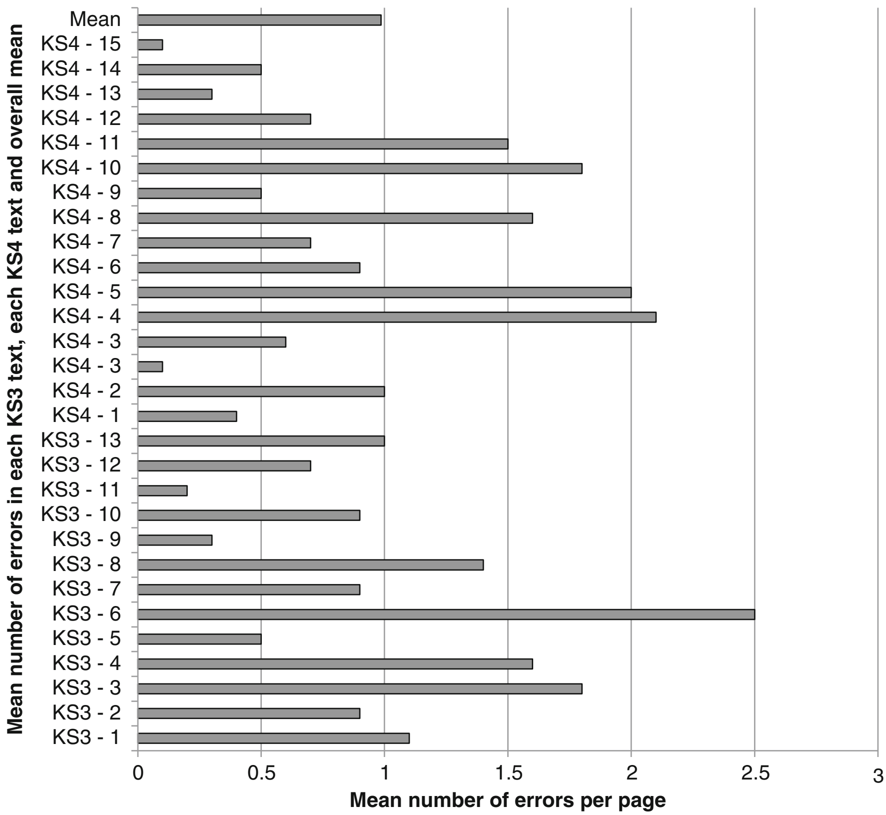

Fig. 7.2 Levels of error/oversimplification in the KS3 texts/series ($n = 13$) and KS4 texts/series ($n = 15$) reviewed, together with the mean error level

An Analysis of the Published Errors/Oversimplifications

The 453 instances of ‘error/oversimplification’ found in the textbook survey (King et al., 2002) were added to the 20 instances previously recorded in the syllabus and examination survey (King et al., 1998). During 2003, a further 58 instances of ‘error/oversimplification’ were identified: 38 from proofreading of prepublication science textbook material and 20 from a BBC science revision website, and these were added to the total. The 531 instances of ‘error/oversimplification’ identified from all these sources formed the basis of the analysis described below.

The data were first subdivided by topic and the results are displayed graphically in Fig. 7.3.

Figure 7.3 shows that the greatest number of errors/oversimplifications was linked to rocks and rock-forming processes (40 %) (particularly to sedimentary rocks/processes [24 %]). A high percentage of errors also related to the ‘earthquakes and Earth’s structure’ category (29 %).

Table 7.4 Baseline data obtained from the survey of the Earth science content of secondary science textbooks, Spring 2002

Criterion	Mean findings at KS3 (17 statements)	Mean findings at KS4 (22 statements)	Mean findings overall (adjusted for different numbersofstatements– out of 19.5 statements)
No. of statements covered at 'Comprehensive' level	2.4	2.1	2.3
No. of statements covered at 'Basic' level	5.0	4.2	4.6
No. of statements covered at 'Less than basic' level	5.7	7.3	6.5
No. of statements covered at 'None' level	3.1	5.2	4.2
No. of statements covered at 'Less than basic' + 'None' levels – i.e. with inadequate coverage	8.8	12.5	10.7
Percentage of Earth science	8.7 (excluding 'Science at work: Earth science')	10.0 (excluding 'Science at work: Earth science')	9.4
No. of 'Errors/ misconceptions' per page	1.1	0.9	1.0
No. of 'Extras'	5.9	4.5	5.2

Many of the errors/oversimplifications occurred as multiple instances in the data, allowing the data to be tabulated, as in Table 7.5. The 'top 15' are shown graphically in Fig. 7.4 and are tabulated in Table 7.6 by reference to quotes from the erroneous sources, the consensus view is provided by reference to published Earth science literature, a commentary is given, and an attempt is made to indicate the 'scale' of the misconception' by reference to common school-level misconceptions of a similar 'scale' in areas of biology, chemistry or physics.

An extensive discussion of these findings, set against the Earth science misconception literature, can be found in King (2010) and is summarised in Table 7.7.

Discussion

The survey of the Earth science content of science textbooks was undertaken, not only to provide a baseline against which future publications could be judged but also to test the general view of Earth science educators in the UK that 'all was not well' with the quality of the Earth science written in science textbooks. This was borne out by the research; indeed, the views of the evaluation team included in the report (King et al., 2002) were summarised strongly as:

> … the evaluators have complained bitterly during their work, of the poor quality of the of published material they have seen, of low levels of coverage, of misleading wording, of high levels of error and misconception and, in a number of cases, of the trivialisation of the Earth science content, particularly in comparison with the coverage of other areas of science. (p. 13)

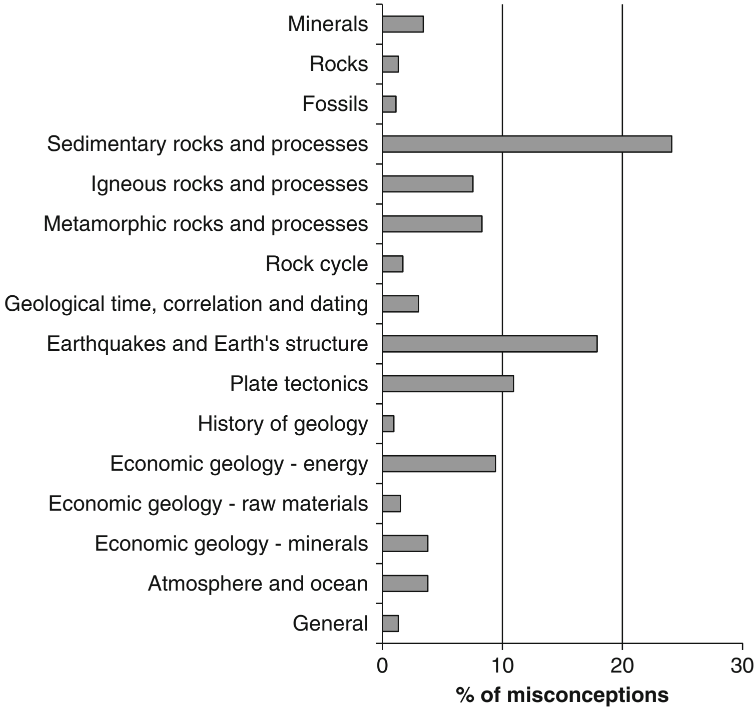

Fig. 7.3 Instances of error/oversimplification appearing in science-based published materials for 11–16-year-olds ($n = 531$) (Taken from King, 2010, p. 572)

The survey results cannot indicate if the error level in the Earth science coverage is worse than for other areas of science in the textbooks reviewed, since this comparison did not form part of the survey. However, it would be surprising if this level of inaccuracy in other areas of science had not been commented on adversely by teachers and other users; therefore, it is likely that the Earth science coverage and accuracy is poorer than for other areas of science.

A possible cause of this poor quality of textbook material is that many science textbook writers were themselves science teachers in the past and therefore probably have similar backgrounds to other science teachers, backgrounds that contained little or no Earth science education or education in Earth science teaching. Nevertheless, it is very disappointing that neither authors nor editors appear to have carried out careful checks for accuracy, in general, or even for proper coverage of the content of the National Curriculum for Science. In an educational situation where the Awarding Bodies (Examination Boards) who set the assessments have to take great care in the accuracy of these assessments, it is worrying that no such checks seem to be made of the accuracy of the materials being used to teach towards those assessments.

The publishing of inadequate and erroneous material is of particular concern in a subject area like Earth science when the readers (teachers and pupils) often lack sufficient experience to recognise the problem themselves and when they are so reliant on the textbooks for their understanding of the topic. Indeed, when teachers

Table 7.5 Categorised and tabulated misconception data, with paraphrased examples ($n = 531$)

Category	Number	%	Misconception subcategory, with examples, often paraphrased
Minerals	8	1.5	Mineral/rock confusion, e.g. "Mineral' and 'rock' mean the same'
	5	0.9	Incorrect mineral definition, e.g. 'A mineral is a chemical that is useful or beautiful'
	3	0.6	Incorrect spelling of Mohs', e.g. 'Moh's scale of hardness'
	2	0.4	Others – single occurrences, e.g. 'Melting point is linked to hardness of minerals'
Total	*18*	*3.4*	
Rocks	3	0.6	Incorrect rock definition, e.g. 'Impure limestone and rock salt are classed as rocks'
	3	0.6	Rock hardness misunderstanding, e.g. 'Rocks are tested using the hardness scale'
	1	0.2	Others – 'Rock particles (grains, crystals) are the same as the particles in particle theory'
Total	*7*	*1.3*	
Fossils	2	0.4	Fossilisation process oversimplified, e.g. 'Replacement by minerals is the only form of fossilisation'
	2	0.4	Confusion between numbers of individuals and diversity
	2	0.4	Others – single occurrences, e.g. diagram showing dinosaurs and grass together
Total	*6*	*1.1*	
Sedimentary rocks and processes	37	7.0	Weathering/erosion confusion, e.g. 'Weathering and erosion are the same'
	23	4.3	Indicating that sedimentary rocks are formed by compression only, e.g. 'Sedimentary rocks are formed when sediments are compressed by the mass of the overlying materials'
	11	2.1	Incorrect definitions of sedimentary terms, e.g. 'Sediment is just particles that settle out of water'
	9	1.7	Misunderstanding of freeze/thaw weathering process, e.g. 'Rocks are broken by freezing'
	9	1.7	Misunderstandings of limestone and chalk, e.g. 'Limestone only has grey porous forms' or 'Chalk is made of the skeletons of sea creatures'
	8	1.5	Others – single occurrences, e.g. 'Conglomerate is found below sand in a sequence because it was nearer the Earth's centre and so was compressed more'
	6	1.1	Indicating that sediment grains are always small, e.g. 'Tiny particles are called sediment'
	6	1.1	Cementation process misunderstood, e.g. 'Grains of rock are cemented together by mineral salts deposited as water evaporated'
	4	0.8	Soil formation misunderstandings, e.g. 'Sediments become small during transportation, eventually forming soil'
	4	0.8	Oversimplified description of sandstone, e.g. 'Sandstone is a soft rock – you can scratch it with your nails'
	4	0.8	Indicating that fossils are found only in sedimentary rocks, e.g. 'Only sedimentary rocks contain fossils' (they occur in low-grade metamorphic rocks too)

(continued)

Table 7.5 (continued)

Category	Number	%	Misconception subcategory, with examples, often paraphrased
	3	0.6	Indicating that rainwater cannot attack non-limestone rocks, e.g. 'Rocks such as granite do not react with rainwater'
	2	0.4	Misunderstanding of the heating/cooling weathering process, e.g. 'This weathering occurs because of the big difference in the mean temperature of summer and winter'
	2	0.4	Indicating that sedimentary rocks do not contain crystals, e.g. 'Sedimentary rocks do not have crystals' (most sand grains are rounded crystals and rock salt is crystalline)
Total	*128*	*24.1*	
Igneous rocks and processes	9	1.7	Others – single occurrences, e.g. 'A country made of igneous rocks must be young'
	8	1.5	Basalt and granite can form from the same magma, e.g. 'A single magma can produce granite or basalt' or 'Granite comes from volcanoes'
	6	1.1	Incorrect definitions of igneous terms, e.g. 'Magma is a mixture of minerals'
	5	0.9	Magma comes from the mantle, e.g. 'Magma is molten rock from the Earth's mantle and core' (much magma comes from the lower crust, never from the core)
	4	0.8	Oversimplified sill/dyke definitions, e.g. 'If the magma makes a horizontal layer it is called a sill' (sills parallel bedding, which may not be horizontal; dykes cut bedding)
	2	0.4	Texture/structure terminology confusion, e.g. 'Igneous rocks tend to be smooth and hard with an irregular crystalline structure' (texture is grain sized; structure is larger)
	2	0.4	Misunderstanding of 'glassy' term (having no crystals), e.g. 'Igneous – glassy appearance made of interlocking crystals'
	2	0.4	Misunderstanding of 'viscosity' when linked to lava, e.g. 'Runny lava flows slowly'
	2	0.4	Errors around the Mt. St. Helens eruption, e.g. 'It erupted with no warning' (there were many warning signs)
Total	*40*	*7.5*	
Metamorphic rocks and processes	10	1.9	Indicating that metamorphism is caused by overburden pressure, e.g. 'Metamorphism is caused when rocks are buried' (it is caused regionally by tectonic stress/locally by heating)
	6	1.1	Stating that metamorphic rocks never contain fossils, e.g. 'Why do metamorphic rocks never contain fossils?' (low-grade metamorphic rocks often can contain fossils)
	6	1.1	Indicating that regional metamorphic rocks are formed by igneous rocks/high temps., e.g. 'Slate is formed from mud by very high temperatures' (they need high tectonic pressures)
	6	1.1	Metamorphic rocks are formed only from sedimentary rocks, e.g. 'Metamorphic rocks can be produced from sedimentary rocks' (they are also formed from igneous rocks)
	6	1.1	Metamorphism involves melting, e.g. 'In metamorphism, rocks melt and recrystallise to form new rocks' (metamorphism is change in the solid state – no melting is involved)

(continued)

Table 7.5 (continued)

Category	Number	%	Misconception subcategory, with examples, often paraphrased
	4	0.8	Confusion of 'quartzite' (metamorphic rock) and 'quartz' (mineral), e.g. 'Sandstone changes into quartz when it is heated and squashed'
	4	0.8	Others – single occurrences, e.g. 'In metamorphism, basalt changes into granite'
	2	0.4	Confusion of 'metamorphism' (change of rocks) and 'metamorphosis' (e.g. caterpillar into butterfly), e.g. 'Why can metamorphosis be used to describe the limestone to marble change?'
Total	*44*	*8.3*	
Rock cycle	5	0.9	Others – single occurrences, e.g. 'Humans have made more changes to the Earth than the rock cycle'
	4	0.8	The rock cycle is continuous (only the sedimentary parts are metamorphic and many igneous parts happen only at intervals, during mountain-building episodes), e.g. 'Rocks are being recycled all the time'
Total	*9*	*1.7*	
Geological time, correlation and dating	6	1.1	Others – single occurrences, e.g. 'The rock type indicates the age of the rock'
	5	0.9	Numerical errors, e.g. 'a rock that is 9,000 million years old will have three times as much lead as uranium' (no rock in the solar system is this old)
	5	0.9	Ordinary rocks or fossils can be dated radiometrically (rocks must contain radioactive isotopes to be dated, fossils never do), e.g. 'Ages of fossils can be found by measuring their radioactivity'
Total	*16*	*3.0*	
Earthquakes and structure of the Earth	35	6.6	Indicating that the mantle is liquid, e.g. 'The mantle is made of magma'
	10	1.9	The thicknesses of Earth layers are given or shown incorrectly
	9	1.7	Indicating that the mantle is semi-liquid or semi-solid, e.g. 'The mantle is semi-liquid'
	6	1.1	Others – single occurrences, e.g. 'The intensity of an earthquake is measured by the Richter scale' (magnitude is measured on the Richter scale)
	4	0.8	Indicating that seismic wave velocity is increased by increase in density, e.g. 'Seismic wave speeds depend on the density of the rock, the greater the density, the greater the speed' (whilst wave velocity in the Earth increases as density increases, the wave velocity/density link is an inverse relationship – the increase in wave velocity is due to other factors)
	4	0.8	The centre of the Earth is kept hot by radioactive decay, e.g. 'Decay of uranium in the inner core keeps it hot' (there are no thermal radioactive minerals in the core)
	3	0.6	There are only two types of seismic waves (there are two types of body waves, P and S, and two types of surface waves too), e.g. 'There are two types of seismic waves'

(continued)

Table 7.5 (continued)

Category	Number	%	Misconception subcategory, with examples, often paraphrased
	3	0.6	L waves are called 'Long' waves (they are 'Love' waves), e.g. 'The L or long waves….'
	3	0.6	The Richter earthquake magnitude scale is not described as a log scale that is open ended, e.g. 'The Richter scale ranges from 0–10'
	3	0.6	The asthenosphere is indicated at the wrong depth in the mantle (it is between around 100 and 350 km deep), e.g. '… the lower mantle (asthenosphere) is …'
	3	0.6	Crust composition incorrect – oceanic crust is not basalt but is formed of rocks of a basaltic composition; continental crust is not granite but comprises a variety of rocks of generally granitic composition, e.g. '… continental crust (granite), oceanic crust (basalt) …'
	3	0.6	The core described as formed of iron and nickel, e.g. 'The core is a ball of iron and nickel'– (there is good evidence that it is mostly iron, but the other element(s) present may or may not be nickel)
	3	0.6	Incorrect seismic wave effects indicated at the core/mantle boundary, e.g. 'S waves are reflected when they hit the core' (they are absorbed)
	2	0.4	Epicentre/focus confusion (the epicentre is the point on the Earth's surface above the focus), e.g. '… seismic waves travel outwards from the centre of the quake (epicentre)'
	2	0.4	The core described as liquid, e.g.' The Earth's core is hot and liquid' (the outer core is liquid, the inner core is solid)
	2	0.4	Numerical errors, e.g. 'At the bottom of the crust the temperature is 1,050 °C' (it is rarely as high as 1,000 °C)
Total	*95*	*17.9*	
Plate tectonics	25	4.7	Plates incorrectly described as made of crust, e.g. 'crustal plates'
	21	4.0	Others – single occurrences, e.g. '… continental plates are dragged down …' (continental plates are too buoyant to be dragged down in subduction)
	6	1.1	Numerical/thickness errors, e.g. '127 million years ago, South America/Africa were one landmass called Gondwanaland' (Gondwanaland existed from around 550 to 190 ma)
	4	0.8	Continental drift described as plate tectonics (continental drift was an early theory, now superseded by plate tectonics), e.g. 'continental drift – the movement of tectonic plates'
	2	0.4	The lithosphere melts because of friction between the plates, e.g. 'Plates rubbing together produce heat by friction, some rock melts …' (most melting is caused by water carried down by the subducting plate, reducing the melting point of minerals)
Total	*58*	*10.9*	

(continued)

Table 7.5 (continued)

Category	Number	%	Misconception subcategory, with examples, often paraphrased
History of geology	3	0.6	Wegener proposed plate tectonics, e.g. '… Wegener proposed his theory of plate tectonics' (Wegener published in the 1910/1920s, plate tectonic theory evolved in the 1960s)
	2	0.4	Others – single occurrences, e.g. 'Uniformitarianism is a theory of gradual change' (it is the theory that past processes have the same rates as at present – both fast and slow)
Total	*5*	*0.9*	
Economic geology – energy	14	2.6	Oil described as forming from animals, e.g. 'Oil and gas formed from dead sea creatures'
	9	1.7	Others – single occurrences, e.g. diagram showing the Sun as the source of geothermal energy
	7	1.3	Oil indicated as forming millions of years ago, e.g. 'Oil formed once in geological time'
	5	0.9	Incorrect descriptions/diagrams of oil traps, e.g. diagram showing layers of water and oil between the rock layers
	5	0.9	Geothermal energy is shown as renewable, e.g. 'Geothermal: clean, cheap, renewable' (these instances discuss geothermal energy from hot rocks – geothermal energy from volcanic areas is renewable, if not extracted too quickly, but from other areas of hot rocks, it is not)
	4	0.8	Natural gas indicated as forming from plankton, e.g. '… natural gas was formed from dead sea animals and plants…' (most gas evolved from coal)
	2	0.4	Oil will be used up, e.g. 'How old will you be when the oil runs out?' (it will never be entirely used up; it may become so expensive to extract that we use other sources of energy instead)
	2	0.4	Porosity/permeability confusion, e.g. '… impermeable rock (rock which has no pores…)' (porosity is a measure of pore space; permeability measures how fast fluids flow through pores; rocks with many tiny pores can be impermeable)
	2	0.4	Geothermal energy from hot rocks wrongly described as being found everywhere, e.g. 'Deep down in the ground the rocks are hot and can be used to change water into steam'
Total	*50*	*9.4*	
Economic geology – raw materials and building	3	0.6	Concrete/mortar recipes incorrectly described, e.g. 'Mortar is made of cement, water and small stones' (not 'small stones' but sand)
	3	0.6	Others – single occurrences, e.g. 'House built of limestone bricks' (bricks are manufactured from clay, these were limestone blocks)
	2	0.4	Slate/tile confusion (slates are natural; tiles are manufactured from clay), e.g. 'This is why slate is good for making roof tiles'
Total	*8*	*1.5*	

(continued)

Table 7.5 (continued)

Category	Number	%	Misconception subcategory, with examples, often paraphrased
Economic geology – minerals	10	1.9	Misunderstanding of 'ore', e.g. 'Rocks containing metals are called ores'
	6	1.1	Others – single occurrences, e.g. 'Pyrite (FeS_2) is an ore of iron' (it contains iron but the iron is too expensive to extract for it to be an ore)
	4	0.8	Vein minerals are formed in only one type of rock (mineral veins could cut any rock), e.g. 'chalcopyrite … is found in igneous and metamorphic rocks'
Total	*20*	*3.8*	
Atmosphere and ocean	5	0.9	Gases are described as acidic, e.g. 'When fossil fuels burn they make acid gases …' (these gases only form acid when dissolved in water)
	5	0.9	Others – single occurrences, e.g. 'When it rains, acid gas falls from acid clouds'
	4	0.8	Incomplete carbon cycle diagrams omitting fossil fuels and limestone rocks
	2	0.4	Diagrams of the CO_2 in the atmosphere reflecting heat back to Earth, e.g. diagram showing energy bouncing back from the edge of the atmosphere (CO_2 absorbs heat)
	2	0.4	Plants shown as appearing too early in geological time, e.g. 'When plants appeared, 3500 million years ago …' (algae are not considered to be plants; early plants were eukaryotes that probably appeared around 2000 ma)
	2	0.4	Numerical errors, e.g. '…the concentration of carbon dioxide has increased from 0.29 to 0.35 per cent since 1860' (it is 0.029–0.035 %)
Total	*20*	*3.8*	
General	5	0.9	Others – single occurrences, e.g. 'The huge granite stones at Stonehenge …' (they are dolerite, rhyolite and tuff – none are of granite)
	2	0.4	Numerical errors, e.g. '[Earth] … is a planet that is nearly 1200 kilometres in diameter' (Earth is nearly 13,000 km. in diameter – around 12,750 km)
Total	*7*	*1.3*	
Total	**531**	**100**	

have been alerted to the errors during professional development workshops, they have been very concerned and dismayed, particularly as they have clearly regarded textbooks as infallible reference works in the past.

At the same time as the review of science textbooks for their Earth science comment was being undertaken, a much wider survey of science textbooks was being conducted by the American Association for the Advancement of Science (AAAS) as part of its Project 2061 (AAAS website). During this work the evaluation team reviewed the Earth science content of textbooks published for 11–14-year-olds (middle school) in the USA against eight Earth science ideas. Their findings were that the texts were almost universally poor when measured against a range of

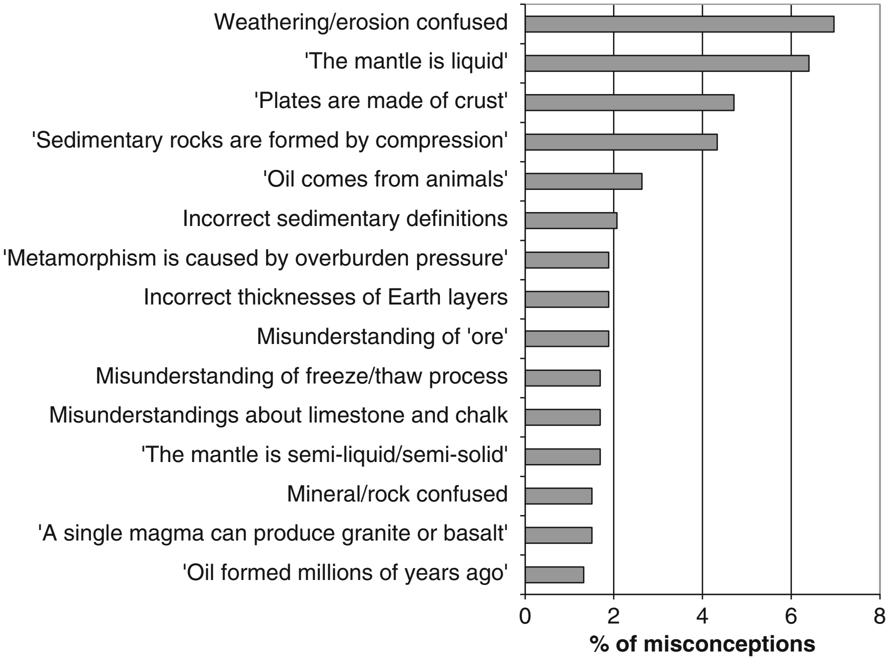

Fig. 7.4 The 'top 15' misconceptions, graphed according to their contribution to the data ($n=531$)

instructional strategies. Meanwhile, one of the reports on the Project (Stern & Ahlgren, 2002) commented, 'Assessment scores of life and earth sciences are almost uniformly poor' (p. 897).

Later Sellés-Martinez (2007) reviewed the Earth science content of seven Spanish introductory science textbooks and his review 'rendered alarming results' (p. 207).

Meanwhile, reports on the whole Project 2061 textbook review corroborated the findings of the King (2001) review of the importance of science textbooks to their teaching. Kesidou and Roseman (2002), members of the Project 2061 team, commented,

> Whereas curriculum materials (and in particular textbooks …) are but one of the resources available to teachers, they have a major role in teaching and learning. Many teachers rely on them to provide some or all of their content and pedagogical knowledge, this is especially so when the teacher is a novice or is teaching outside his or her area of expertise …. (p. 522)

Meanwhile, Stern and Roseman (2004) commented,

> For better or for worse, the majority of schools are still relying on textbooks as the primary sources of the classroom curriculum, and textbooks strongly influence student learning through their influence on teachers. (p. 556)

Note that although the research methodology of the Project 2061 team has been questioned (Holliday, 2003), it has also been strongly defended (Kesidou & Roseman, 2003).

Table 7.6 Common Earth science 'errors/oversimplifications' in secondary (11–16-year-old) science textbooks in England and Wales – in rank order of frequency (Taken from King, 2010, pp. 573–583)

Earth science 'error/ oversimplification'	Prevalence in 531 'errors/ oversimplifications' found	Examples of quotes containing 'errors/ oversimplifications' from textbooks, syllabuses and examinations	Scientific consensus view	Discussion	Misconception of similar significance in another science area
A. Weathering/erosion confusion, e.g. 'weathering and erosion are the same' or 'weather causes weathering'	37	'Stone is worn away by the air, wind and rain. This is called weathering' (O1 – B2, 85 – textbook series for 11–14-year-olds)	'Weathering. The breakdown of rocks and minerals at the Earth's surface by the action of physical and chemical processes' (Allaby & Allaby, 1991, p. 401)	Weathering happens *in place* and so no solid material is removed. Weathering causes chemical breakdown or physical disintegration (e.g. by freeze thaw action, plant root growth). Erosion is the *removal* of material from the site.	Confusing the dissolving of salt and the 'dissolving' of calcium carbonate in acid
	7.0 %	'Rocks can be worn away in 3 ways: • physical weathering, • chemical weathering, and, • biological weathering' (N4 – C, 282, textbook series for 14–16-year-olds)	'Erosion is the process that moves material resulting from the breakdown, or weathering of bedrock' (Hancock & Skinner, 2000, p. 314)*	Erosion occurs when one or more erosive agents (such as gravity, wind, moving water or moving ice) remove weathered material (so wind is an agent of erosion, not weathering). [Note: the chemical attack of rainwater on limestone removes material *in solution* and so is weathering and not erosion]	
B. Indicating that the mantle is liquid, e.g. 'the mantle is made of magma' (see also the section below of nine misconceptions that the mantle is 'semi-liquid or 'semi-solid')	35	'The earth's crust is split into different sections called 'plates'. These plates float around on the hot liquid magma beneath' C3 – B2, 136, textbook series for 11–14-year-olds)	'The asthenosphere (derived from the Greek for 'weak sphere') is the relatively weak, ductile layer in the upper mantle immediately underlying the lithosphere. Although solid at normal strain rates, like the rest of the non-lithospheric mantle, it can deform slowly in solid state creep' (Hancock & Skinner, 2000, p. 47)	The mantle is almost entirely solid, as shown by the fact that it transmits seismic S waves which can only pass through solid material. There is a zone in the upper mantle between the solid lithosphere above and the solid mantle below, called the asthenosphere, that is between 1 % and 5 % liquid (i.e. is 95–99 % solid).	Considering that glass is a liquid when it has the characteristics of a solid

	6.6 %	'Material which enters the liquid mantle can emerge through volcanoes to form igneous rocks' (B5 – 96, a revision guide for 11–14-year-olds)	'This view, that the crust is a relatively thin layer of solid rock on a liquid interior, became widely prevalent until about a century ago, when it was shown to be unsound' (Duff, 1993, p. 12)	As the molten material is found as films around the edges of crystals, it allows the solid material of the asthenosphere to flow very slowly. However, the mantle beneath can also flow, even though it is completely solid. A good analogy is that ice, although solid (and capable of being broken by a hammer), can flow downhill in glaciers. When it is near its melting point, it can flow more easily	
C. Plates incorrectly described as made of crust, e.g. 'plates are made of crust' or 'crustal plates'	25	'Plates can be made from oceanic or continental crust' (L8 – 106, a chemistry textbook for 14–16-year-olds)	'Plate. A segment of the lithosphere which is bounded by … plate margins' (Allaby & Allaby, 1991, p. 284)	The tectonic plates are plates of rigid lithosphere around 100 km thick. They overlie the ductile asthenosphere beneath, which flows slowly, moving the plates – thus, there is a physical boundary between the solid lithosphere and the ductile asthenosphere (the 1,300 °C isotherm). The lithosphere comprises the crust and the uppermost mantle, which are chemically different but both physically solid and rigid. The crust is around 7 km thick in oceanic areas and averages 35 km thick in continental areas – much thinner than the lithosphere	Thinking that leaves are made of a layer of palisade cells only
	4.7 %	'… the Earth's crust consists of a number of pieces called plates …' (L3 – 34, an examination syllabus for 14–16-year-olds)	'Lithosphere. The upper (oceanic and continental) layer of the solid Earth, comprising all crustal rocks and the brittle part of the uppermost mantle' (Allaby & Allaby, 1991, p. 219)		

(continued)

Table 7.6 (continued)

Earth science 'error/ oversimplification'	Prevalence in 531 'errors/ oversimplifications' found	Examples of quotes containing 'errors/ oversimplifications' from textbooks, syllabuses and examinations	Scientific consensus view	Discussion	Misconception of similar significance in another science area
D. Indicating that sedimentary rocks are formed by compression only, e.g. 'sedimentary rocks are formed when sediments are compressed by the mass of the overlying materials'	23 4.3 %	'Layers of sediment form sedimentary rock when put under great pressure' (L14 – B2, 95, textbook series for 11–14-year-olds) 'The rocks made when sediments settle under pressure are called sedimentary rocks' (C5 – B1, 111, textbook series for 14–16-year-olds)	'Lithification. The process of changing unconsolidated sediment into rock. This involves cementation … of the grains, but not necessarily … compaction' (Allaby & Allaby, 1991, p. 218)	Most sedimentary rocks cannot be formed by compaction alone; some 'cementation' is required to 'glue' the grains together. Fluids flowing through the pore spaces deposit natural mineral 'cement'. Only fine-grained sediment such as mud can be changed into sedimentary rocks like mudstone or shale by the compression of the overlying rocks alone; sandstones and limestones need cementation	Considering that plants need only a source of light to photosynthesise
E. Oil described as forming from animals, e.g. 'oil and gas formed from dead sea creatures' (often implying the remains of fish and other large animals)	14	'Crude oil is made from the decomposition of the bodies of the same sea creatures whose shells and skeletons make up limestone' (O1 – B2, 90, textbook series for 11–14-year-olds)	'Oil and gas are derived almost entirely from decayed plants and bacteria' (Clark, Grogan, Oates, & Volk, 1997, p. 2)	Oil and some natural gas are formed as microscopic plankton becomes buried and heated in the Earth's crust. The oil-producing plankton is mostly microscopic plants. Most natural gas is formed as buried land vegetation becomes coal	Thinking that plastics are made from coal

	2.6 %	'When these creatures died … partial decomposition of the remains produced crude oil and the natural gas associated with it' (L15, 140 – revision guide for 16-year-olds)	'Source rocks for oil and gas are usually fine-grained sediments … rich in organic matter derived from bacterial and chemical alteration of algae, bacteria or land plants. Organic sediments, such as coals, can also act as source rocks, principally for natural gas …' (Hancock & Skinner, 2000, p. 810)		
F. Incorrect definitions of sedimentary terms, e.g. 'sediment is just particles that settle out of water' and 'there are just two sorts of physical weathering' or 'there are just two sorts of chemical weathering'	11	'Sediment = particles that settle out from a suspension' (C2 – BII, 151, textbook series for 11–14-year-olds)	'Sediments are accumulations … that were deposited in layers from a fluid (water or air) … at the Earth's surface' (Hancock & Skinner, 2000, p. 944)	Sediments are not only deposited in water but can be deposited by gravity, wind or melting ice. They are transported in fluids (water or air) by rolling, sliding and bouncing or in suspension and are deposited when the energy of the transporting medium falls	Considering that plants = trees and flowers
	2.1 %	'Understand that weathering of rocks can produce particles of rock which can settle out from rivers as sediments … e.g. limestone, mudstone, rock salt' (L3 – 33, science examination syllabus for 16-year-olds)	'Weathering. The group of processes, such as the chemical action of rainwater and of plants and bacteria and the mechanical action of changes of temperature, whereby rocks on exposure to the weather change in character, decay and finally crumble into soil' (AGI, 1962, p. 536)	Weathering involves a range of processes that usually act together. Several different physical, biological and chemical weathering processes are involved	

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Table 7.6 (continued)

Earth science 'error/ oversimplification'	Prevalence in 531 'errors/ oversimplifications' found	Examples of quotes containing 'errors/ oversimplifications' from textbooks, syllabuses and examinations	Scientific consensus view	Discussion	Misconception of similar significance in another science area
G. Indicating that metamorphism is caused by overburden pressure, e.g. 'metamorphism is caused when rocks are buried and heated' or 'metamorphic rocks are formed by the pressure of the overlying rocks and heat'	10	'Metamorphic: Some igneous and sedimentary rocks may be buried. Heat and pressure change these rocks. This change makes metamorphic rocks' (N3 – B9, 38, textbook series for 11–14-year-olds)	'Regional metamorphism. The recrystallisation of preexisting rocks in response to simultaneous changes of temperature, lithostatic pressure and, in many cases, shear stress, occurring in orogenic belts where lithospheric plates are converging' (Allaby & Allaby, 1991, p. 311)	Widespread (regional) metamorphism that produces slates, schists and gneisses requires regimes of very high compression and heating. These conditions only occur when plates collide. There is normally not enough compression or heating produced by burial alone to cause metamorphism. Meanwhile, baking by hot igneous intrusions can cause localised metamorphism	Thinking that water can boil at 50 °C at normal (atmospheric) pressures
	1.9 %	'Metamorphic rocks as those formed from rocks which became buried deep underground …' (S1/2 – 50, science examination syllabus for 16-year-olds)	'Contact metamorphism. The recrystallisation of rocks surrounding an igneous intrusion in response to the heat supplied by the intrusion' (Allaby & Allaby, 1991, p. 83)		
H. The thicknesses of Earth layers are given or shown incorrectly	10	'The rock surface of the Earth is at most 10 kilometres thick' (H2 – BB, 130, textbook series for 11–14-year-olds)	'The thickness of the lithosphere varies between about 80–125 km, compared with an average crustal thickness of 35 km for the continents and 7 km for the oceans …' (Duff, 1993, p. 599)	The crust comprises the continental crust and the oceanic crust, with a mean thickness of around 18 km. The crust is chemically different from the mantle so the boundary, the Moho, is a chemical boundary. This boundary does not influence plate tectonics	Thinking that skin is 0.1 mm thick (skin actually averages 1–2 mm thick)

1.9 %	'Crust … At its thickest it is about 40 km' (H4 – 166, textbook for 14–16-year-olds)	'Continental crust … averaging 35 km and reaching 70 km in some places' (Duff, 1993, p. 14)	
	Earth cross-section diagram showing the core too small and the crust far too thick (C1 – C, 147, textbook for 14–16-year-olds)	'The boundary [of the core] with the mantle lies at a depth of c2900 km from the surface and the core therefore occupies … over 50 percent of the radius' (Duff, 1993, p. 13)	The tectonic plates are of lithosphere, comprising the crust and the outermost mantle, and are around 100 km thick. The lithosphere is solid and rigid and the boundary between it and the asthenosphere beneath is the 1,300 °C isotherm. The asthenosphere is the 'weak sphere' of the Earth and, although 95–99 % solid, is able to flow, affecting plate movement. The base of the asthenosphere is about 350 km down. The mantle continues down to the core/mantle boundary at 2,891 km depth, a boundary between the solid mantle and the liquid outer iron-rich core that is both mechanical and chemical. The mechanical boundary between the liquid outer core and solid inner core is at 5,149 km depth. The centre of the Earth is 6,371 km deep

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Table 7.6 (continued)

Earth science 'error/ oversimplification'	Prevalence in 531 'errors/ oversimplifications' found	Examples of quotes containing 'errors/ oversimplifications' from textbooks, syllabuses and examinations	Scientific consensus view	Discussion	Misconception of similar significance in another science area
I. Misunderstanding of 'ore', e.g. 'rocks containing metals are called ores'	10	'Rocks containing metals or metal compounds are called ores' (C3 – B2, 124, textbook series for 11–14-year-olds)	'Ore. A mineral or rock that can be worked economically' (Allaby & Allaby, 1991, p. 261)	The minerals that make up most rocks contain metal compounds but are not ores. The term 'ore' has an economic context. A rock or mineral deposit is only an ore if it is rich enough for potential commercial exploitation	Considering that a coal seam 1 mm thick is a useful energy resource
	1.9 %	'Ores are mixtures of rocks and minerals' (C5 – B1, 104, textbook series for 14–16-year-olds)			
J. Misunderstanding of freeze/thaw process, e.g. 'rocks are broken by freezing'	9	'In cold weather the water freezes and expands. The forces generated by the ice cause pieces of rock to snap off' (J1 – C100, textbook series for 11–14-year-olds)	'Water expends on freezing, and through repeated alternations of frost and thaw in water-filled pores and cracks, the rocks are relentlessly broken to bits' (Duff, 1993, p. 22)	Freezing alone does not cause physical weathering of rocks; many cycles of freezing and thawing are necessary. During each thaw, water penetrates more deeply into the crack widened by the previous freeze, until a fragment eventually breaks off	Thinking that a plant will die if you forget to water it for 1 day
	1.7 %	'Rocks are weathered by the freezing of water …' (B5 – 96, revision guide for 14-year-olds)		The expansion of water on freezing, causing this process, can be demonstrated by freezing a sealed syringe of 10 ml of water (Williams, 1984)	

K. Misunderstandings of limestone and chalk, e.g. 'lime-stone only has grey porous forms' or 'chalk is made of the skeletons of sea creatures'	9	'Limestone is a grey rock with a rough powdery texture' (J1 – C99, textbook series for 11–14-year-olds)	'Limestones … exhibit the same variety of grain sizes, textures and sedimentary structures as siliclastic deposits [conglomer-ates, sandstones, mudstones, etc.] and, in addition, others not exhibited by siliclastic deposits' (Hancock & Skinner, 2000, p. 605)	Limestones occur in a wide variety of textures and colours. Some are soft and porous; others are harder and at hand specimen scale are non-porous (but can be porous at a larger scale because of cracks and fissures)	Thinking that iron and steel are different metals – and steel is mainly carbon
	1.7 %	'Chalk: A soft crumbly rock composed of the calcium carbonate shells of prehistoric sea animals' (H2 – BB, 93, textbook series for 11–14-year-olds)		Chalk is a type of limestone formed mainly of the microscopic plates of planktonic single-celled plants (i.e. they are microscopic plant remains)	
		'Chalk is one form of calcium carbonate …. Limestone is the most important form of calcium carbonate… The third form of calcium carbonate is marble' (N4 – C, 121, textbook series for 14–16-year-olds)	'The Cretaceous chalks … are composed largely of coccoliths …' (Tucker, 1982, p. 155) 'Coccolithophorids … are planktonic algae which have a … skeleton … composed of numerous calcareous plates called coccoliths (Tucker, 1982, p. 111)		

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Table 7.6 (continued)

Earth science 'error/ oversimplification'	Prevalence in 531 'errors/ oversimplifications' found	Examples of quotes containing 'errors/ oversimplifications' from textbooks, syllabuses and examinations	Scientific consensus view	Discussion	Misconception of similar significance in another science area
L. Indicating that the mantle is semi-liquid or semi-solid	9 1.7 %	See 'the mantle is liquid' section above			
M. Mineral/rock confusion, e.g. ''mineral' and 'rock' mean the same'	8	'Olivine is a hard, dense rock … Olivine is an example of a silicate rock. … Olivine is an example of an igneous rock. … Olivine and similar minerals are sometimes found …' (L4 – 11, question in a science examination for 16-year-olds)	'A mineral can be defined as a naturally occurring homogenous solid, inorganically formed, with a definite chemical composition or a definite range of composition, and an ordered atomic arrangement' (Hancock & Skinner, 2000, p. 692)	A mineral is an element or compound. Thus, a mineral has a definite chemical composition, atomic structure and physical properties (that vary between fixed limits). A rock is a mixture of one or more minerals (or fragments of rocks or fossils), so the compositions and structures of most rocks can be very variable.	Confusing mixtures and compounds (e.g. a mixture of iron filings and sulphur with iron sulphide)
	1.5 %	'Some minerals, like limestone, are found in rocks on their own' L8 – 47, textbook for 14–16-year-olds)	'Rock. A consolidated or unconsolidated aggregate of minerals or organic matter. The minerals may be all of one type … or of many types …' (Allaby & Allaby, 1991, p. 319)	However, some rocks are formed of predominantly one mineral, such as limestone (largely calcite), quartzite (largely quartz) and rock salt (largely halite). Igneous rocks usually contain more than one mineral	

N. Basalt and granite can form from the same magma, e.g. 'a single magma can produce granite or basalt' or 'granite comes from volcanoes'	8	'Molten rock which emerges through volcanoes is called lava. As this cools it forms a variety of solids and these are known as igneous rock … – one example is granite' (L11 – 100, textbook for 11–14–year-olds)	'Basalt, a dark-coloured, fine-grained extrusive igneous rock … containing not more than 53 wt% SiO_2' (Allaby & Allaby, 1991, 34)	Granite and basalt are chemically very different and so cannot change from one to the other. When the *mantle* partially melts, dark magma forms. This iron-rich, silica-poor magma produces basalt if it cools quickly at the surface or coarse-grained gabbro if it cools slowly at depth. When the *crust* partially melts, a paler, silica-rich magma is formed. This is rarely erupted as lava but can explode as ash or pumice. Usually this magma crystallises slowly underground to form coarse-grained granite	Confusing caustic soda (sodium hydroxide) with common salt (sodium chloride)
	1.5 %	'Edinburgh Castle stands on a 'plug' of granite that was once inside a volcano' (N4 – C, 282, textbook series for 14–16-year-olds)	'Granite. A light-coloured, coarse grained igneous rock …' (Allaby & Allaby, 1991, p. 164) 'Granites are intrusive igneous rocks that contain large amounts of silica (SiO_2)' (Hancock & Skinner, 2000, p. 464)		
O. Oil indicated as forming millions of years ago, e.g. 'oil formed once in geological time'	7	'Coal, oil and natural gas are called fossil fuels. They were made from plants and animals that lived on Earth about 100 million years ago' (N3 – B7, 42, textbook series for 11–14-year-olds)	'In the North Sea … oil forms at 3–4.5 km depth, gas at 4–6 km. … Burial to these depths occurs in areas where the Earth's crust is sagging … These processes continue today …' (Clark et al., 1997, p. 3)	Most of the gas in the UK was formed from coals deposited as swamp deposits some 300 million years ago. Most of the oil and some gas were formed from algae and bacteria that settled on the sea floor around 140 million years ago. These formed source rocks that were heated and compressed to release their oil and gas and are still slowly releasing them today	Thinking that evolution happened millions of years ago
	1.3 %	'Oil was formed from the remains of organisms which lived millions of years ago' (N1/2 – 38, science examination syllabus for 16-year-olds)			

Key: N4 – C, 282. Reference to textbook, syllabus or examination source of quote containing 'error/oversimplification'

*In the past, the term 'erosion' has been used more broadly to include weathering, but this is not the normal usage in scientific discussion today

Table 7.7 The categories of misconception found in the textbook survey set against related misconceptions discussed in the academic literature (Taken from King, 2010, pp. 585–595)

Category	% of data	Summary of discussions in the 'Misconceptions Literature'
Minerals, rocks and fossils	5.8	*Minerals:* Blake (2004) noted that the term "mineral" was a problematic concept for 9- to 11-year-old children, whilst Happs (1982, p. 18) found no 11- to 18-year-old students able to use the term 'mineral' in the scientific sense, and Happs (1985) and Oversby (1996) found children confusing minerals with rocks *Rocks:* Piaget (1929) described how children thought rocks were provided by men or God or grew from seeds in the soil, whilst Dove (1998, p. 185) showed that pupils of all ages regarded rocks as, 'dull, heavy, large, dark material …; colour was also an important criterion'. Ford (2003) found that most primary (elementary) children, 87 % of his survey, looked for properties that provided no evidence of the mode of rock formation. Blake (2004) summarised his work and others as, 'Children's *alternative conceptions* for describing and classifying rocks centre on simple physical properties such as colour or shape and reveal only limited ideas about the origins of rocks' (p. 1857). Trainee (preservice) teachers, when asked to teach rock identification, showed relatively high anxiety levels (Westerback, Gonzalez, & Primavera, 1985) *Fossils:* Oversby (1996) showed that many pupils and preservice teachers, when given descriptions of fossils and nonfossils, were unable to distinguish between them The textbook survey showed marked similarities between the misconceptions concerning minerals, rocks and fossils in textbooks and those described in the literature. Misconceived rock definitions were found in the both the textbook survey and the literature, with similar confusion around processes of fossilisation
Sedimentary rocks and processes	24.1	*Sedimentary processes:* Dove (1997) uncovered a range of misconceptions in student ideas about weathering and erosion. This is probably because the terms have altered in meaning over time and can still be interpreted in different ways by textbooks of today (Dove 1997, 1998). Many of the misconceptions identified by Dove were also found in the textbook survey, where confusion between the terms 'weathering' and 'erosion' provided the greatest incidence of misconception recorded (Cosgrove & Osborne, 1983; Dove, 1997) *Sedimentary, igneous and metamorphic rocks:* Happs (1982) found a range of misunderstandings in children about the concepts of sedimentary, igneous and metamorphic rocks such that Driver, Squires, Rushworth and Wood-Robinson (1994) summarised his work as, 'Very few children … appreciated the relationship between sedimentary rocks and the sedimentary

Igneous rocks and processes	7.5	*Igneous processes:* Dove's (1998) review found a 'tendency for students to confuse earthquake with volcanic activity' (p. 187). Lillo (1994) and Dahl, Anderson and Libarkin (2005) showed the misunderstanding that magma that erupts through volcanoes originates in the Earth's core – when virtually all magma is thought to originate in the upper portion of the mantle or crust. Libarkin et al. (2005, p. 24) found that US college students 'believed that volcanoes only occur on islands, that they are associated with warm climates, and that volcanoes only occur along the equator, among other ideas'. Marques (1988) reported similar findings for Portuguese students of ages 10–11 and 14–15 (Dahl et al., 2005; Dove, 1998; Libarkin, Dahl, Beilfuss, & Boone, 2005; Lillo, 1994)	processes by which they are formed. … Most children …, when confronted with specimens of igneous rocks had no ideas on formation to offer …' and, '… the word 'metamorphic' was associated by most children with metamorphosis in animals …' (p. 113). Stofflett's (1993) work with preservice primary (elementary) teachers found that 'The misconceptions exhibited in this study [about rocks and their formation] were, quite frankly, appalling' (p. 230). Stofflett (1994) also showed that the 'average teacher candidate understood only 18 percent of the concepts [relating to rock-forming processes] presented' (p. 495). Kusnick (2002), in a survey of preservice primary teachers, showed that 'Students hold a surprising number of misconceptions about how rocks form' (p. 31) and 'a startling number of students described rocks as forming by processes that no geologist would recognise' (p. 37)
Metamorphic rocks and processes	8.3	*Metamorphic processes:* No literature specific to this topic was found	
The rock cycle	1.7	*Rock cycle:* Ford (2005) found that 11–12-year-old US pupils, having previously learned about the rock cycle, rarely mentioned it in their explanations of the formation of different types of rocks. She found that 'students did not grasp the purpose of instruction about the rock cycle' (p. 375). Kali, Orion and Eylon (2003) showed that the type of thinking needed to understand the rock cycle involves high-order thinking skills	

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Table 7.7 (continued)

Category	% of data	Summary of discussions in the 'Misconceptions Literature'
Geological time, correlation and dating	3.0	*Geological time and dating of events:* Schoon (1992, 1995) showed that nearly a third of the US primary (10–11-year-old) pupils and a fifth of the preservice primary teachers he surveyed thought that dinosaurs lived at the same time as cavemen
		Trend (1998) studied the understanding of upper primary (10–11-year-old) UK pupils, showing that although the children had 'a general awareness of major events such as the Ice Age and moving continents … a clear chronology is almost entirely lacking' (p. 973). Trend further studied understandings of geological time among UK preservice primary teachers (2000) and concluded that 'Trainee teachers … are more comfortable and imaginative with their teaching of history than with their geology, despite the parallels' (p. 539). In further commentary, Trend (2001) 'proposed that the nature and quality of UK society's engagement with geoscience phenomena is constrained by an all-pervasive confusion with deep time, both relative and absolute' (p. 196). He also found that 'Primary teachers do not have a secure grasp of deep time either in absolute or relative terms' (p. 215) – indicating that they are neither secure with the magnitude of geological time (the big numbers) or the ordering of time (the relative dating and correlation of geological events). Trend's findings are supported by that of Hidalgo and Otero (2004) who showed that students find it difficult to remember timed events in isolation
		Libarkin et al. (2005) found that US college students held misconceptions about the dating of the formation of the Earth and the formation of life. Libarkin and Anderson (2005) further found that students had poor ideas of the scale of geological time, the occurrence of events in geological history and absolute age dating. Dahl et al. (2005), working with US practising teachers, found that they were fairly comfortable with relative dating but not comfortable with allocating dates to geological events. Dodick and Orion (2003) showed that most Israeli students surveyed did not have the cognitive skills to cope with the concept of geological time until they reached the age of 12 or older
		Like the literature instances above, the textbook survey showed both numerical errors (e.g. that radiometric dating might show a rock to be 9,000 million years old, i.e. older than the solar system) and general misunderstandings (e.g. by stating that the age of a rock can be determined from the rock type)
Earthquakes and the structure of the Earth	17.9	*Earthquakes:* Leather (1987) in studying the understanding of earthquakes by UK children of different ages showed how their misconceptions diminished with age and the scientific view became dominant. So, whilst most 11-year-olds thought earthquakes were related to hot countries, were directly related to volcanic activity and could never occur in Britain, they had mainly lost these views by the age of 17. But Schoon (1992, 1995) showed in separate surveys that nearly a third of both US primary pupils (10–11-year-olds) and preservice primary teachers thought incorrectly that Chicago could not be damaged by an earthquake; this misconception therefore did not diminish with age. In Israel, a country prone to earthquakes, Rutin and Sofer (2007) found that 77 % of the 12–16-year-old students surveyed were unaware that their school was situated in a high-risk area

		Ross and Shuell (1993) in the US and Sharp, Mackintosh and Seedhouse (1995) in the UK showed that many primary children (5–11-year-olds) had little understanding of the causes of earthquakes, whilst the mythological and supernatural views of the origin of earthquakes held by some pupils in Taiwan were studied by Tsai (2001). The misconceptions about earthquakes held by younger children were generally not found in UK science textbooks
		Libarkin et al. (2005) showed that, whilst most of the US college students they surveyed related earthquakes to plate tectonics, 'Alternative explanations for the primary causes of earthquakes included the influence of heat, temperature, climate, weather, people and animals … gas pressure, gravity, the rotation of the Earth and processes in the Earth's core, "exploding soil" and volcanoes …' and the expanding Earth (p. 23)
		Structure of the Earth: Lillo (1994) showed that most 10–15-year-old Spanish children surveyed thought the Earth was formed of concentric layers, and this view increased with age. Many students also drew the thicknesses of the layers wrongly, with the crust often much too thick. This paralleled a similar misconception of UK practising science teachers (King, 2000) and US college students (Steer, Knight, Owens, & McConnell, 2005). Marques and Thompson (1997) asked Portuguese students to indicate on a diagram where they thought the densest materials in the Earth would be found, and many of primary age indicated near the South Pole; a significant but reduced number of older students also showed this misconception
		Libarkin et al. (2005) found, 'almost all students mixed physical state (lithosphere, asthenosphere, mesosphere, inner core, outer core) and chemical boundary (crust, mantle, core) terms, indicating a lack of understanding of the basis of subdividing the Earth's interior' (p. 24). King (2000) found high levels of misconception among practising teachers about the states (solid, partial solid, partial liquid or liquid) of the different layers of the Earth and of the thickness of the crust. Poor understanding was also shown of how the density of the Earth changes with depth and where different depths of earthquakes are likely to be found
		The misconceptions prevalent in US college students and UK teachers were common in the science textbooks. Confusion about the physical state of Earth layers (such as statements that the mantle is liquid, when it is almost entirely solid) and their thickness (e.g. the crust being shown much thicker than it actually is) was particularly common in both the literature relating to older students and the textbook survey
Plate tectonics	10.9	*Plate tectonic processes:* Marques and Thompson (1997) researched the understanding of plate tectonics held by 16–17-year-old Portuguese students after they had been taught the topic, finding that many students had developed little idea of how continents and oceans form and develop. They also had poor understanding of the term 'plate', of how plates move or the causes of this movement. King (2000) showed that practising UK science teachers had little

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Table 7.7 (continued)

Category	% of data	Summary of discussions in the 'Misconceptions Literature'
		understanding of how earthquake and heat flow distributions on Earth were linked to plate tectonics. Libarkin et al. (2005) showed that some US college students (mainly 19–20-year-olds), 'were unsure about the location of the Earth's tectonic plates, believing them to be somewhere below the surface …', whilst a few 'place tectonic plates at the Earth's core or in the atmosphere …' (p. 23). Many of the students surveyed 'were unable to conceive of tectonic plates … and most preferred to disconnect tectonic plates and their movement from the Earth's surface' (p. 23), whilst not many students connected volcanoes with plate tectonics. Libarkin and Anderson (2005) found that most US college students 'are exiting courses with a poor understanding of the location of tectonic plates' (p. 394) and Libarkin (2006) commented on, 'the fact that most [US] college students would claim that they have learned about gravity or plate tectonics in prior coursework does not mean that they fully understand these phenomena.' (p. 9)
		Most instances of misconception in the textbook survey related to confusion between the thin crust and the thicker lithosphere that forms the plates, a finding that did not figure strongly in the research literature. However, there were also many single instances of misconception in the textbooks (such as indicating that the continental crust was dragged down in subduction, when it is much too buoyant for this to happen), reflecting confusions identified in the literature
Economic geology	14.7	*Oilformation:* Leather (1987) asked UK pupils what oil formed from and found that 'Dead sea creatures (or animals) … [was] the most popular idea at all ages, and plants, vegetation, leaves or seaweed … [comes] a strong second' (p. 105), although some pupils thought oil formed from water, and others from coal. Few of the pupils he surveyed had a clear idea of how oil was trapped underground. He stated, 'The most popular view was that oil is contained below the sea bed in some sort of hollow, described as pockets, holes, spaces, potholes, gaps, cavities, crannies, pools, ponds, crevices, chambers and caves. This answer was given by 16 % of the eleven year olds, 35 % of the fourteen year olds and 24 % of the seventeen year olds. A less common misconception was that oil collects on the sea bed (14 % of eleven year olds)' (p. 106)
		These findings relate closely to the textbook survey misconceptions. The textbooks also refer to oil being formed from animals/creatures (when the consensus view is that almost all oil and gas is derived from plant material and bacteria). The textbook survey identified several confused diagrams and statements about oil/gas-trapping mechanisms that relate to the misconceptions of pupils noted above
Others	6.0	*History of geology:* There was little in the literature relating to the 'history of geology'
		Atmosphere and ocean: The extensive literature relating to misconceptions concerning 'atmosphere and ocean' was not covered by the King (2010) survey
		General: The misconceptions noted here were not included in the literature
Total	100.0	

Conclusion

The 2002 review of the Earth science content of science textbooks used in the UK (apart from Scotland – which has a different educational system) showed that the coverage of the Earth science content of the National Curriculum for Science (NCS) was poor, with more than half the NCS statements being inadequately covered (particularly the geological ones) and with a mean error/oversimplification level of one error per page. Analysis of the 453 instances of error/oversimplification found showed that the main errors were in the categories of 'rocks and rock-forming processes' (40 %) and 'earthquakes and Earth's structure' (29 %).

Whilst the review cannot judge whether or not this coverage is worse than for other areas of science, this is likely to be so.

In the light of these findings, although the work is likely to be unpleasant (taking note of the bitter complaints of the evaluation team during their work), useful areas of further textbook evaluation are likely to be:

- Evaluation of the Earth science content of science textbooks currently being used in UK schools – to establish whether or not they have improved from the low baseline established in 2002
- Evaluation of the Earth science content of geography textbooks currently being used across the UK – to discover if this coverage is equally bad (as anecdotal evidence indicates that it is)

Meanwhile, other areas of fruitful research would cover:

- The Earth science misconceptions in the UK held by different groups of people, such as secondary science teachers, geography teachers, pupils and the public, to establish if the patterns of misconceptions found match those identified in the textbook survey (following on from the analysis carried out by King (2010) which indicated that this was largely the case)
- Finding the most appropriate methods of addressing these misconceptions
- Disseminating the methods widely
- Researching the effectiveness of methods used to address the poor levels of understanding identified

Attempts are currently being made across the UK by the Earth Science Education Unit (ESEU) to address the latter issues of poor Earth science teaching which propagate misconceptions. The ESEU provides short but effective professional developments to practising and trainee (preservice) teachers free of charge across the UK (see Lydon & King, 2009). Meanwhile, attempts are also being made to address these issues internationally through the Earthlearningidea website (King, Kennett, & Devon, 2013), which publishes activities for the teaching of Earth science, aimed at both less-developed and more-developed countries, at a rate of 1 every 2 weeks. Currently there are more than 100 activities available in English, and many have been translated into other languages (Chinese (Mandarin), German, Italian, Norwegian, Portuguese and Spanish). Each activity is deliberately designed to foster high-quality Earth science teaching whilst addressing misconceptions and developing critical thinking skills (Earthlearningidea website).

Given the level of poor understanding of the Earth science concepts relevant to the teaching of 11–16-year-olds through the science curriculum, revealed by textbook surveys, it is clearly going to be a 'long and rocky road' to improvement across the system. It is therefore to be hoped that the publication of consensus views on the topics of the most widespread misconceptions (as in King, 2010) together with deliberate attempts to address the poor understanding of teachers (e.g. by ESEU and Earthlearningidea) will improve the situation over time. Given the importance of understanding the dynamics of our planet at a time of diminishing global resources, increasing geohazard risk and climate change – it is clearly important that these issues are addressed with zeal and commitment by those involved.

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Chapter 8
A Content Analysis of Science in Nineteenth-Century US Readers: Early American Science Education

Peter Rillero

Introduction

Textbooks have had a prominent place in education (Altbach, 1991; Wong & Loveless, 1991). While the recent rise of standards-based education may have loosened the role of textbooks in education, a century ago textbooks were *the* curriculum in most US schools. In 1880 William T. Harris concluded that "'Text-book instruction' is the form of school instruction adopted by the deep instinct of modern society, as the most direct and effective method of initiating the individual man into spiritual participation in the activity of his race" (Harris, 1880, p. 9). William C. Bagley (1931), in the *Thirtieth Yearbook* for the National Society for the Study of Education, quotes from state reports. "The result is that prescribed text-books, literally followed, constitute the course of study in the elementary schools of Delaware" (from a 1919 report as quoted by Bagley, p. 9) and "In practice the text-book is the course of study in most Missouri schools" (from a 1929 report, as quoted by Bagley, p. 10). Bagley went onto conclude, "These excerpts are fairly typical of what the more recent survey reports have to say about the use of textbooks in the schools" (Bagley, 1931, pp. 10–11).

In the nineteenth century, textbooks were not only the curriculum but reading from textbooks was the primary means of instruction (Elson, 1964). The readers contained lessons pertaining to literature, history, ethics, religion, and science. One of the best ways to examine what was learned in nineteenth-century schools, therefore, is to examine the contents of commonly used textbooks. The reading textbook called the reader was the dominant textbook of the nineteenth century. This chapter describes methods to explore the contents of readers and reports the science content of these key books.

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Nineteenth-Century Schooling

The Textbook of the Century

While other reasons for education evolved, the primary motivation for starting schools was to enable students to be able to read the Bible and religious texts (Resnick & Resnick, 1977; Smith, 1967; Wakefield, 1998). A 1647 law in Massachusetts commonly referred to as the "Old Deluder Satan Act" ordered that towns with 50 or more households to employ a person to help children read and write so that Satan does not succeed in "keeping men from the knowledge of the scriptures."

In the nineteenth century, students typically attended common schools, which were typically one-room schoolhouses established for children ages 6–14. The formation of a separate nation from Great Britain, the expanding press and commerce, and the plurality of religions led to a reduced focus on presenting religion in schools and reading materials (Smith, 1967). The focus of the curricula expanded to include topics such as math and geography (Säljö, 2010). The curriculum and common schools evolved into elementary schools.

Although reading, writing, and arithmetic were taught, reading had the strongest emphasis (Soltow & Stevens, 1981). In the nineteenth century, *the* dominant textbook was the textbook of reading called the reader. Indeed, the most famous textbook in the USA is the McGuffey Reader of the nineteenth century (Nietz, 1961). The readers of the nineteenth century evolved into the basal readers of the twentieth century. "The evolution of the modern reading textbook is in part the history of American education and in part the history of American culture" (Venezky, 1990, p. x).

The pages of readers were varied from three inches by five inches to four by seven inches, and the books were approximately one to two inches thick. Readers contained lessons or selections, which were passages from one to several pages about aspects of the world. Although readers listed an author, the lessons were typically compilations written by other people. By reading these passages, students learned to read and they learned about the world. As the nineteenth century progressed, readers increasingly came in series. Most students never got beyond the third reader in a series; those who did were considered to be well educated. Before 1890, only 3.8 % of the population between ages 14 and 17 went to school (Hurd, 1961). An analysis of the content of the first three readers in the most popular series provides an important glimpse into nineteenth-century schools.

The Teaching Method of the Century

Teachers were generally not trained as teachers nor were they highly educated (Elson, 1964). Reading from the textbook with rote learning did not require sophisticated teaching skills. Oral reading was used in classrooms because it was a useful skill to have in social and religious gatherings (Robinson, 1977). In fact, in Clark's 1908 book *How to Teach Reading in the Public Schools*, an early footnote indicates, "Throughout this work reading is used as an equivalent for oral expression." According to Resnick and Weaver (1979), "During the nineteenth century, an able reader – according to the definition used in most schools – was one who could give a good public rendition of a text, declaiming it with appropriate phrasing and emphasis" (p. 4). Readers were *the* textbook of the nineteenth century and reading from textbooks was *the* method of teaching (Nietz, 1961).

Science Education

In the beginning of the nineteenth century, science in the USA was like most of the nation, undeveloped and unexplored. Science gained in popularity during the century, but science was not firmly established as a stand-alone course in common schools. There were key movements that portended the arrival of science into the elementary school. These were the Object Teaching Revolution of the 1860s (Rillero, 1993) and the Nature Study Movement of the 1890s (Underhill, 1941). Science, as an established separate course of study, did not occur until the early 1900s. So the science that was contained in readers was for most nineteenth-century students the only science they encountered in schools. Thus, an analysis of the science in these readers gives us important insights into the science education of nineteenth-century students. For many of these students, it was their first and only formal science education.

Methods

The research approach used is historical content analysis. Document analysis is an important component of historical research. Content analysis, a category of document analysis, can be historical or contemporary. This historical content analysis was conducted following the protocol of Selltiz, Jahoda, Deutsch, and Cook (1986). The study was designed to answer the following questions: (a) How did the quantity of science presented vary in vicennial periods? (b) How did the type of science (biological, earth, and physical sciences) vary in the vicennial periods?

Lesson Analysis

Reader lessons were the unit of analysis. The length of a lesson was from one-half a page to a few pages, and lessons typically appeared in the table of contents. A lesson was counted as science if the main focus was to present scientific information, for example, about an organism or a structure of the Earth. For types of science, biology consists of zoology, botany, and physiology; Earth science consists of physical geography, geology, meteorology, and astronomy; and physics and chemistry are the subjects of physical science. These subject groupings are similar to the groupings made for science conferences in 1892 for the Committee of Ten (National Education Association, 1893). This study analyzed 8,459 pages, which contained 3,875 different selections or lessons. The number of science lessons in the readers and the number of pages of these lessons were systematically tabulated. The lengths of the lessons were recorded to the nearest quarter of a page.

Popular Readers of the Nineteenth Century

A key component of the analysis was to identify the most popular readers of the era. In the beginning of the century, there were not strict copyright laws in place, so other readers frequently copied lessons in popular readers. Experts have analyzed sales records, number of editions published, school and school board reports, and other sources and have identified lists of the most popular (Smith, 1967). The expert opinions of Carpenter (1967), Lamport (1937), Nietz (1961), Reeder (1900), and Smith (1967) were used to guide the identification of the most popular readers (Appendix A) of the nineteenth century for vicennial periods. For readers that came in a series, the first three books in the series were analyzed.

Accessing Nineteenth-Century Books

To be sure, libraries tend not to have systematic collections of textbooks (Venezky, 1990). However, several prominent libraries maintain collections of readers. Places with strong nineteenth-century textbook collections include the University of Pittsburgh, the University of Miami (Ohio), the Library of Congress, the American Antiquarian Society, Trinity College, New York University, Teachers College–Columbia University, Harvard University, The Ohio State University, State University of New York at Oswego, and Arizona State University. A physical examination of readers over 111 years old moves beyond the intellect to become an awe-inspiring experience.

The move to scan editions of old textbooks and put them online makes access considerably easier, although it may have the unintended consequence of causing libraries not to maintain their rare book collections. Prominent online collections for nineteenth-century interests include Google Books (http://books.google.com), Project Gutenberg (http://www.gutenberg.org), and Open Library (http://openlibrary.org). These online sources have large collections and the books are in a variety of easy to read form. The Internet Archive (http://www.archive.org) is a facile way to search many collections at once. The expiration of copyrights for nineteenth-century books makes for a large amount of availability, and the digital format makes it easy to access from anywhere around the world. Research into these free materials can help increase our understanding of education in other eras.

Results

Science Quantity

A reader lesson was judged to be science if its main focus was on presenting science information or descriptions. The readers of the nineteenth century contained a significant amount of science. The percentage of the lessons devoted to science was 14.25 %. Science pages were counted to the nearest quarter of a page and compared to the total number of student pages in the book; 12.76 % of the total page contents were science lessons. The amount of science by selection percentage and page percentage is shown in Fig. 8.1.

The amount of science in the first vicennium was a relatively low 5.28 % of the total lessons and 3.86 % of the total pages. These amounts increased from the beginning of the century, peaking in the middle of the century (Fig. 8.1). The lesson percentage (20.47 %) peaked in the 1820–1839 period, and the page percentage peaked (19.52 %) in the 1840–1859 period.

Science Content

The type of science was classified as biology, physical science, and Earth science. Figure 8.2 shows that biology started as the highest content area, and it showed an almost steady rise relative to the other science content areas. At its beginning,

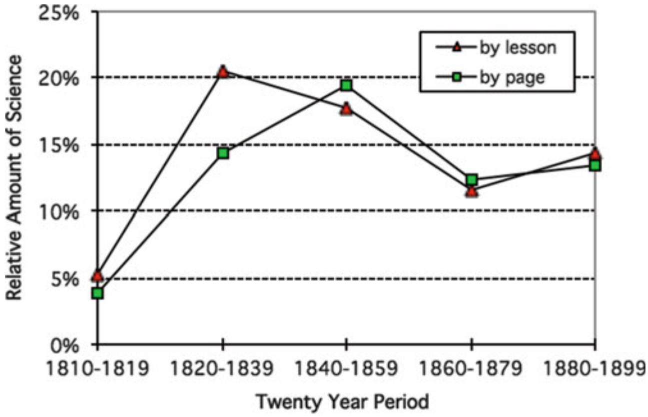

Fig. 8.1 The percentage of science in readers by vicennial periods

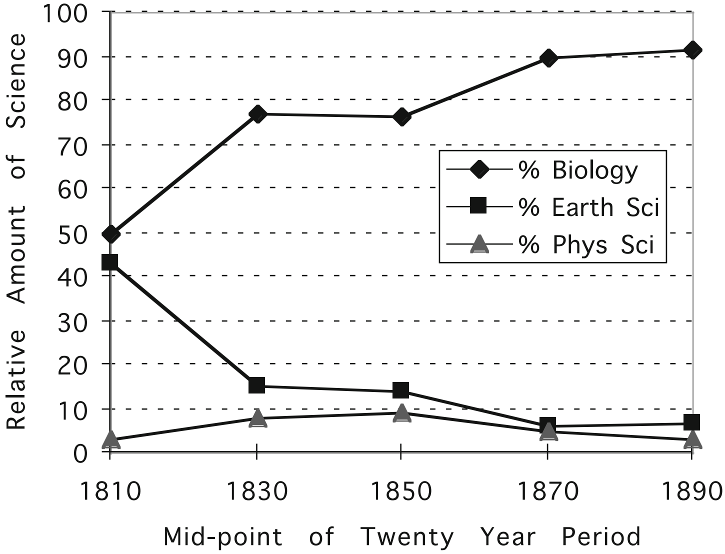

Fig. 8.2 The percentage of the type of science in readers by vicennium

biology represented 53.3 % of all of the science lessons and grew steadily so that at the end of the century, biology represented 90.5 % of all of the science. The increase in biology content roughly follows the decrease in Earth science content, which went from 43.33 % to 6.74 %. Physical science started the century at 3.33 %, increased to 9.27 % during the middle of the century, and closed the century at 2.80 %.

Methods of Depiction

Lessons of science came in a variety of forms including descriptions and didactic presentations similar to contemporary textbooks. An example of this is presented in Fig. 8.3. Science lessons also existed as dialogs between adults and children. An example of a dialog is presented from Parker's Second Reader (1857, p. 74).

Mother Heat does not always make fire, Caroline; for, if it did, everything would be on fire.

Daughter Everything on fire, mother! why, what do you mean?

Mother I mean, my dear, that everything contains heat.

Daughter Everything contains heat, mother, did you say? Why, then, is not everything warm? Some things, mother, are very cold; as ice, and snow, and that marble slab.

Mother Yes, my child, everything contains heat, as I shall presently show you. When Alice goes to make a fire in a cold day, she does not carry the heat with her, and put it into the fire, nor into the wood, nor the coal, does she?

READING LESSON VIII.

Heat.

1. Heat, as a cause of sensation, that is, the matter of heat, is considered to be a subtile fluid, contained in a greater or less degree in all bodies.
2. In modern chemistry, it is called caloric.
3. It expands all bodies in different proportion, and is the cause of fluidity and evaporation.
4. A certain degree of it is also essential to animal and vegetable life.
5. Heat is latent, when so combined with other matter as not to be perceptible. It is sensible, when it is evolved and perceptible.
6. Heat, as a sensation, is the effect produced on the perceptive organs of animals, by the passage of caloric, disengaged from surrounding bodies, to the organs.
7. When we touch or approach a hot body, the caloric or heat passes from that body to our organs of feeling, and gives the sensation of heat.
8. On the contrary, when we touch a cold body, the caloric or heat passes from the hand to that body, and causes a sensation of cold.

Fig. 8.3 Heat lesson from Cobb's third reader (1847)

There was also an effort to integrate science with other content areas. For example, a scientific lesson about thunderstorms precedes a poem about thunderstorms in McGuffey's Third Reader (1853). It was also very common to include religion with the science. For example, in Sanders' First Reader (1858), a lesson with a conversation about fireflies ends with the mother saying, "the earth is full of the works of the Lord, and no life is long enough to learn them all."

Discussion

Science content rose in the mid-nineteenth century and then declined. The rise in science could reflect the popularization of science during this century and the emergence of science as a profession. Significant scientific, technological, and engineering advances enamored the public. Famous scientists and inventors of the era include Louis Agassiz, Amedeo Avogadro, Henri Becquerel, Alexander Graham Bell, Robert Bunsen, Marie Curie, Georges Cuvier, Charles Darwin, Christian Doppler, Thomas Edison, Michael Faraday, Carl Friedrich Gauss, Ernst

Haeckel, Heinrich Hertz, William Thomson Kelvin, Robert Koch, Charles Lyell, James Clerk Maxwell, Gregor Mendel, Dmitri Mendeleev, Alfred Nobel, Louis Pasteur, Ivan Pavlov, William Smith, Nikola Tesla, and Alessandro Volta. Science shows, replete with demonstrations and lectures, were well attended (Nadis, 2005). Many popular scientific journals were started including *Scientific American* and *Popular Science*.

While the popularization of science can explain the rise in the science content of the readers, it does not explain the subsequent decline towards the end of the century. There are two strong possible explanations: (a) the movement to make reading content literary and (b) the nascent movement to establish science as a separate subject. During the later part of the nineteenth century, there was a shift to focus on literature in the teaching of reading. As an example of this overt shift and the removal of science, the Conference on the Study of English of the Committee of Ten recommended, "Reading-books should be of a literary character and should not attempt to teach physical science or natural history" (National Education Association, 1893, p. 89). This seems to be one of the reasons for the decline of science. During the late nineteenth century, scientists began to promote the idea of science as a separate subject (Underhill, 1941). Beginning with object teaching and then nature study, science was just starting to earn a place in the school curriculum, and perhaps because of this trend, it was thought that it was okay to reduce the science in the readers. It is also possible that as science was removed from readers, the movement to establish it as a separate subject intensified.

The increase in biology relative to other science subjects is also interesting, as biology started out as the most represented. Its greatest competitor was Earth science, which consisted of geology, astronomy, and geography. Geography was an area that included many topics of what we now consider Earth science in addition to mapping skills and knowledge. After the Civil War, geography was established as a separate subject area (Finney, 1921). Geography textbooks were used in teaching this subject (Nietz, 1961). The geography books contained Earth science topics such as astronomy, winds, tides, and soils. So it is possible that Earth science content of readers decreased as geography as a separate subject gained acceptance. It is not clear why physical science lessons were so few. It could be that the compilers thought that the explanations would be too difficult for younger students or not interesting enough.

Conclusion

An analysis of popular textbooks of the nineteenth century gives strong views into both what educational leaders thought should be taught and what was actually taught. Digitized work makes analyses of textbooks easier than ever. No textbook was more important than the reader – the textbook of reading. The science content in the readers was probably the first formal science education of most students. Biology content increased relative to other science subjects. Science rose in content towards the middle of the century and then it was reduced as reading strove to use more literature. Science was pushed out of the readers, and it started a long path to becoming a separate subject in elementary schools.

Appendix A

Bibliography for Most Popular Readers by Vicennial Periods Organized by Year of Publishing

1800–1819

Webster, N. (1803). *An American selection of lessons in reading and speaking*. Baltimore: Thomas Andrews.

Bingham, C. (1805). *The American preceptor; being a new selection of lessons for reading and speaking* (23rd ed.). Boston: Manning and Loring.

Murray, L. (1808). *Sequel to the English reader: Or, elegant selections in prose and poetry*. New York: Collins and Perkins.

Murray, L. (1812). *Introduction to the English reader*. Philadelphia: Bennett and Walton.

Bingham, C. (1815). *The Columbian orator* (Sixth Troy edition). Troy: Parker and Bliss.

Murray, L. (1818). *The English reader; or, pieces in prose and poetry, selected from the best writers*. Pittsburgh: Patterson and Lambdin.

1820–1839

Murray, L. (1826). *The English reader; or, pieces in prose and poetry, selected from the best writers*. Philadelphia: Edwin T. Scott.

Murray, L. (1827). *Sequel to the English reader: Or, elegant selections in prose and poetry*. Philadelphia: S. Probasco.

Pierpont, J. (1828). *Introduction to the national reader*. Boston: Richardson and Lord.

Murray, L. (1829). *Introduction to the English reader*. Pittsburgh: Bennett and H. Holdship.

Pierpont, J. (1829). *The national reader*. Boston: Richardson, Lord, and Holbrook.

Cobb, L. (1830). *Cobb's juvenile reader number 1*. Ithaca: Andrus, Woodruff, and Gauntlett.

Cobb, L. (1831). *Cobb's juvenile reader number 2*. Chambersburg, PA: Hickok and Blood.

Cobb, L. (1835). *Cobb's juvenile reader number 3*. Bennington, VT: John C. Haswell.

Pierpont, J. (1835). *The young reader; to go with the spelling book*. New York: George F. Cooledge.

1840–1859

Sanders, C. W. (1840). *The school reader. Second book*. Cincinnati: William H. Moore.

Cobb, L. (1842). *Cobb's new juvenile reader, number I*. Ithaca: Mack, Andrus.

Sanders, C. W. (1843). *The school reader. First book*. New York: Mark H. Newman.

McGuffey, W. H. (1844). *McGuffey's newly revised first reader; the eclectic first reader for young children*. Cincinnati: Winthrop B. Smith.

Cobb, L. (1845a). *Cobb's new juvenile reader, number II*. Oxford, NY: W.E. Chapman.

Cobb, L. (1845b). *Cobb's new juvenile reader, number III*. Cincinnati: B. Davenport.

Murray, L. (1846). *The English reader; or, pieces in prose and poetry, selected from the best writers*. Philadelphia: W.A. Leary.

McGuffey, W. H. (1848). *McGuffey's newly revised eclectic third reader*. Cincinnati: Winthrop B. Smith.

Sanders, C. W. (1848). *The school reader. Third book*. New York: Ivison and Phinney.

McGuffey, W. H. (1853). *McGuffey's newly revised eclectic second reader*. Cincinnati: Sargent, Wilson, and Hinkle.

1860–1879

Sanders, C. W. (1861). *The school reader. Third book*. New York: Ivison and Phinney.

McGuffey, W. H. (1863a). *McGuffey's new first eclectic reader*. Cincinnati: Van Antwerp, Bragg.

Hillard, G. S., & Campbell, L. J. (1864). *The new series. The primer of first reader*. Philadelphia: Eldridge and Brother.

McGuffey, W. H. (1863b). *McGuffey's new second eclectic reader: For young learners*. Cincinnati: Wilson, Hinkle.

McGuffey, W. H. (1865). *McGuffey's new third eclectic reader: For young learners*. Cincinnati: Wilson, Hinkle.

Sanders, C. W. (1869). *Sander's new series. The school reader, second book*. New York: Ivison, Phinney, Blakeman.

Parker, R. G., & Watson, J. M. (1860). *National first reader or word-builder*. New York: A.S. Barnes.

Parker, R. G., & Watson, J. M. (1869). *National third reader or word-builder*. New York: A.S. Barnes.

Sanders, C. W. (1871). *Sander's new series. The school reader, first book*. New York: Ivison, Blakeman, and Taylor.

Parker, R. G., & Watson, J. M. (1857 and 1885). *National second reader or word-builder*. New York: A.S. Barnes.

Hillard, G. S., & Campbell, L. J. (1873a). *The new series. The third reader, for primary schools*. Boston: Brewer and Tileson.

Hillard, G. S., & Campbell, L. J. (1873b). *The Franklin second reader*. New York: Taintor Brothers, Merril.

1880–1899

Harris, W. T., & Rickoff, A. J. (1884). *Appleton's school readers. The first reader*. New York: D. Appleton.

McGuffey, W. H. (1885a). *McGuffey's new first eclectic reader: For young learners*. New York: American Book Company.

McGuffey, W. H. (1885b). *McGuffey's new third eclectic reader: For young learners*. New York: American Book Company.

Harris, W. T., & Rickoff, A. J. (1886). *Appleton's school readers. Second reader*. New York: D. Appleton.

Harris, W. T., & Rickoff, A. J. (1887). *Appleton's school readers. The third reader*. New York: D. Appleton.
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Baldwin, J. (1897c). *Baldwin's readers third year*. New York: American Book Company.

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Nadis, F. (2005). *Wonder shows: Performing science, magic, and religion in America*. New Brunswick, NJ: Rutgers University Press.
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Chapter 9
Educational Approach to Environmental Complexity in Life Sciences School Manuals: An Analysis Across Countries

Silvia Caravita and Adriana Valente

Introduction

The BIOHEAD-Citizen project[1] was aimed to deepen the understanding of how different aspects of citizenship can be promoted through biology, health and environmental education. Teachers' conceptions, defined as constructs emerging from the interaction of knowledge, values and social practices (Clément, 2006), and the conceptions implicit in the messages conveyed by science school manuals were the targets of the investigations. This chapter is aimed at presenting an overview of the main findings concerning environmental education (EE) that resulted from the analyses of life sciences manuals carried out in the countries participating in the European project "Biology, Health and Environmental Education for better citizenship".

School teaching relies on manuals, and these remain one of the pillars of instruction, even when teachers promote inquiry learning and encourage the students to consult diverse sources of information. Textbooks offer guidelines for the contents indicated in the national programmes; they are didactical resources for the teachers; they are the main reference for the students to prepare the examinations. The pedagogical approach of the books has therefore important consequences on the school class practices:

[1]This study was accomplished within the European research project "Biology, Health and Environmental Education for Better Citizenship" (BIOHEAD-Citizen FP6, STREP CIT2-CT2004-506015), coordinated by Graça Carvalho (Portugal), Pierre Clément (France) and Franz Bogner (Germany) involving 19 countries: 13 European countries (Cyprus, Estonia, England, Finland, France, Germany, Hungary, Italy, Lithuania, Malta, Poland, Portugal and Romania), five African countries (Algeria, Morocco, Mozambique, Tunisia and Senegal) and one from the Middle East (Lebanon).

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it can be consistent with rote teaching/learning when the books are mere exposition of subject matters, or it can support the active construction of knowledge. When this is the case, manuals may display a variety of functions:

– Offering context-based disciplinary knowledge, thus diminishing the gap with the reality familiar to the students' and facilitating the mobilisation of their experience
– Presenting/explaining/argumenting information with references to documents, to the methods for collecting and representing data
– Inviting students to situate new information with concrete cases or, on the opposite, to transfer and generalise it by taking broader perspectives
– Highlighting relationships among concepts, revealing the nature of models as devices for understanding, though constrained, debatable and historically determined
– Showing the processes of knowledge building instantiated in inquiries in progress in which non-stabilised science deals with still ill-defined problems
– Fostering reflective thinking to increase the awareness of how beliefs, values and worldviews are interwoven with knowledge
– Providing stimuli for collaborative inquiries and for using learnt information

The development of critical minds in the transfer and application of knowledge in life contexts is the goal of education and in science at the utmost. "A reductionist view of natural sciences is too often conveyed owing to the implicit belief that scientific results need not certain information about the systemic circumstances of their production, especially when they are transformed into general-purpose *facts* for teaching and applications. Hence it has been easy to foster the illusion that those circumstances are irrelevant to the understanding of science" (Ravetz, 2006, p. 30).

In general, educational policy makers and researchers give more attention to teachers' training and to the guidelines included in the syllabi than to the improvement of school manuals to promote curricular innovation, therefore underestimating the role that textbooks have in the conservation of traditional teaching practices. School should be very demanding about the quality of the manuals, and teachers should be prepared to select and to discuss with the publishers editorial criteria which satisfy the requirements envisaged by the innovative intentions of the training courses that they attend and by the recommendations displayed in the official documents.

The production of manuals, their rate of change and the access of teachers to them vary considerably across countries. In most European countries, teachers have a wide choice among several manuals, which are issued by publishers without any control from the National Ministry of Education; in other countries, teachers may have a limited choice among a set of manuals which have been evaluated and selected by committees appointed by the Ministry, as it happens, for instance, in Brazil, in North African countries and in Malta. There are science manuals having specific contents for each school grade (e.g. France, Morocco) or manuals covering the year's span of a school level. In this case, it is up to the teachers to select the parts suitable for the curricula which are yearly planned by the teachers' community in the school institutes (e.g. Italy, Malta). Therefore, the relationship between the content of school manuals, the national syllabi and the actual teaching is locally determined, obliging caution in the generalisation of conclusions drawn from comparative analyses across countries.

The Specific Concerns of Environmental Education

Environmental education (EE) has been introduced in the curricula of the European countries since many years, and it is widely conceived as transversal to the disciplines. Steering documents from the national school departments and from international organisations (Education, Audiovisual and Culture Executive Agency [EACEA P9 Eurydice], 2011) stress the importance of connecting EE with education to citizenship aimed at preparing young generations to be active participants in the care of the environment and in the creative devise of socioeconomic policies more respectful of the ecological dynamics and of equity in the use of resources.

Oversimplification is often evident in the teaching practices of EE: the challenges that are implicit in rethinking our future are understated, the didactics tend to remain discipline oriented, and little time is allocated to project-oriented students' activities. These limitations contradict the approach to complexity explicitly stated in the documents by the UNESCO and European Community which promote Education for Sustainable Development (OECD, 2007; Rychen & Thiana, 2004; UNECE, 2009, 2010; UNESCO, 2009). Even though life and earth sciences remains one of the main subjects of reference for EE, the themes and topics relevant for ESD are at the intersection of environmental, economic, social and cultural dimensions (Clément & Caravita, 2011; UNESCO, 2006): "Environmental learning may encompass a hugely diverse content, from the form and function of physical systems (such as ecosystems and hurricanes) to global-scale interactions between people and the physical environment (…) is thus not reducible to accumulation of facts or transmission of a fixed body of knowledge: it often implies dealing with the values and perspectives of oneself and others" (Rickinson, Lundholm, & Hopwood, 2009).

Environmental sciences have undergone unforeseen development in the last century starting from the extension of the system modelling elaborated by Bertalanffy and the advancement of nonequilibrium thermodynamics.

The complexity of ecological systems demands complex approaches (theoretical and methodological) for studying the quality and quantity of energy, matter and information exchanges which occur among the high number of distinct components, at different interconnected sub- or sovra-ordered systems, at different scales (of space, size, time). Non-linear relationships and retroactive processes make the interpretation of the dynamical states and phases of the systems not always and not easily predictable.

As Giampietro – a scientist involved in agricultural economics – underlines (2003b, p. 43), the definition of system proposed by Kampis (1991) relates description with formalisation and with goal-oriented choices: system is thought as "the domain of reality delimited by interactions of interest". Traditional separation of ecological and social sciences tends to hinder a more integrative view of the complexity of coupled human and natural systems, but an increasing number of interdisciplinary programmes which involve teams of scientists over the world are taking this perspective. They investigate the complex interactions and feedbacks with methods that originate in diverse science fields; their projects are simultaneously context-specific and longitudinal to highlight dynamical processes. The phenomena which are pointed out in their findings have great importance for building ways of viewing environmental systems. Liu et al. (2007) synthesise them: feedback loops, non-linearity and thresholds (systems can "flip" between states when their homeostatic mechanisms are overwhelmed), surprises (outcomes can be totally unexpected because of poor understanding), time lags (the ecological and socioeconomic impacts may not be immediately observable; different causes of change may become apparent over different time periods; the same cause may have effects that emerge at different time lags), resilience and interactions among even geographically distant systems and across scales, as globalisation intensifies.

These investigations also get confirmation of the heterogeneity of human-nature couplings, which vary across space, time and organisational units. The articulated systems theory developed by Giampietro (2003a) has its grounding in the assumption that each level in any system has its unique properties; therefore descriptions, measurements and evaluations cannot be uniform across levels or they fail their goals.

In this chapter, we aim at providing some evidence on how the authors of school manuals take in charge complexity as content and as thinking strategy. We maintain that focusing on the conflict between current lifestyles and the consequences of human impact on the environment is not really effective to foster environmentally friendly behaviours. This approach reflects the normative tradition of education. The promotion of pro-environmental practices should have its ground in the deep understanding of the systemic functioning of environments, and this should be supported by exposition to emblematic cases: outcomes of researches or of actions undertaken in real contexts to overcome problems.

"Environment-related content also poses challenges relating to defining and understanding particular problems, processes relationships, identifying their cause, and thinking solutions, actions, or responses" (Rickinson, Lundholm, & Hopwood, 2009). Students have problems in applying principles to specific cases; they do not know how evidence from scientific data is used and systematically processed; they imply that conclusions drawn from evidence are always certain, that there are always solutions for problems. OCSE PISA assessments have widely documented this kind of thinking failures. Helping students to becoming environmentally knowledgeable is deeply rooted in the comprehension of and reflexion upon practices that may not have univocal outcomes and that can be evaluated from legitimate and diverse points of view. The awareness about the limits and the constraints that accompany human agency and about the risk of privileging points of view is crucial for changing the way of facing environmental problems with the power of science and technology. If the final goal of EE is the development of thinking tools effective for interpreting and taking action in life contexts, teaching of the scientific concepts demands also attention on epistemological, ethical and practical aspects and on their interrelations.

Clément (2004) reminds the notion of *umwelt* proposed by von Uexküll to point out that environment is an individual construction and that spaces for civil participation can open up if these individual constructions integrate in social and negotiable ones. This is another important aim of education to be pursued.

To which extent life sciences school manuals for secondary school reflect the state of the art of environmental sciences? Do simplified expositions frustrate the efforts of the teachers' didactical projects and the attainment of the aims pursued by EE? To which extent a simplistic approach does actually reflect conceptions concerning human-nature relationship and pedagogical assumptions about education? Do manuals reflect different cultural contexts across countries?

EE is a complementary activity and may be included in the curricula of various disciplines with topics treated in the textbooks of natural sciences, biology, physics, chemistry and geography. The BIOHEAD project examined the manuals for life and Earth sciences; therefore it has attained a partial information on the contribution provided by textbooks to EE. Life and Earth science manuals, though, are the main reference for science subjects at lower secondary school (students aged 11–14) which is also the instructional level more homogeneous across countries making the comparison more feasible and reliable. Our comments will mainly concern this school level.

The findings of the comparative analyses across countries have appeared in published papers and conference proceedings. Some of the comparisons concerned countries from Western and Eastern Europe and Africa (Carvalho, Tracana, Skujiene, & Turcinaviciene, 2011; Ferreira, Tracana, Ferreira, & Carvalho, 2008; Tracana & Carvalho, 2010; Tracana, Ferreira, Ferreira, & Carvalho, 2008); other ones took into account Mediterranean countries (Agoram et al., 2009; Caravita, Agorram, Valente, Luzi, & Margnelli, 2008; Caravita, Berthou-Gueydan, Agorram, & Clément, 2012). We wish to offer here a synthesis of which appear to be the main trends and differences among countries in the narratives of the life sciences manuals, to draw from this evidence some negative and positive examples of how they contribute to build students' understanding of the complexity of ecological processes and their ways of conceiving the relationship of humans with the environment. The analysis of some Italian and French manuals more recently published showed that, besides diversities among countries, differences may emerge due to changes taking place in the cultural and educational national contexts over time.

Methodological Aspects of the Analyses of School Manuals in the BIOHEAD-Citizen Project

The narratives contained in the books emerge from the articulation between texts and the images (Pozzer & Roth, 2003); this rhetorical structure which guides reading and learning can be highlighted (Izquierdo, Marquez, & Gouvea, 2008) and was considered by the items that were included in the grids to be used for the manuals' analysis. The procedure followed to design the grids is extensively illustrated in the paper by Caravita, Valente, Luzi, Pace, Khalil, Valanides, Nisiforou, Berthou-Gueydan, Kozan-Naumescu, & Clément (2008).

The BIOHEAD partners selected four topics relevant in ecology and environmental education: ecosystems and cycles (*Ec&cy*), pollution (*Po*), use of resources (*UoR*) and biodiversity (*Biody*). The analyses aimed at tracing the *conceptions* which featured the exposition about these topics. In particular, four conceptions were identified as targets and the definition of the extreme poles was meant to include a continuum of ideas:

– Complex vs linear approach to systems
– Anthropocentric vs ecocentric relationship with nature
– Global vs local approach to environmental issues
– Individual vs social responsibility

This chapter will concentrate on two topics, *Ec&cy* and *Po*, and we will take into account key dimensions that shape the approach to the complexity of environmental systems.

Two sets of grids were applied to the school manuals: the *general grids* contained checklists of items common to the four examined topics, and the *specific grids* contained checklists of concepts (*indicators*) concerning each topic, which were considered to be pertinent and adequate for revealing the explicit/implicit presence of *conceptions.*

The *complex* vs *linear* approach was conceived as emerging from the co-occurrence in the narratives of many different issues like the following:

– Webs vs chains of ecological components.
– High number and diversity of components of the ecological webs vs stereotyped simplification of their components.
– Functional vs structural description. A functional perspective highlights factors, variables and constraints.
– Interdependence among the components vs one-way relationships.
– Presence vs absence of feedbacks, retroactions and cycles. Time scales consideration, reversibilility of processes vs “here and now” descriptions.
– Interpretation of events from systems as emergent from cofactors, from parallel processing vs description/explanation of events deterministically caused.

We report synthetically the main indicators included in the grids without listing their specifications into concepts.

Main Items in the General Grids

Number of pages and of images dedicated to the topics
Kinds of images (the categories are illustrated in the legend of table)
Relationships of the topics with the other contents of the manual (book index)

Epistemological concern: occurrence of statements mentioning the limits of scientific knowledge and the instantiation of multiple perspectives in the interpretation/solution of ecological problems.
References to cultural, socioeconomic and ethical aspects and to controversies in the management of environmental problems treated as emblematic cases
Presence of a historical approach
Educational style of the exposition: merely informative, sometimes persuasive, conveying assertive messages and fostering students' active involvement

Main Items in the Specifc Grid for the Subtopic Ec&cy

Definition of ecosystem
Variety and plurality of components
Variety and plurality of ecological relationships
Flow of matter and energy
Cycles of elements
Ecological changes, ecosystemic changes and regulatory processes
Anthropic factor
Motivation for conservation and management of ecosystems

Main Items Included in the Specific Grid for the Subtopic Po

Environmental components affected by pollution
Sources of polluting events (accidents, human activities, wars)
Sources of pollution control (technological devices, laws, international agreements)
Interconnections between local and global levels mentioned when cases of pollution are illustrated
One cause-multiple effects or one effect-multiple causes
Variables taken into account (ecosystem's size or complexity, time scale, severity of pollution)
Sources of regulation (in ecosystems, in biosphere)
Pollution prevention and management (changes in individual/social behaviours or in the interaction between individual and social behaviours; advancement of technology)
Types of impact of pollution and consequences (on humankind, on ecosystems)

Common guidelines were agreed among the partners of the project for the application of grids and for the sampling of at least three manuals for each school level (elementary, lower secondary, higher secondary), possibly selected because in top positions in the national list of the most selected ones by the teachers.

An Extension of the BIOHEAD Poject

The analyses carried out within the BIOHEAD project considered manuals which had been published around the year 2000. We decided to repeat the analyses on few manuals for checking whether they revealed new trends in the approach to environmental education. We chose the same Italian and French life sciences manuals for lower secondary school, written by the same authors and issued by the same publishers around the years 2009–2010.

The Space That Ecology and Environmental Issues Have in the Life Sciences Manuals of Secondary School

The comparison across countries becomes complicated when it deals with the science manuals for higher secondary education, since this school level splits into specialisations (in science, humanities, art, technology, economy, etc.) having a diversity of lines and steps. Courses for students of the same age may or may not include life sciences, and their content is not the same according to the kind of specialisation. Therefore, the comparative analyses which appeared more feasible and reliable by the BIOHEAD partners were accomplished on the manuals for students aged 11–15 (extending it to 11–16 for Malta). This chapter focuses on lower secondary education manuals, making references, when needed, to upper level, in order to include relevant findings reported from other BIOHEAD analyses and to show eventual developmental trends.

In all Mediterranean countries participating in the project (Caravita et al., 2012), ecology is mainly included in the curriculum of the first year of lower secondary, and it is treated again in more depth at the beginning of higher secondary school. In the initial levels, the programmes insist on the discovery of natural environment, the description of biotic and abiotic components and their relationship and the trophic relationships among living beings. These topics may be treated in parallel with nutrition and respiration of plants and animals living in different environments. The description of ecosystems, the ecological cycles and the flow of matter and energy between biosphere and physical environment are topics studied in more depth in the following levels (students aged 14–15 or 15–16). The urban environment is taken into account in some of the manuals of Italy, Portugal and Tunisia. Almost the same amount of pages dedicated to *Ec&cy* can be found in the manuals examined in Italy, in Malta, in Morocco and in Tunisia. In France and Portugal, the number of pages is much higher by summing up the pages of each manual for the whole age span of 11–15. On the opposite, this space is very limited in the Lebanese book for students aged 11–12.

In the Mediterranean countries, the number of pages dedicated to *Po* is low in respect to the total number of pages of the books, particularly in the initial levels of lower education. Environmental issues do not make the content of chapters but are treated as bits of extra information inserted in additional documents. The topic pollution often appears in connection with the physical components of the planet – water, air and soil – and with human health. Topics like the presence of humans and their activities – their responsibility in the use of these resources, in the changes of composition of the atmosphere and in the preservation of biodiversity – are introduced in the curricula for students aged 14–15 or later. The space that these topics have in the manuals does not considerably increase in the upper levels, particularly in the manuals examined in Morocco, Malta and Tunisia.

The colleagues of Hungarian team noticed that in Hungary, the environmental problems do not find space in science manuals and are more likely included in geography manuals, due to the circumstance that in Hungary textbooks are discipline- and not problem-oriented. This remark might be extended to all the countries where manuals are organised following a similar structure.

The Rhetorical Function of the Images

The images inserted in the chapters or in the additional documents have been categorised into several types, and the percentage of each type over the total number of images has been calculated. The following types and their percentages will be considered here:

Type 1 – Images reporting empirical data
Type 2 – Non-figurative images representing scientific conceptualisations
Type 3 – Figurative images (photos and drawings)
Type 4 – Figurative conceptualisations
Type 5 – Maps containing data related to geographical distribution
Type 6 – Satellite images

Figurative images clearly prevail over the other types of images in the text concerning *Ec&cy* and *Po* in the examined manuals, but there are some differences among countries. The percentages of images which illustrate empirical data are higher for *Po* than for *Ec&cy*; images of this type are more numerous in the manuals of France (except for ages 11–12), of Portugal, of Lebanon and of Malta (about 25 % as average). They are few in the manuals of Morocco, and they are completely lacking in those examined in Italy.

In the Moroccan manual, the percentage of conceptualisation is high in respect to the other manuals. Outstanding is the very high percentage of images showing non-figurative conceptualisations included in the Maltese manuals, since this type of images is either absent or in a very low percentage in the other countries. In the countries in which several manuals of different publishers have been examined, as in France and Italy, the percentages of the images with figurative and non-figurative conceptualisations vary, and it is presumably more related to the authors' and publishers' editorial style than with the students' age.

Images of maps appear in French manuals in considerable number in respect to the other countries.

In conclusion, we found evidence that in the manuals of some countries (e.g. Italy, Morocco), the images have the main if not exclusive function of showing reality, whilst in other countries they are used by the authors also to support the construction of ideas. In fact, the images fulfil a wider range of rhetorical functions to attain more scientific levels of description of phenomena: they familiarise with different forms of abstraction and data representations; they convey information on how ecological processes can be investigated and quantified, also supporting comparisons and debate.

The Human-Nature Relationship: Conceptions Conveyed by the Images

The figurative images inserted in the chapters dealing with *Ec&cy* show "natural and wild" environments where people are generally absent, reinforcing a view of people "apart from nature" and not "as part of nature". Textbooks from Finland and Morocco make exception to some extent. Scientists or students engaged in ecological investigations may appear; therefore, the role of humans as "observers" of nature is emphasised in the very few instances found (in Tunisia, for instance, as reported by Alaya, 2010). On the other hand, in the parts of the manuals dealing with *Po* and *UoR*, images of environments with anthropic components are prevalent.

Carvalho et al. (2011) made a survey of the images occurring in the 25 manuals for 14-16-year-old students that had been examined in 14 countries, related to the four topics: *Ec&cy*, *Po*, *UoR* and *Biody*. The authors report that in Western European countries, images showing urban and rural environments appear in higher percentage than the images of wild nature, compared with Eastern European and African, except for Tunisia; in Western countries, a large proportion of images illustrate the negative human impact plus examples of human management of the environment. These examples never appear in the manuals of Lithuania, Cyprus and Morocco and in one of the Italian books. Therefore, humans are presented as "owners" of nature, but the presence of people, their artefacts, and activities tend to perturbate the natural beauty and order of nature.

The images illustrate almost the same subjects in different countries: the catastrophic consequences of accidents such as oil spillage from tanks, the spread of fumes from industrial activities and smog from car traffic, trees killed by acid rains, pesticides sprayed from aeroplanes, the overgrowth of algae for the eutrophication of waters, desertification of lands and heaps of plastic wastes. The message conveyed by these images aims to be very effective at the emotional level.

In general, we might comment how the selection of images done by the authors and publishers is influenced by the globalised communication coming from the media.

Also the relatively few occurrences of images that exemplify the positive intervention of humans to control pollution are recurrent in the manuals across countries: techniques for biological agriculture, plants of solar energy, and plants for water regeneration and reforestation. The manuals examined in Portugal, Tunisia, Finland

and Lebanon resulted to pay more attention to include images of environmental management. An interesting case was found in the Finnish book where only men appear in the images showing the detrimental effects of human activities, whereas more frequently women than men appear in the images showing positive human interventions in the environment (Skujiené, 2007).

Interesting comments have been proposed concerning the Hungarian manuals: the few pictures showing the negative human impact illustrate environments of other countries more frequently than local ones. In addition, they rarely show people as responsible agents, but they just show the consequences of human actions, whilst humans are often shown as the victims of the polluting agents or of the degradation of the environment (e.g. images of children playing nearby a polluted river or next to the dirty and polluted area of a chemical factory).

In conclusion, we remark that the separation human-nature that is suggested by the life sciences manuals re-proposes the opposition between two alternative conceptions, ecocentrism and anthropocentrism. This is also the result of a linear thinking unable to cope with the complexity and with the difficult task of finding new perspectives in the alternative between nature and humans. Composing the alternatives may also mean finding new ways of sharing the planet with all its guests, accepting that all living beings – humans included – have unique features and needs and ways of inhabiting it.

An evolving situation can be found in most recently published manuals, as we will see later.

The Approach to the Complexity of Ecosystem and Their Perturbation from Pollutants

The theme of complexity has been directly taken into account within BIOHEAD analyses with specific reference to Mediterranean countries (Caravita et al., 2012; Agorram, Caravita, Valente, Luzi, & Margnelli, 2009); anyway, other analyses within BIOHEAD, including a larger sample of countries, add evidence to some of the findings on which we draw our conclusions.

How Complex Versus Linear Is the Approach to **Ec&cy** *and* **Po** *in the Text and Images Inserted in the Text*

In the lower secondary school manuals that were examined, the structural description of "natural" environments prevails, even articulated and with rich illustration of the components. The functional aspects and the dynamics of ecosystems are not treated by the manuals of some countries (France, Lebanon, Morocco); when they are included in the contents, the description of the flowing of matter and energy through the systems is simplified, either in the text or in the images of food webs and cycles. Dissipation of energy is not always represented.

The notion of climax in the ecosystem's succession may be absent; anyway the conception of stability of the ecosystems emerges even when this notion is considered:

> The final, stable stage of a plant succession is called the climax vegetation for that region. (Malta)

The only dynamical phenomenon which is more often considered is the relationship between the population of preys and predators (usually rabbits and foxes): their proportion may become unbalanced, but it recovers its balance, without any possible failure, without mentioning factors and variables which might prevent the "final goal" to be attained. The occurrence of regulatory processes is just vaguely hinted: "depends on various factors"; it rarely is described, as in this example from the Maltese manual:

> These are the kind of checks which stop populations growing for ever. The first two involve competition: the rabbits compete with each other for food and living space. Competition between members of the same species is called intraspecific competition. You can also get competition between different species: that's called interspecific competition.

It is interesting to point out that in some of the manuals (in Italy, in Morocco, in Tunisia) the term of "equilibrium" appears to define a condition of the ecosystems: it is generally characterised as a dynamical condition, but sometimes it is also qualified as "natural" or "biological", kept as long as no external factor perturbates it. In these cases, human activity is quoted as the main perturbating factor.

The science manuals examined in the six Mediterranean countries make reference to well-known, exemplar cases of pollution at the global or local level: Chernobyl, dioxin from Seveso industrial factory, oil pollution from tanks, DDT spreading and its concentration along food chains and the destruction of the ozone layer. When local cases are illustrated, such as eutrophication of waters and damages to fishing industry, few sentences were found in the texts which make explicit the interconnections between the local and global phenomena of air and water pollution. In the Maltese manuals, the lack of local/global relations appears even more significant, in spite of the great number of examples of polluting agents and events that are mentioned to produce local consequences. Differently, in the French manuals (students aged 14–15), urban pollution is related with acid rains and with modification of the climate; water pollution is dealt with at local or regional scale (green algae, sewage, oil). Similar examples have been found in two of the Italian manuals.

In some cases, the explanations concerning the processes of degradation caused by polluting agents point out the many kind of events that a single cause may trigger off; co-occurrent factors as causes of one specific event are also identified. Both these lines of reasoning have been reported at least in one occurrence by the examiners, but the manuals never go in depth with the description of specific cases. When the topic of pollution appears in just few pages, as in the Moroccan and Tunisian manuals, it is obviously dealt with in a rather simplistic way.

Other significant indicators of a complex approach can be found in the presentation of the ecological dynamics that take place as reactions of the system to the perturbations caused by polluting agents. It is interesting to highlight that facts, rather than processes, are reported sometimes as chains of events, but eventual regulatory mechanisms are never mentioned by the manuals, neither variables that may influence and modulate the consequences primed by perturbating agents, with the exception of rare statements found in some of the examined manuals (in France, Italy, Lebanon, Malta). Time is most often taken into account, followed by the degree of severity of the perturbation according to the source of pollution.

Finally, the manuals do not consider in any acceptable depth the potential approaches that can be taken to solve pollution problems; they simply offer to the readers pre-codified solutions (virtuous behaviours, specific agricultural practices), more than giving them the idea of eventual pros and cons, of the possibility for the individuals, associations, communities, etc. to cooperate in the identification and evaluation of new and articulated strategies for the prevention/solution of pollution issues.

The interactions between individual and social behaviours as sources of changes in the management of the environment are only very superficially mentioned in some of the examined manuals in France, Italy and Lebanon.

The comparison between 16 countries made by Ferreira, Tracana, Ferreira, & Carvalho (2008) adds additional information. Changes in social rather than in individual behaviours as relevant to solve pollution problems resulted to be mentioned more often in some Western European countries than in Eastern and North African. But, again, the interaction between the two factors is understated.

Information about national legislative actions and international agreements is rarely offered to the students. Changes due to the application of new technologies are instead very frequently presented as a way to cope with these.

The graphic images with schematisations that represent the complexity of ecosystems and their dynamical phenomena have been examined and classified to categorise growing complexity in the representation: from chains or linear connections to webs showing directional interdependence and from unidirectional cycles to representations of feedbacks and of quantified interactions.

In all the examined manuals, the total number of even simple schematisations related to *Ec&cy* is very low and it is zero in connection with *Po*. Rather simple food webs, sometimes having only links and not arrows, and linear cycles of O_2, CO_2 and water are schematised. For example, in one French manual for students aged 11–12, two linear food chains, one for the construction and one for decomposition of living beings, were not interconnected in a cycle. The image of water cycle is present, but in general, representations of cycles are more common in the manuals for the higher school levels, though they rarely include more than three levels, interconnections among cycles and numerical values. Food chains may appear to illustrate contagion of poisonous elements or they are associated to the biomass pyramid. The most complex schematisations were found in the Lebanese and Maltese manuals.

Socioeconomic and Ethical Dimensions in the Management of Environmental Problems

These dimensions are almost ignored in the manuals. The grids applied to the manuals demanded to search for examples of controversial issues opposing human activities to the quality of the ecosystems to checking in the exposition the occurrence of sentences that considered cultural (religions, customs, taboos), socioeconomic (economic stakes) and ethical aspects.

In the great majority of the books, the text contained statements that hinted in abstract and very general terms to conflicts existing between the needs of growing human population, its technological development and the life of the planet, and to the misuse or over-use of chemicals in agriculture, the importance of clean technologies. An example from a French manual for 13–14-year-old students:

> The effectiveness of the use of chemical products is well known, but their use present many disadvantages.

In one of the Italian manuals mentioning of the conflicts generated by the improvement of life conditions, the economical benefits produced by the development of technologies and the risks that originate from environmental degradation was repeatedly found.

Except for the manual of Morocco, almost no exemplification of specific cases was found in the chapters dealing with ecology:

> Since its construction in the Maurienne area in France in 1960, the electro-industrial complex processing Aluminium releases about 1230 tons of fluoride fumes. This area has undergone significant environmental disasters such as the death of the forests, the extinction of insects, (…).

But instantiations of socioeconomic dimensions in concrete cases are also absent or sporadic in the pages dealing with *Po* in all the six Mediterranean countries. In a French manual for students aged 11–12, economic aspects are repeatedly mentioned in relation with the treatment of waters intended for human use, but without any figures. Some quantitative data appear where other themes, such as wastes, also appear:

> France produces 580 millions of tons of waste every year.
>
> Almost 2 millions vehicles have been wrecked in 1988.
>
> The law 13 july 1993 imposes to close the traditional discharges before 2002. (France)

Other examples can be quoted from French manuals for students aged 14–15:

> Modern agriculture and the industrial breedings are at the origin of pollution of the environment: massive use of manure and pesticides, dejections of animals….
>
> Industry and transport are an important reason of pollution of air, what sometimes imposes restrictions of circulation in the big cities.

> […] but, for some decades, they notice a net increase of atmospheric concentration and the responsibility of industrial and agrarian activities seemed obvious. […] They estimate 6 billion tonnes for instance at the same time.

Quotations from the Maltese manuals seem to suggest that more precise arguments and data are brought to bear to discuss the conflict between environmental concerns and economical benefits:

> Claims that cars would not run so well on unleaded petrol, or that it would cause increased engine wear are not soundly based. It would be neither difficult nor expensive to provide alternatives to leaded petrol.

> Most of the forms of pollution described in this chapter could be prevented provided we were prepared to pay the cost of the necessary measures. Removal of sulphur dioxide from the waste gases of power stations might increase our electricity bills by 5 per cent. Lead-free petrol may cost a little more than leaded petrol. It is probably essential to bear these extra costs if we are to preserve our environment. Furthermore, when the costs of reducing pollution are compared with the costs of environmental damage and human ill-health, the difference may not be all that great.

> The concern over the damaging effects of acid rain has led several countries to press for regulations to reduce emissions of these acid gases. In 1983, nine European countries proposed a 30 per cent reduction in sulphur dioxide emissions over 10 years, but this move was blocked by Britain and France. In 1984, the EEC proposed a reduction of 60 per cent in sulphur dioxide for large factories, and France announced an over-all reduction of 50 per cent in the next 10 years. Britain has agreed to reduce sulphur dioxide emissions from three power stations by 1997.

And about sulphur dioxide reduction methods:

> Although both processes add to the costs of, e.g. generating electricity, they can produce marketable by-products.

An interesting issue is raised by an Italian manual which makes reference to housekeeping practices, therefore evoking everyday experience close to the students:

> A misconcept of hygiene has spread all over the western world and has produced an authentic **phobia for germs,** that is sustained by the multimillionaire industries.

Expressions of ethical concerns were found in Tunisian, Maltese and Italian manuals about radioactive waste disposal:

> The wastes can be disposed of at sea or by burying on land or on the sea bed but, at present, there is considerable opposition to both these methods.

> Finally chemical waste products from factories are sometimes discharged into seas and rivers. They may be so concentrated that the fish are killed straight away. But sometimes they are taken up into food chains just like DDT. Some years ago over 60 people died in Japan from eating fish whose bodies contained mercury. The mercury had been discharged into the sea from a local factory and had then passed right through the food chain.

Narratives taken from the discourses of different wise men to be viewed as influential references in Western culture are reported in one of the additional documents attached to the chapters in an Italian manual. These speeches make appeal to moral beliefs, such as:

> If you' will give up the idea of uncontrolled and savage dominion on the nature together with the blind and utopian subdual to it, if you keep equidistant from the feverish interventions and from extreme caution., if …, if … etc. if you will do all this then you will have learnt to enjoy all the goods of the world together with the other creatures and, more importantly you will be a man, my dear son.

The comparative analyses across 16 countries which were reported at the XIII IOSTE Symposium by Ferreira et al. (2008) confirmed that the illustration of socio-economic and ethical controversies is rare even in the manuals for higher secondary school students (with some divergence in Tunisia and Finland) and is completely absent in the textbooks analysed in Cyprus, Lebanon, Lithuania, Poland, Romania and Morocco.

An example from a Finnish manual:

> The population/amount of human beings of the Earth grows. Every new citizen increases the use of resources and the amount of emissions. The recourses on the biosphere cannot offer the same occidental level of consumption to all citizens. Though, it is morally difficult to deny people in the developing countries not to improve their low standard of living. Is it time to take a look at environmental questions universally and in a new way?

Occurrence of Sentences That Reveal Epistemological Concern

In the examined life sciences manuals of six Mediterranean countries, the chapters dealing with *Ec&cy* do not reveal great epistemological concern, except for rare sentences that state conditions of incomplete knowledge, uncertainty and diversity of arguments with expressions such as "it would seems that…" and "some thinking suggests that…". An example from a French manual for students aged 14–15:

> With the current data on the evolution of the concentration of greenhouse effect gases (…), the scientists estimate that (…).

More examples have been reported by the examiners of the two Maltese manuals for ages 13–16. We add here their quotations:

> These new insecticides had been thoroughly tested in the laboratory to show that they were harmless to humans and other animals when used in low concentrations. It had not been foreseen that the insecticides would become more concentrated as they passed along the food chain.

> Some people think the elephants are too numerous and could destroy their own habitat. Others disagree and feel that the population is self-regulating.

Sentences expressing limitations of available knowledge or partial solutions to the problems have been found in relation with greenhouse effect or the consequences of water pollution. Though limited in number, these sentences appear only in the manuals examined in Italy and France and are more frequent in the manuals of Malta:

> The damages caused by the water pollution are unpredictable, not quantifiable and only the seriousness of some events has been able to impress the public opinion and to arise the awareness of the risks that nature and humankind are running into. (Italy)

> This would be the cause of the climatic variations according to numerous scientists. (Italy)

> A longer-term solution is to redesign car engines to burn petrol at lower temperatures and so produce smaller amounts of nitrogen oxides. However, this will not reduce emissions of hydrocarbons. (Malta)

> It is often difficult to know for certain whether a particular substance is harmful or not. Its effects may not appear straight away, but only after a long period of time. (Malta)

> DDT is known to damage animal tissues, and may be a danger to man. For this reason it has been banned in many countries. Here we have an example of a useful substance turning out to be a pollutant.

> For example, high levels of lead and cadmium have been found in the soil and crops in certain areas where mining used to be carried out. The trouble is that we just don't know the long-term effects which this kind of thing might have on people's health. However, many people feel that it is better to be safe than sorry and to err on the side of caution. (Malta)

> In the last 100 years or so the amount of carbon dioxide in the atmosphere has increased by about twelve per cent. The cause of this is not known for certain, but the burning of fossil fuels and farm waste is thought to have been at least partly responsible. (Malta)

The Pedagogical Style

The exposition of the contents that characterises the manuals has been defined by the examiners of the six Mediterranean countries as prevailingly informative: facts, descriptions and notions are reported, and concepts are illustrated. The students are seen as readers and as recipients of task assignments but not as actors to be involved in reasoning, questioning, and confronting different sources of information, interpretations and modelling of phenomena.

The three quotations that follow are rare sentences illustrating a more participative approach, though it is closer to activity assignments. The examples are taken from manuals of Morocco, France and Lebanon, respectively:

> Factories discharge wastewater into the rivers and seas. This wastewater differs according to the productions of these factories. It may contain: suspended substances, soluble iron, organic substances mainly from the food industry and tannery, acidic or basic substances, hydrocarbons from the oil industry. These wastes result in major damage to water organisms. You can use your knowledge in physics to show the effect of these substances on the environment. In your opinion, how can we fight against the industrial pollution?

> The human activities seem to effectively modify the content in the ozone gas of the atmosphere: its content decreases in the high atmosphere and increases in the lower atmosphere. And it is a **concern in both cases! Let us try to understand why**.

> Let's try to tackle this problem by analysing the objects that we bring to school, to see if it is possible to limit the production of waste materials.

On the other, it can be positively commented that, in general, the manuals do not tend to impose opinions and use moralistic tones.

Including Time Dimension: A Comparison of Italian and French Textbooks Published in the Period 1996–2011

All the points, so far described, provide snapshots of the ways textbooks deal with main themes of EE at a given time. The geographical dimension has been a project priority in order to verify if and what different views and values were conveyed in various social and cultural contexts.

Anyway, time dimension has a very important role when analysing textbooks, particularly with reference to the concept of delay linked with that of didactic transposition (DT). DT has been proposed by Verret (1975) and then by Chevallard, regarding the manner in which a scientific knowledge is selected and then transformed in order to be taught; it has been placed directly in relation to textbooks by Clément and Hovart (2000). Quessada and Clément (2007) have introduced the concept of didactic transposition delay (didactic transposition delay – DTD), with reference to the time that elapses between the appearance of a new scientific achievement and the moment in which it is introduced in curricula and textbooks. DTD has been crucial in the analysis of the topic human evolution inside textbooks (Quessada, Clément, Oerke, &Valente, 2008; Valente & Clément, 2011).

Respect to time approach, we are now wondering if and how research findings that have been produced in last decades, as well as changes in the environmental culture, did find place in more recently published textbooks. Other studies have compared textbooks in the field EE, with the aims of verifying to which extent school manuals reflected changes in the national school programmes (Tracana, Ferreira, Carvalho, & Ferreira, 2008) and of verifying possible evolution of the anthropocentric approach inside Tunisian textbooks (Alaya, 2010).

We chose three Italian science textbooks (five volumes) for low secondary school and one French life and Earth science textbook (two volumes) for college and compared different editions of these textbooks published in the period from 1996 to 2011 for French textbooks and in the period from 2001 to 2011 for Italian textbooks, for a total of 17 volumes analysed.

List of textbooks:

FR1.1 C.Lizeaux, R.Tavernier, Sciences de la Vie et de la Terre 3°, Bordas, 1999
FR1.2 C.Lizeaux, R.Tavernier, Sciences de la Vie et de la Terre 3°, Bordas (ed.2008), 2011
FR2.1 C.Lizeaux, R.Tavernier, Sciences de la Vie et de la Terre 6°, Bordas, 1996
FR2.2 C.Lizeaux, R.Tavernier, Sciences de la Vie et de la Terre 6°, Bordas, 2000
FR2.3 C.Lizeaux, R.Tavernier, Sciences de la Vie et de la Terre 6°, Bordas, 2005
FR2.4 C.Lizeaux, R.Tavernier, Sciences de la Vie et de la Terre 6°, Bordas, (ed.2009), 2011

IT 1.1 G. Flaccavento e N. Romano – La materia e la natura, Fabbri, 2004
1.1 Vol. 3 "Il mondo dei viventi" (Ec&cy)
1.1 Vol. 2 "La Terra e l'Universo" (Po)

IT 1.2 G. Flaccavento e N. Romano – Universo Scienza, Fabbri, 2011
1.2 Vol. 3 "I viventi" (Ec&cy)
1.2 Vol. 2 "Il sistema Terra" (Po)

IT 2.1 N.Colombi, B. Negrino, D. Rondano – Sperimentare scienze, Il Capitello, 2001
2.1 Vol.C "I viventi e l'ambiente naturale" (Ec&cy)
2.1 Vol. B "La Terra e l'Universo" (Po)

IT 2.2 B. Negrino, D. Rondano – Esplorare le scienze, Il Capitello, 2010
2.2 Vol. C "I viventi e l'ambiente" (Ec&cy)
2.2 Vol. B "La Terra nell'Universo" (Po)

IT 3.1 Leopardi, Gariboldi – Nuovo libro delle Scienze, Garzanti Scuola, 2004
3.1 Vol. B "La varietà dei viventi" (Ec&cy)
3.1 Vol. D "La Terra e l'ambiente" (Po)

IT 3.2 Leopardi, Gariboldi – Linea scienza di base, Garzanti Scuola, 2009
3.2 Vol. 3 "L'Uomo e l'ambiente" (Po)

We have applied the same methodology used in the BIOHEAD project, taking into account texts and images.

The indicators of the general and specific grids for the analysis applied to the newly published books did not reveal substantive differences in the didactical approach to environmental complexity. Nevertheless, some changes were noticed.

A first consideration is related to quantitative elements, the number of pages and images related to *Po* and *Ec&cy*.

The number of pages each textbook devotes to *Po* and to *Ec&cy* may change according to the general editorial plan. That is why some slight diversities occur in the different editions of textbooks analysed, but it is hard to identify a regular trend valid for all.

Besides the actual number of pages devoted to the topic, *Po* continues to be treated in pages inserted at the end of chapters as additional information for environmental and health education, without recognising an autonomous space and a disciplinary relevance.

What is very relevant in respect to the images is their growing number in recent publications. Considering *Po*, we can see that over time, the number of images increases both in absolute terms (with the only exception of IT1, in which the high decrease of the number of pages involves inevitably also the number of images) and in the relative terms of number of images for page and in this case without exceptions. The new editions of Italian textbooks gain percentages of images for pages, respectively, of +0.65 for IT1, +1.5 for IT2 and +0.4 for IT3. The percentage of growth of the number of images for page in FR2 stays in + 0.75 from the oldest to the newest edition analysed.

So, a first consideration is that the number of images tends to increase regardless of the number of pages, and this is coherent with the high role that images and multimedia are playing in our societies.

We also wondered which kind of images are growing in textbooks. Most of them still are figurative images, supporting the emotional and esthetical side of communication, as it has been found in all analyses within BIOHEAD. Anyway, we found a slight increase of the percentage of the images representing conceptualisations, which contribute to the familiarisation with a diversity of levels of scientific representation.

In Italian manuals, the chapters treating the topics *Ec&cy* deal with natural environments and the included figurative images do not show people; the anthropic factor is mentioned as perturbating the condition of equilibrium.

Vice versa, in the latest editions of the French manual FR2.4, the human being is more frequently considered together with the other living beings, e.g. it is explained that even human beings settle where climate conditions are more favourable; in the chapters dealing with *Ec&cy*, images do not exclude environments inhabited by human beings, so bridging the gap between a wild nature without human beings and a nature that includes human beings with their culture and artefacts.

In the most recent editions of both Italian and French textbooks, the rhetoric of the discourse concerning the impact of human activities seems to put less emphasis on catastrophic consequences. Change between old and new editions can be found particularly in the French textbook: the old editions (1996 and 2000) mainly showed the damages resulting from human intervention, whilst the new editions (2005 and 2009) better show that human presence may have different impacts, e.g. two images compare the same environment after the human intervention and the result has not impoverished the environment; another example is the presence of images of reforestation.

We cannot find many differences in the pedagogical style of the text that remains mainly *informative* in most of the chapters. A slight evolution towards the *participative* style may be found in the French manual FR1 that is addressed to the oldest students of the last year of college (ages 14–15). The oldest edition FR1.1 only included some sentences that apparently promoted students participation, like "let us try to understand why". The new edition constantly introduces paragraphs in which students are encouraged in taking part in research and in autonomous search of information, suggesting to contact organisations that deal with specific matters in the field of pollution, explaining them how to retrieve information, even from internet sources.

Besides the indicators of complexity that were included in the grids used in BIOHEAD, we also considered gender equality as a new emblematic indicator and we checked it in texts and images. Gender representation has always been very well balanced in images where people appeared, both in Italian and French manuals. French manuals also show a tendency to overcoming limits of sexist language: the new editions no longer use the term *homme* (man) to include male and female but use *Homme* (humans).

Each one of the new manuals preserves its own didactical style respect to ecological complexity or it introduces only slight changes in its narratives. For example, a sentence suggesting non-linear relationships between cause and effects appears in one of the new Italian textbook:

> Small variations in the average temperature of the Earth may have important consequences for the ecosystems; in particular ….

Another sentence introduces caution about the limit of knowledge, and it is included in a document entitled "We do not still know enough":

> If these data are certain, there is uncertainty about the data collected by other fields of inquiry. We still do not clearly know which are the effects on the increase of temperature of all these emissions, therefore produced by the global human activity.

Finally, we remark that the term "ecosystem" does not appear in French textbooks, neither the term "equilibrium" referred to a condition of environmental systems.

Both these terms and concepts are treated in the Italian manuals.

It is interesting to report some of the statements concerning the condition of equilibrium because they confirm the value overloading that these sentences reveal.

This sentence is included in a paragraph entitled "Protection of the environment":

> We already know that the biosphere is a system having a very delicate equilibrium (underlined in the original text) which is maintained through the collaboration of all the organisms who are part of the ecosystems that make the biosphere.

The following sentence is in a chapter about the dynamics of ecosystems, and it is a more complex reformulation of a statement that was already present in the older manual:

> Perfect equilibrium is reached as result of competition and predation taking place within the food chains. An ecosystem is in a condition of biological equilibrium if the number of species that occupy the diverse levels of the food chains is set adequately to the available alimentary resources. No group completely prevails over the other ones, thanks to this type of equilibrium which is fundamental for the surviving of all the living beings". And further on "… every ecosystem therefore keeps a constant biological equilibrium, though there are always variations with time (….) it always repairs or modifies its structure to search a new balance.

Conclusions

The life sciences manuals that were examined by the BIOHEAD project do not seem to offer a great contribution to enable students' understanding and reasoning about the model of complex environmental systems and, even more importantly, its application in concrete life contexts.

The resistance of teaching to take into account concepts such as feedback, cycles and regulation in biological education has a long tradition (Rumelhard, 1994) and has relevant consequences on the culture of people; particularly it produces the misunderstanding of genetics and nervous system physiology (Castéra et al., 2008; Clément & Castéra, 2013; Clément, Mouehli, & Abrougui, 2006).

To support our conclusions, we can point out some of the arguments drawn from the analyses accomplished by the BIOHEAD teams:

- The separate treatment of nature and environment in the contents of the manuals
- The prevalence of static descriptions of ecologic components and facts over the analyses of processes, framed in space and time
- The lack of attention to familiarising students with scientific ways of investigating and modelling ecosystems and their dynamics
- The implicit communication of a conception of nature as "resource" for humans
- The little commitment to promote ethical reflection
- The insufficient information in terms of quantified data (figures, frequencies, distributions, trends, etc.) about environmental issues
- The low attention to the construction of epistemological beliefs and attitudes when dealing with information
- The weak encouragement to reflective and critical thinking

Our analysis on recently published Italian and French manuals, to compare the old with the new editions, shows that something is slightly changing only in some of the textbooks considered and only with reference to a few indicators: images (that start to include conceptualisations, but still not data); a bit more articulated view of human intervention, which is no longer seen as simply intrusive and altering nature's harmony; humans viewed within living beings; and, sometimes, a greater attention to participative pedagogical style.

With reference to the other indicators, it is hard to expect an improvement in the representation of a complex view of environmental systems and of EE not to be led by a process of change in science didactics. The success in overcoming the delay in didactic transposition (DTD) depends on joint will and efforts from science community, educational policies and school community.

In the widespread public debate and teaching practice, environmental problems are opinion-based and solutions are liable value laden so that ritual understanding rather than principled understanding takes place. Therefore, the engagement of students in complex thinking and in learning about the multilevel organisation of interacting systems can be the way out to ideological views. But apparently school manuals are not prepared to take this challenge, and very likely their discipline-oriented approach limits the possibility of treating problems aside with science contents, by making knowledge from different fields to converge on their understanding.

The analyses showed that the broad theme of environment, which takes into account anthropic factors – humans as intentional agents responsible for choices and decisions, rather than as biological components only – has very limited space in the manuals, particularly at the lower secondary school level. Not much and good information is conveyed and the development of values is seldom pursued. Humans-environment relationship is treated in more depth in the manuals for higher secondary school, but we gathered some evidence that the quality of the pedagogical approach does not substantively improve (Agorram et al., 2009; Berthou-Gueydan, Clément & Clément, 2008; Carvalho et al., 2011).

The issues concerning pollution are good candidates for evaluating the contribution of life sciences manuals to environmental education. This topic is often considered as "integrative" or "additional" to the main contents illustrated in the chapters. We found that in most cases, the students are made sensitised to some of the environmental problems presented by the media and are made aware that they themselves can take actions. But the sociocultural aspects of the problems are never approached; the economical dimension is usually treated in general terms when taken into account.

The presentation of pollution problems usually focuses on the scientific report of causes and effects and gives less emphasis on strategies for prevention and solution. When specific, local cases are illustrated, they rarely become emblematic examples for pointing out interconnections with global cases or for throwing light on the nature of the conflicts existing among different interests. Even when the style of the text is aimed at eliciting debate in the class or active participation of the students, not enough data to go further in the search for information and to prepare them to make rational choices are provided.

Controversial solutions of problems, in which a composition among different interests has to be attained and has to acknowledge and confront the constraints imposed by the environment, may challenge students' reflection. On the other hand, the repeated presentation of solutions, produced by technological development that does not offer to the readers hints for questioning their validity in relation to specific conditions, risks to reinforce an a-critical trust on the possibility of relying on expertise and technology, ignoring that decisions among alternatives imply also ethical criteria. The problems are complicated rather than the systems complex, and science can device how to solve them!

Usually a single point of view is presented, and the exposition encourages the idea that the reported facts are certain; the need for cautious endeavours, at the social as well as at the individual level, and for agreements on priorities with the involvement of citizens are themes not dealt with.

The negative evaluation about human actions largely prevails in the exposition, and it is reflected in the high number of images that show their catastrophic consequences for nature. On the other hand, the ethical statements (about the rights of other living beings, the undeveloped populations, future generations, etc.) appear as due moral recommendations that do not find "flesh and bones" in the presentation of concrete cases that might be examined by the students to learn how things work in situations and how potential alternatives can be searched for. For instance, the Mediterranean area is never presented as an issue of common concerns for the countries that converge on its sea. It would be interesting to check if this is the case also in the manuals for geography or for upper education.

Human health and economy are very present as motivations for worrying about environmental damages together with regrets for the ecosystems. The impact of pollution on the aesthetic value of the environment is hardly mentioned, as it has been underlined in one of the comparative reports across countries (Carvalho et al., 2011).

The young age of lower secondary school students cannot justify trivialisation of concepts. We do not want to underestimate the difficulty that the authors of the manuals meet when they produce books for young students, the constraints that they have to face, not least the fact that catching youngsters' attention in reading makes teachers desperate. But we think that the challenge is worth, that more efforts should be placed in this task and that teachers should be more selective and demanding to the publishers.

Few comments about the differences among the manuals published in different countries, particularly concerning their rhetorical style. The differences are certainly not outstanding, probably for the effect of globalisation. Anyway, we can catch some distinctive features: higher attention for ecology in the manuals of some countries (France); greater emphasis on human component and its negative and positive consequences in Western European countries; greater concern for the impact that pollution has on ecosystems in Portugal; familiarisation of students with more abstract scientific representations, with data on environmental problems and socioeconomic dimensions in the Maltese manuals; and on the opposite, preference for a more "literary" than scientific use of language and images in the Italian manuals. The North African manuals seem to dedicate little space to environmental themes, at least in lower secondary education.

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Chapter 10
Analysis of Turkish General Chemistry Textbooks Based on a History and Philosophy of Science Perspective

Mansoor Niaz and Bayram Coştu

Introduction

In recent years, Turkey has been undertaking efforts to reform precollege education, including development of new science and technology education curricula and associated instructional materials (Ministry of National Education, 2000). It is plausible to suggest that the development of new instructional materials would benefit from an understanding of students' and teachers' conceptions of nature of science (NOS). In a recent study, Dogan and Abd-El-Khalick (2008) elucidated high school Turkish students' and science teachers' conceptions of NOS to help inform curriculum material development at the high school level in relation to NOS. The study was based on a representative national sample comprising 2,087 students and 378 science teachers. All participants were administered a questionnaire comprising 14 items that targeted the following NOS aspects:

(a) Theory-driven nature of scientific observations
(b) Tentative nature of scientific knowledge
(c) Relationship between scientific constructs (models) and reality
(d) Epistemological status of hypotheses, theories, and laws
(e) Nature of and relationship between scientific theories and laws
(f) Myth of a universal and/or stepwise "scientific method"
(g) Nonlinearity of scientific investigations
(h) Role of probabilistic reasoning in the development of scientific knowledge

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This may seem to be an ambitious agenda. However, it is important to note that these and similar aspects of NOS have been emphasized in science education reform documents (e.g., American Association for Advancement of Science [AAAS], 1989, 1990; National Research Council [NRC], 1996) and by science education researchers (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Niaz, 2008; Osborne, Collins, Ratcliffe, & Duschl, 2003). Dogan and Abd-El-Khalick (2008) based on their study found that a majority of the participants (Turkish students and teachers) held naive views of most NOS aspects. Interestingly, teachers' NOS views were mostly similar to those of their students. Similar views with respect to Turkish students and teachers have also been found in other studies (Macaroglu, Taşar, & Catloglu, 1998; Sahin, Deniz, & Görgen, 2006; Yalvac & Crawford, 2002).

This clearly shows the need for appropriate changes in the science curriculum and textbooks. Reform efforts in Turkey have also targeted new national textbooks for the elementary and middle school grades. Development of textbooks and associated materials for high school and college levels has still to be undertaken. The new textbooks would emphasize not only history, philosophy of science, and NOS but other aspects as well. Based on these considerations, the objective of this study is to evaluate general chemistry textbooks published in Turkey based on the following topics: (a) atomic structure, (b) determination of the elementary electrical charge (oil drop experiment), (c) kinetic molecular theory of gases, and (d) origin of the covalent bond.

Method

Based on a historical reconstruction of each of the topics, criteria were developed for evaluating Turkish general chemistry textbooks (Appendix provides a complete list). The following guidelines were used to select Turkish general chemistry textbooks: (a) availability of textbooks in Turkish libraries, (b) inclusion of recent and older textbooks, and (c) textbooks widely used by chemistry teachers.

Procedure for Implementing the Criteria

The following classifications were generated to evaluate the textbooks in each of the topics:

Satisfactory (S): Treatment of the subject in the textbook is considered to be satisfactory if the criterion is described and educational implications are drawn.

Mention (M): A simple mention of the criterion, without explicit elaboration.

No-mention (N): No-mention of the issues involved in the criterion.

The following procedure was used to establish the reliability of the evaluation of textbooks in each of the four topics:

First stage: The first author analyzed two textbooks published in Turkey as translations of books originally published in the USA. These evaluations were discussed with the second author and all differences were resolved by discussion.

Second stage: The second author analyzed two more textbooks published in the USA. This provided further experience with respect to the evaluation of textbooks.

Third stage: Two Turkish university chemistry professors with a Ph.D. in inorganic chemistry (one with 15 years and the other 14 years of teaching experience) and the second author applied the criteria separately to evaluate three textbooks published in Turkey (selected randomly). All differences were resolved once again through discussion.

Results and Discussion

Evaluation of Atomic Structure in Turkish General Chemistry Textbooks

Based on the historical reconstruction presented by Niaz (1998), here we present criteria for the evaluation of Turkish general chemistry textbooks (see Appendix). To refer to the criteria based on the three models, the following symbols are used: T = Thomson, R = Rutherford, and B = Bohr.

T1 – Cathode Rays as Charged Particles or Waves in the Ether

Thomson's experiments were conducted against the backdrop of a conflicting framework. Thomson (1897) explicitly pointed out that his experiments were conducted to clarify the controversy with regard to the nature of the cathode rays, that is, charged particles or waves in the ether. This criterion is based on Achinstein (1991), Falconer (1987), and Thomson (1897).

T2 – Determination of Mass-to-Charge Ratio to Decide Whether Cathode Rays Were Ions or a Universal Charged Particle

Thomson decided to measure mass-to-charge ratio to identify cathode rays as ions (if the ratio was not constant) or as a universal charged particle (constant ratio for all gases). This criterion is based on Achinstein (1991), Niaz (1994), and Thomson (1897).

R1 – Nuclear Atom

Rutherford's experiments with alpha particles and the resulting model of the nuclear atom had to compete with a rival framework, namely, Thomson's model of the atom (referred to as "plum-pudding" in most textbooks). This criterion is based on Niaz (1994) and Rutherford (1911).

R2 – Probability of Large Deflections Is Exceedingly Small, as the Atom Is the Seat of an Intense Electric Field

The crucial argument that clinched the argument in favor of Rutherford's model was not the large angle deflection of alpha particles (an important finding), but rather the knowledge that 1 in 20,000 particles deflected through large angles. This criterion is based on Herron (1977), Millikan (1947), and Rutherford (1911).

R3 – Single/Compound Scattering of Alpha Particles

To maintain his model of the atom and to explain large angle deflections of alpha particles, Thomson put forward the hypothesis of compound scattering (multitudes of small scatterings). The rivalry between Rutherford's hypothesis of single scattering based on a single encounter and Thomson's hypothesis of compound scattering led to a bitter dispute between the proponents of the two hypotheses. This criterion is based on Rutherford (1911) and Wilson (1983).

B1 – Paradoxical Stability of the Rutherford Model of the Atom

Bohr's main objective was to explain the paradoxical stability of the Rutherford model of the atom, which constituted a rival framework for his own model. This criterion is based on Bohr (1913), Lakatos (1970), and Niaz (1994).

B2 – Explanation of the Hydrogen Line Spectrum

Bohr had not even heard of the Balmer and Paschen formulas for the hydrogen line spectrum when he wrote the first version of his 1913 article. Failure to understand this episode within a historical perspective led to an inductivist/positivist interpretation, referred to as the "Baconian inductive ascent" by Lakatos (1970). Interestingly, Kuhn and Lakatos, in spite of their so many differences, agree that Bohr's major contribution was the quantization of the Rutherford model of the atom. This criterion is based on Bohr (1913), Heilbron and Kuhn (1969), and Lakatos (1970).

B3 – Deep Philosophical Chasm

Bohr's incorporation of Planck's "quantum of action" to the classical electrodynamics of Maxwell represented a strange "mixture" for many of Bohr's contemporaries and philosophers of science. This episode illustrates how scientists, when faced with difficulties, often resort to such contradictory "grafts." This criterion is based on Bohr (1913), Holton (1986), Lakatos (1970), and Margenau (1950).

Table 10.1 shows that on Criteria T1, R3, B2, and B3, none of the textbooks had a satisfactory (S) presentation. The following is an example of a textbook that had a satisfactory (S) presentation on Criterion T2:

> In 1879 Thomson computed cathode rays' (electrons) e/m [charge-to-mass] ratio by measuring deflections in both electrical and magnetic fields… [the textbook gives mathematical details about e/m ratio] …The experiments provide e/m ratio for cathode

Table 10.1 Distribution of Turkish general chemistry textbooks according to criteria (atomic structure) and classification ($n=21$)

	Classification[a]		
Criteria	N	M	S
T1	21	–	–
T2	15	5	1
R1	4	2	15
R2	8	11	2
R3	21	–	–
B1	13	2	6
B2	21	–	–
B3	21	–	–

[a]N = no-mention, M = mention, S = satisfactory

> rays as e/m = 5.27×10^{17}esu/g. And, this value does not depend on the gas inside the tube or the metal used for the cathode or anode. Moreover, it was also known earlier that e/m ratio for electrolysis is less than (at least 1000 times) the carriers of the electricity in the cathode rays and takes different values for different gaseous ions. Taking into consideration the two findings, Thomson proposed that cathode rays were universal charged particles and not ions. (Yavuz, 1978, p. 4)

An important aspect of this presentation is that it provides students with arguments as to why Thomson concluded that cathode rays were universal charged particles and not ions. Now, let us compare this presentation with another that simply states the experimental results and was thus classified as no-mention (N):

> Cathode rays are deflected by electrical fields as indicated by Fig…This deflection proves that cathode rays are composed of negatively charged particles [Conclusions]. These negatively charged particles were called electrons. Cathode rays (electrons) are also deflected by magnetic fields. Thomson, in 1897, observing deflections of cathode rays in both electrical and magnetic fields computed the e/m ratio for the electron and found it to be -1.75588×10^8 …. (Alpaydın & Şimşek, 2006, p. 38)

These two presentations clearly show how, by including appropriate arguments (based on a historical reconstruction), we can facilitate greater conceptual understanding.

The following is an example of a satisfactory (S) presentation on Criterion R1, in which the author presents experimental details in the context of two competing/rival models (Thomson/Rutherford) based on a historical reconstruction:

> Rutherford performed an experiment known as alpha particle scattering to verify the Thomson model. In 1911, Rutherford sent alpha particles radiated from a radioactive source to layers of gold, copper, lead and platinum foil about 0.0004 cm. thick… Rutherford observed in the experiments that most of the particles pass through with no deflection, a few particles pass through with little deflection, and very few particles scattered backwards, as seen in Figure… If Thomson's model, that is the positive charge and the mass are distributed evenly throughout the metal is valid, alpha particles must pass through with no deflection… However, alpha particles pass through with large deflection … Rutherford concluded that rare scattering of particles at big angles may be explained by the presence in matter of a massive nucleus, the size of which is much smaller when compared to the atom. (Özcan, 1998, p. 86)

This study shows that the presentation of atomic structure in Turkish general chemistry textbooks (1964–2006) generally lacks a history and philosophy of science framework. Results obtained, however, are quite similar to those of general chemistry textbooks published in the USA (Niaz, 1998). Further details with respect to this study are available in Niaz and Coştu (2009).

Evaluation of Determination of the Elementary Electrical Charge (Oil Drop Experiment) in Turkish General Chemistry Textbooks

Based on a historical reconstruction presented by Niaz (2000a), here we present criteria for evaluation of Turkish general chemistry textbooks:

Criterion 1. Millikan–Ehrenhaft controversy. Millikan and Ehrenhaft obtained similar experimental results and yet the two interpreted their findings within different theoretical frameworks (guiding assumptions). The controversy started in 1910 with Millikan's critique of Ehrenhaft's method. The controversy turned into a bitter dispute for the next 15 years. According to Millikan, there existed an elementary electrical charge and charges on all droplets were integral multiples of this fundamental charge. Ehrenhaft argued that the charges on the droplets varied widely, and hence the existence of an elementary electrical charge could not be sustained. This criterion is based on Dirac (1977), Ehrenhaft (1910, 1914), Holton (1978), and Millikan (1913, 1917).

Criterion 2. Millikan's guiding assumption. Drawing inspiration from Franklin, Faraday, Stoney, Thomson, and others, Millikan formulated the guiding assumption of his research program early in his career. According to this guiding assumption, based on the atomic nature of electricity, Millikan hypothesized the existence of an elementary electrical charge. In his experiments, Millikan found droplets with a wide range of electrical charges. Despite such anomalous data, if it were not for the guiding assumption, Millikan would have abandoned the search for the elementary electrical charge. This criterion is based on Holton (1978) and Millikan (1913, 1917).

Criterion 3. Suspension of disbelief. An important characteristic of Millikan's methodology was to hold the falsification of his guiding assumption in abeyance – that is, suspension of disbelief. In contrast to the traditional scientific method inculcated in school science, Millikan's methodology has found support in modern philosophy of science. This criterion is based on Holton (1978), Lakatos (1970), and Millikan (1913, 1917).

Criterion 4. Transfer of charge as an integral multiple of the elementary electrical charge. Millikan did not measure the charge on the electron itself but rather the transfer of charge on droplets as an integral multiple of the elementary electrical charge (e). This criterion is based on Holton (1978) and Millikan (1917).

Table 10.2 Distribution of Turkish general chemistry textbooks according to criteria (oil drop experiment) and classification ($n=27$)

	Classification[a]		
Criteria	N	M	S
1	27	–	–
2	26	1	–
3	27	–	–
4	19	8	–
5	27	–	–
6	27	–	–

[a]N = no-mention, M = mention, S = satisfactory

Criterion 5. Dependence of the elementary electrical charge on experimental variables. The oil drop experiment is extremely difficult to handle. Millikan was constantly trying to improve his experimental conditions to obtain the charge on the droplets as an integral multiple of the elementary electrical charge. Some of the variables that he constantly referred to were evaporation, sphericity, and radius of the droplets, change in density of the droplets, changes in battery voltages, temperature, and viscosity of the air. The oil drop experiment is still difficult to perform in the laboratory. A comparison of Millikan's laboratory notebooks and published results showed that given the complexity of the experimental conditions, he discarded droplets that did not have velocities within a certain range. This criterion is based on Holton (1978) and Millikan (1913, 1965).

Criterion 6. Millikan's experiments as part of a progressive sequence of heuristic principles. Millikan's work started by repeating and a critical evaluation of the experimental work of Townsend, Thomson, and Wilson on charged clouds of water droplets. The first progressive transition was the balanced drop method by using a sufficiently strong electrical field, which later led to the oil drop experiment. It can be argued that Millikan did not design the experiment, but rather discovered it. This criterion is based on Holton (1978) and Millikan (1913, 1917, 1950).

Table 10.2 shows that none of the textbooks had a satisfactory (S) presentation on any of the six criteria. Similar to general chemistry textbooks published in the USA (Niaz, 2000a), Turkish chemistry textbooks do not seem to appreciate the importance of controversy in scientific progress (Criterion 1) and therefore deprive students of an opportunity to see how scientists really work.

None of the textbooks described satisfactorily (S) Millikan's guiding assumptions (Criterion 2). Only one textbook made a simple mention (M) of Millikan's guiding assumption in the following terms:

> …Millikan measured charges on the charged droplets [to obtain the charge on the electron]. In the experiments, charges of the droplets were found to be, q = a. 1.6 10^{-19} C. In this equation, a = 1, 2, 3,.. and so forth were integer numbers. These numbers showed that there is no charge lower than 1.6 10^{-19} C on the droplets. [Thus] Millikan assumed that the charge on the electron has to be 1.6 10^{-19} C… (Yavuz, 1978, pp. 5–6)

Twenty-six textbooks made no-mention (N) of Millikan's guiding assumption, and the following is an example:

> In 1909 R. A. Millikan measured successfully both the charge and mass of an electron by performing an experiment known as oil drop experiment (see Fig…) (Hazer, 1997, p. 22)

The difference between the two types of presentations can easily be appreciated by a teacher. Presentation classified as mention (M) attempts to provide some background reasons (of course, it could have been better) and thus convince the students. On the other hand, the presentation classified as no-mention (N) is simply prescriptive, and the student has simply to memorize it. Such presentations can easily be interpreted as an inductive generalization. In other words, the experimental results led Millikan to deduce the elementary electrical charge, and his guiding assumptions played no part.

None of the textbooks mentioned (N) one of the most important feature of Millikan's methodology (Criterion 3), that is, in the face of anomalous data, a scientist perseveres with his guiding assumption, holding its falsification in abeyance – in other words, suspension of disbelief. A brief introduction to the historical details would help students to understand as to how Millikan handled data from his experiments. This could provide an insight for students with respect to how creative imagination of the scientist plays a crucial role.

As seen from Table 10.2, eight textbooks mentioned (M) that Millikan did not measure the charge of the electron itself (Criterion 4) but rather the transfer of charge on droplets as an integral multiple of the elementary electrical charge (e), and the following is an example:

> …after Millikan's many repetitions of the oil drop experiment, he observed that a droplet would gain or lose a charge of an integer multiple of $1.6 \cdot 10^{-19}$ C. From the experiments, he concluded that charges on an oil droplet stem from gaining or losing of one or more electrons. Thus, [he assumed that] the elementary charge of the electron is $1.6 \cdot 10^{-19}$ C. (Soydan & Saraç, 1998, p. 56)

In contrast to this presentation, consider the following example from a textbook that was classified as no-mention (N):

> In 1906, Millikan had calculated charge of the electron and discovered it as $1.6 \cdot 10^{-19}$ C. (Alpaydın & Şimşek, 2006, p. 38)

In contrast to Turkish textbooks, it is interesting to note that none of the general chemistry textbooks published in the USA (Niaz, 2000a) mentioned (M) that Millikan measured the transfer of charge on droplets as an integral multiple of the elementary electrical charge.

None of the textbooks described satisfactorily (S) or mentioned (M) the different experimental variables that made the oil drop experiment so difficult and its interpretations controversial (Criterion 5). However, three textbooks (Ergül, 2006; Erdik & Sarıkaya, 1991; Özcan, 1998) hinted at the difficulties involved in the experiment, and the following is an example:

> … instead of measuring radius of the droplets, Millikan chose the less erroneous and indirect method to measure [charges of the droplets]. For this purpose, [he] observed the rate of fall of the drop, shortly after it reached limiting velocity because of friction of the air and gravitational force [provides mathematical details]…. (Erdik & Sarıkaya, 1991, p. 39)

Interestingly, most textbooks emphasize the experimental nature of chemistry and still ignored how the manipulation of the experimental variables played an important role in the Millikan–Ehrenhaft controversy.

None of the textbooks presented (N) Millikan's work as part of a sequence of heuristic principles (Criterion 6). However, it would be helpful if a textbook briefly reviews some of the earlier experiments that attempted to determine the elementary electrical charge in order to understand the genesis of the oil drop experiment. Before Millikan, Townsend, Thomson, and Wilson studied charged clouds of water droplets, which led to the balancing of individual droplets by Millikan and Ehrenhaft and finally Millikan's oil drop experiment. Such an approach can facilitate students' understanding of how scientific endeavor is not a solitary activity but rather a continuous process of critical appraisals (Niaz, 2009).

Evaluation of Kinetic Molecular Theory of Gases in Turkish General Chemistry Textbooks

Based on a historical reconstruction presented by Niaz (2000b), here we present criteria for evaluation of Turkish general chemistry textbooks:

Criterion 1. Maxwell's simplifying (basic) assumptions: Maxwell's assumptions, although speculative, were an attempt to reduce the complexity of the problem by introducing ceteris paribus clauses. This methodology helped scientists to build a series of successive theories based on a particular model of the "ideal" gas. Each tentative theory was designed to be a closer approximation to properties known to obtain in the "real" gases. This criterion is based on Achinstein (1991), Cartwright (1983), Clark (1976), Lakatos (1970), Maxwell (1860), and McMullin (1985).

Criterion 2. Inconsistent nature of Maxwell's research program: Maxwell's theory was based on the assumption that motion of the particles was subject to Newtonian mechanics. However, at least two of the assumptions, namely, movement of the particles and the consequent generation of gas pressure, were in contradiction with Newton's hypothesis explaining the gas laws based on the repulsive forces between particles. History of science shows that many programs progressed similarly on inconsistent foundations (cf. Bohr's program in Lakatos 1970, p. 142). This criterion is based on Achinstein (1987), Brush (1976), and Lakatos (1970).

Criterion 3. Maxwell's statistical considerations: Based on statistical considerations Maxwell showed that the collisions of the gas molecules would not simply tend to equalize all their speeds (as some had expected) but, on the contrary, would produce a range of different speeds. This consideration later led to the Maxwell–Boltzmann distribution of molecular speeds, which showed that the majority of the molecules have speeds lying within a relatively limited range and a certain proportion of the molecules have very low and very high speeds. On increasing the temperature, the general shape of the distribution curve remains unchanged, but there is a flattening of the maximum, which now occurs at a higher speed. In other words, as the temperature increases, there is a wider distribution of speeds and the fraction of the molecules possessing high speed increases. This criterion is based on Maxwell (1860) and Porter (1981).

Criterion 4. Van der Waals' contribution: reducing/modifying basic assumptions: If Maxwell's basic assumptions were speculative, van der Waals followed the same methodology, by providing greater insight into Maxwell's theory. His major contribution was to reduce the assumptions in order to include the continuity of intermolecular forces, which facilitated the transition from "ideal" to "real" gases – a "progressive problemshift." This criterion is based on Brush (1976), Clark (1976), Gavroglu (1990), and van der Waals (1873).

Criterion 5. Kinetic theory and chemical thermodynamics as rival research programs: Kinetic theory had to face from the very beginning a serious challenge from the proponents of chemical thermodynamics. This opposition was based primarily on the grounds that any theory having "arbitrary" assumptions based on invisible and undetectable atoms was beyond the fold of science. According to Lakatos (1970), history of science is a history of rival research programs. This criterion is based on Brush (1974, 1976) and Lakatos (1970).

Criterion 6. From "algorithmic mode" to "conceptual gestalt" in understanding the behavior of gases: A major contribution of Maxwell and Boltzmann was to have facilitated our understanding of gases beyond the observable, hydrodynamical laws (Boyle, Charles, Gay-Lusaac) and explained the internal properties based on the kinetic molecular theory. This criterion evaluates the degree to which textbook presentation (examples, illustrations, end of chapter problems, etc.) explicitly recognizes that there are two modes of solving gas problems, namely, "algorithmic mode" and "conceptual gestalt." For example, in order to understand that pressure of a gas is a consequence of molecular collisions, it is not sufficient to repeat Maxwell's assumption. In order for this property of the gases to be meaningful for the students, it will have to be incorporated in a problem situation (cf. Item 4, Niaz & Robinson, 1992). This criterion is based on Clark (1976), Hanson (1958), Coştu (2007), and Nurrenbern and Pickering (1987). Website by Robinson and Nurrenbern (2009) provides examples of algorithmic and conceptual problems.

Table 10.3 shows that most textbooks (11) simply mentioned (M) and five textbooks described Maxwell's simplifying assumptions (Criterion 1) satisfactorily (S), and the following are two examples:

> Why does a gas behave as Boyle, Charles or Gay-Lussac Laws describe? Why does a gas produce pressure? What does it mean "heat of gases"? These questions about gases were answered by the kinetic molecular theory of gases. In 1738, Bernoulli first proposed the kinetic theory of gases. After then, Clasusius, Maxwell, Boltzmann and other scientists put forward the kinetic molecular model using statistical mechanics. It is not possible to explain behaviors of gases by using derivations from directly measured properties of gases. Deducing actual characteristics of a gas from its physical properties is an approximation. Critical glance on the experimental observations about behaviors of gases leads to useful approximations of a real gas [to predict approximate behaviors of a real gas]. An approximation about behavior of a gas is named as a model. Models should be containing structure and actual behaviors of them [gases]…. The model referred to as kinetic molecular theory is based on some postulates or assumptions about behavior of gases… (Baykut, 1964, pp. 54–55)

Table 10.3 Distribution of Turkish general chemistry textbooks according to criteria (kinetic molecular theory of gases) and classification ($n=22$)

	Classification[a]		
Criteria	N	M	S
1	6	11	5
2	22	–	–
3	14	–	8
4	4	2	16
5	22	–	–
6	22	–	–

[a]N = no-mention, M = mention, S = satisfactory

…up until now, we have examined important properties of the gases. We generalized the properties-regularity relating to gases- as gas laws. There is one question that needs to be answered. Do gases have such a structure in order to fit the properties? Scientists put forward models or theories in order to respond to such a question. The models or theories the scientists suggest are counted as viable until they truly explain related circumstances. Kinetic molecular theory is also a model (or theory) in order to explain both behaviors of gases and all facts concerning gases. Kinetic molecular theory incorporates some assumptions [or postulates] as all theories do … (Bayın, 1982, p. 93)

As seen from the aforementioned explanations about the kinetic molecular theory, the textbooks emphasize that kinetic molecular theory and its assumptions (or postulates) are considered to be models, approximate and tentative (models develop) in order to explain the behavior of gases. Compare this to the following example that makes a simple mention (M) of the assumptions:

…in the previous section, we discussed how gas laws were put forward to explain empirical observations. At present, we need a theory as to why gases act in accordance with gas laws. Kinetic molecular theory by accepting that gases move in random motion successfully explain these gas laws… [after this, textbook gives Brownian motion and kinetic molecular theory] (Özcan, 1998, pp. 300–301)

Of the 22 textbooks, none mentioned (N) nor gave details of the inconsistent nature of Maxwell's research program (Criterion 2, see Table 10.3). Similar to general chemistry textbooks published in the USA (Niaz, 2000b), Turkish chemistry textbooks ignored that, like many other programs in the history of science, Maxwell's program, although successful, was also based on an inconsistent foundation.

Eight textbooks described Maxwell's statistical considerations (Criterion 3) satisfactorily (S), and the following are two examples:

In the 19th century, two famous theoretical physicists, James Clerk Maxwell and Ludwig Boltzmann, examined distributions of the molecular speeds of gas molecules. The two scientists formulated the distributions of the molecular speeds and kinetic energies of gas molecules based on statistical considerations… [they] postulated that the distributions of kinetic energies of gas molecules as shown in Fig…when the temperature of a gas is increased, average kinetic energy of the gas molecules increases. The curve broadens and shifts toward higher kinetic energies as shown in Fig…. (Bayın, 1982, pp. 92–93)

One of the important and useful results derived from the kinetic molecular theory is distributions of kinetic molecular energies and molecular speeds dependent on temperature. Fig…indicates these distributions. This is called Maxwell-Boltzmann distribution. As seen Fig…the fraction of the total number of molecules that has a particular speed is plotted against molecular speed as for three different temperatures…when the temperature of a gas is increased as in Fig…, the curve broadens and shifts toward higher speeds. Fewer molecules than previously move at the lower speeds and more molecules move at the higher speeds… (Özcan, 1998, pp. 309–310)

Table 10.3 also shows that fourteen textbooks do not mention (N) an important contribution of Maxwell and Boltzmann distribution of molecular speed. Besides, these textbooks give superficial explanations about changes in molecular speeds of gases against temperature changes without the Maxwell–Boltzmann distributions.

On Criterion 4 (Table 10.3), sixteen textbooks described satisfactorily (S) van der Waals' contribution as an attempt to reduce/modify the basic assumptions. While two textbooks simply mention (M) van der Waals' contribution, four textbooks do not mention it (N). The following are two examples of satisfactory (S) descriptions:

…in 1873, Van Der Waals, a physicist, suggested that two of the postulates of the kinetic molecular theory had to be modified based on deviations of real gases from the behavior of ideal gases… Van Der Waals attributed to two reasons, as to why equation PV=nRT for ideal gases does not follow for real gases. These are: (1) The actual volume of the gas molecules, (2) Attractive forces between gas molecules… [after then, textbook gives detailed information to formulate van der Waals equation] (Baykut, 1964, pp. 58–59)

The behavior of real gases deviates from the behavior of ideal gases for two reasons: (1) The kinetic theory assumes that there are no attractive forces between gas molecules, viz., it assumes that all gas molecules move freely. However, such attractions must exist in real gases and thus pressure of a real gas should be less than ideal gas. As a result, $PV \langle RT$, (2) The kinetic theory also assume that gas molecules are points in space and that the actual volume of the gas molecules is not significant. However, this does not hold for real gases and thus $PV \rangle RT$. Because of the two derivations, Van Der Waals, a Dutch physicist, corrected the equation of state for an ideal gas based on the two effects… (Şenvar, 1989, p. 54)

Some of the textbooks, although classified as satisfactory (S), simply mentioned that van der Waals modified/corrected the ideal gas equation, without any reference to the tentativeness of the simplifying assumptions. This was done on the ground that these textbooks gave a fairly detailed, step-by-step description of the two corrections by van der Waals. Nevertheless, it is important to emphasize that most of the textbooks that were classified as satisfactory (S) do not conceptualize van der Waals' contribution as an attempt to modify Maxwell's simplifying assumptions (ceteris paribus clauses), which led to a "progressive problem shift" (Lakatos, 1970).

None of the textbooks described satisfactorily (S) or briefly mentioned (M) the historical background (Criterion 5) that led to the rivalry between the research programs of the kinetic theory and chemical thermodynamics.

On Criterion 6, none of the textbooks described satisfactorily (S) or briefly mentioned (M) the two modes of solving gas problems, namely, the algorithmic mode and that of conceptual understanding. Almost all of the textbooks focused mainly on problem solving as an algorithmic mode. These textbooks generally present problems that require mathematical calculations. Two typical examples of such problems are presented here:

Calculate the u_{rms} speed, in m/s, for H_2 at 50°C. (Soydan & Saraç, 1998, p. 155)

Calculate the pressure exerted by 142.0 g of $Cl_{2\,(g)}$ confined to a volume of 5.0 liter at 25 °C, using both ideal gas laws and the van der Waals equation. (Alpaydın & Şimşek, 2006, p. 162)

It is concluded that very few Turkish general chemistry textbooks presented the development of the kinetic molecular theory within a historical perspective. Similar results have been reported for general chemistry textbooks published in the USA (Niaz, 2000b).

Evaluation of the Origin of the Covalent Bond in Turkish General Chemistry Textbooks

Based on a historical reconstruction presented by Niaz (2001), here we present criteria for evaluation of Turkish general chemistry textbooks:

Criterion 1. Lewis's cubic atom as a theoretical device for understanding the sharing of electrons: Lewis's cubic atom was based on his atomic theory based on postulates formulated in 1902. The cubic atom was thus a theoretical device that was later used for understanding the sharing of electrons (covalent bond) and provided the rationale for the octet rule. This criterion is based on the following references: Jensen (1984), Kohler (1971), and Lewis (1916, 1923). The following classifications were elaborated: *Satisfactory (S)*: Treatment of the subject in the textbook is considered to be satisfactory if it is briefly explained that Lewis (1916) used his model of the cubic atom to explain the sharing of electrons and the octet rule; *mention (M)*: a simple mention of Lewis's cubic atom; and *no-mention (N)*: no-mention of Lewis's cubic atom.

Criterion 2. Sharing of electrons (covalent bond) had to compete with the transfer of electrons (ionic bond): Lewis's idea of sharing electrons (covalent bond) had to compete with the transfer of electrons (polar/ionic bond). The origin of the polar bond as the dominant paradigm in chemical combination can be traced to Thomson's discovery of the electron in 1897. By 1913 the polar theory completely dominated chemistry, and it was in the early 1920s that Lewis's idea of sharing electrons became acceptable. This criterion is based on the following references: Kohler (1971), Lakatos (1970), Lewis (1916, 1923), and Thomson (1897, 1907, 1914). The following classifications were elaborated: *Satisfactory (S)*: Treatment of the subject is considered to be satisfactory if the role of competing frameworks (polar/nonpolar) is briefly described; *mention (M)*: a simple mention of the competing frameworks; and *no-mention (N)*: no-mention of the competing frameworks.

Criterion 3. Covalent bond: inductive generalization/derived from the cubical atom: The objective of this criterion (Kohler, 1971; Lakatos, 1970; Rodebush, 1928) is to evaluate if the textbooks follow one of the following interpretations with respect to the origin of the (shared pair) covalent bond: *Inductivist (I)*: Lewis's covalent bond was an inductive generalization based on the following: Stability of the noble gases or formation of the hydrogen molecule leads to a lowering of the energy, or helium, an inert gas, has a pair of electrons or numbers of electrons in most compounds that are even; *Lakatosian (L)*: Lewis's (shared pair) covalent bond was not induced from experimental evidence but derived from the cubic atom;

Table 10.4 Distribution of Turkish general chemistry textbooks according to criteria (origin of the covalent bond) and classification ($n=27$)

Criteria	Classification[a] N	M	S
1	27	–	–
2	24	3	–
3	22	3	2
	I	L	N
4	19	–	8

[a]N = no-mention, M = mention, S = satisfactory, I = inductivist, L = Lakatosian

and *no-mention (N)*: Textbook makes no-mention explicitly to either of the two interpretations presented above.

Criterion 4. Pauli exclusion principle as an explanation of the sharing of electrons in covalent bonds: The objective of this criterion is to evaluate if textbooks consider Pauli's exclusion principle to provide an explanation of the sharing of electrons. This criterion is based on the following references: Kohler (1971), Lakatos (1970), Pauli (1925), and Rodebush (1928). The following classifications were elaborated: *Satisfactory (S)*: Treatment of the subject in the textbook is considered to be satisfactory if the role of Pauli exclusion principle is briefly described, in order to explain the covalent bond; *mention (M)*: a simple mention of Pauli exclusion principle, in the context of the covalent bond; and *no-mention (N)*: no-mention of Pauli exclusion principle.

On Criterion 1 (Table 10.4) none of the textbooks described satisfactorily (S) or mentioned (M) Lewis's cubic atom within a history and philosophy of science (HPS) framework.

None of the textbooks described satisfactorily (S) that Lewis's idea of sharing of electrons (covalent bond) had to compete with the transfer of electrons, that is, ionic bond (Criterion 2). Only three textbooks made a simple mention (M), and the following are two examples:

> Previously, it was commonly accepted that all chemical bonds can form between ions through electrostatic attractions, that is, it was accepted that all chemical bonds were ionic bonds. However, in 1906, American chemist G. N. Lewis said that in some cases, the idea that electrons transfer entirely from one atom to another atom was illogical… [Comment: Textbook provides the example of formation of H_2 to rebut ionic bond theory. However, it does not explicitly interpret the origin of the covalent bond as a rival research program based on an HPS perspective] (Aydın, Sevinç, & Şengil, 2001, pp. 73–74)

> Examining the ionic bond, we saw a bond formed by transfer of one or more electrons between two atoms, whose electron affinity and ionization energies were very different. In a wide variety of cases, a more stable state did not form with ionic bonding. On the contrary, a more stable state formed with covalent bonding between two atoms whose electron affinity and ionization energies were identical. As an example, consider the bond formed by two hydrogen atoms… [textbook explains formation of the hydrogen molecule in detail]… in the formation of this bond [H-H], electron transfer from one atom to the other is impossible [textbook gives detailed reasons, implying rebuttal of the ionic bond] … therefore, covalent bond is formed differently as compared to ionic bonding… [Comment: Textbook also provides

detailed information in following paragraphs, implying rebuttal of ionic bonding. However, the textbook does not explicitly interpret the origin of the covalent bond as a rival research program based on an HPS perspective]. (Özcan, 1998, pp. 184–185)

Most textbooks (24) made no-mention (N) that Lewis's idea of sharing of electrons (covalent bond) had to compete with the transfer of electrons (ionic bond). The controversial origin of the covalent bond and its rivalry with the ionic bond provides a good opportunity to illustrate how progress in science is based on controversy and how established theories or ways of thinking are difficult to change. The following is an example of a textbook that was classified as N and shows the difference between textbooks classified as M:

Covalent bonds are bonds between two identical or different non-metals. Since the electronegativity of two atoms is close to each other, there is little difference in the abilities of two atoms to attract the bonding electrons to them. Therefore, electron transfer between two atoms does not occur; instead, the electrons involved in such a bond are shared. A chemical bond formed by sharing electrons is called covalent bond… (Alpaydın & Şimşek, 2006, p. 93)

As seen from the evaluation of textbooks, they do not interpret the origin of the covalent bond as a rival research program, based on an HPS framework (Lakatos, 1970). Besides, the textbooks only provide students' detailed information for writing the Lewis structures. Even a brief mention of the historical details can facilitate conceptual understanding of the difference between ionic and covalent bonds.

On Criterion 3 (Table 10.4), none of the textbooks presented the Lakatosian interpretation (L), namely, tracing the origin of the stability of the covalent bond to the cubic atom and giving enough details to show that Lewis's ideas developed slowly based on conjectures. Most textbooks (19) consider the origin of the covalent bond to be an inductive (I) generalization, and the following are three examples:

… between two identical atoms, ionic bonds cannot be formed. Therefore, how is a bond formed between such atoms? The question was answered in 1916 by the American chemist Gilbert. N. Lewis…G.N. Lewis supposed that the bond [between two identical atoms] is a covalent bond…. [textbook gives additional information about covalent bonds and an example of H_2 molecule]…as a result of filled in outer shell of the atom with shared electron, a bond between two atoms lead to stable molecules if they share electrons in such a way as to create a noble gas configuration for each atom as shown Figure… [one page later, textbook gives following explanation dealing with inductive generalization] …Helium does not form a molecule of He_2, because repulsive forces exert on attractive forces as distance between the two helium atoms decreases. Therefore, the atoms do not come near enough to form a bond… (Bayin, 1982, p. 226)

Lewis and Langmiur explained formation of ionic and covalent bonds by using the octet rule (or duplet rule [for He]). According to this rule, atoms share or transfer electrons in the outermost shell to create a noble gas configuration… (Pamuk, 1984, p. 110)

[textbook explains the covalent bond by giving an example of H_2 molecule] … as the distance between two hydrogen atoms decreases, the electrostatic interactions between each electron and nuclei of the other atom, as well as between the two electrons and between the two nuclei, become increasingly important. When attractive forces exert on repulsive forces, atoms close up… [textbook gives extra information about attraction and repulsion forces]… since electrons revolving around the two nuclei were distributed in a greater region, repulsive forces between the two electrons were lower than attractive forces from the two nuclei. Therefore, as compared with hydrogen atoms, they were more stable and lower energies as hydrogen molecule (as seen Figure…)… (Tunalı & Aras, 1977, p. 254)

These presentations are quite representative of most textbooks and show explicitly that the octet rule is sustained by empirical evidence. On the other hand, eight textbooks made no-mention explicitly to either of the two interpretations (Lakatosian or inductive generalization).

Table 10.4 (Criterion 4) shows that three textbooks mentioned (M) and only two textbooks described satisfactorily (S) Pauli exclusion principle as an explanation of the sharing of electrons in covalent bonds. The following were considered to be two examples of a satisfactory description:

> [textbook explains the covalent bond and then gives an example of H_2 molecule] … one hydrogen atom has only one electron that is symmetrically distributed around the nucleus in a 1s orbital. When two hydrogen atoms form a covalent bond, two atomic orbitals overlap in such a way that the electron clouds are in the region between the two nuclei, and there is an increased probability of finding an electron in this region. According to Pauli Exclusion Principle, the two electrons of the bond must have opposite spins. (Bekaroğlu & Tan, 1986, pp. 74–75)

> …spins of two electrons in a [covalent] bond must have opposite directions (see page 211) [on page 211, textbook explains Pauli Exclusion Principle in detail]. (Ün, 1967, p. 228)

Three textbooks made a simple mention (M) of Criterion 4, and the following was considered to be an example:

> … a single covalent bond consists of a pair electrons, with opposite spin, shared by two atoms…. (Ünal, 1992, p. 42)

Very few textbooks presented the development of the kinetic molecular theory within a historical perspective. Similar results have been reported for general chemistry textbooks published in the USA (Niaz, 2001). It is concluded that the inclusion of HPS aspects can facilitate students' interest, motivation, and conceptual understanding.

Conclusion and Educational Implications

Research reported here can help to improve general chemistry textbooks published in Turkey and other countries. It could also help in the design and implementation of studies that use history and philosophy of science-related materials to facilitate students' conceptual understanding. In recent years, Turkish universities have encouraged its faculty members and doctoral students to engage in science education research. It is plausible to suggest that this may encourage faculty members to use in the classroom research alongside the textbooks. Appropriate historical reconstructions can benefit students both by providing them with models for alternative/rival approaches and by instilling in them a deeper conceptual understanding of the topic. Furthermore, it is important to note that such approaches approximate a strategy based on "science as practiced by scientists" (Niaz, 2011).

Finally, science education in the twenty-first century cannot continue to repeat the *rhetoric of conclusions* (Schwab, 1974) found in most textbooks. Instead, we need to break the mold and provide students an insight into the dynamics of scientific progress. Textbooks, instead of forcing students to memorize facts, can provide historical reconstructions based on the development of scientific theories that frequently involve controversies, conflicts, and rivalries among scientists. Such presentations can stimulate students to think that all the work has not yet been done and progress in science needs their contribution.

Appendix: List of Turkish General Chemistry Textbooks Analyzed (n = 27)

1. Alpaydın, S., & Şimşek, A. (2006). *Genel kimya* (2. Baskı). Ankara: Nobel Yayın Dağıtım.
2. Aydın, A. O., Sevinç, V., & Şengil, İ. A. (2001). *Temel kimya* (2. Baskı). Adapazarı: Aşiyan Yayınları.
3. Atasoy, B. (2000). *Genel kimya*. Ankara: Gündüz Eğitim ve Yayıncılık.
4. Atasoy, B. (2004). *Temel kimya kavramları* (2. Baskı). Ankara: Asil Yayın Dağıtım.
5. Bağ, H. (2006). *Genel kimya-I* (1. Baskı). Ankara: Pegem A Yayıncılık.
6. Bayın, Ö. (1982). *Modern kavramlar yaklaşımıyla kimya*. İstanbul: Fil Yayınevi.
7. Baykut F. (1964). *Modern denel, genel kimya dersleri*. İstanbul: İstanbul Üniversitesi Yayınları.
8. Bekaroğlu, Ö., & Tan, N. (1986). *Genel kimya (teori ve problemler)*. İstanbul: Kipaş Dağıtımcılık.
9. Dikman, E. (1975). *Temel kimya (anorganik)*. İzmir: Ege Üniversitesi Fen Fakültesi Yayınları.
10. Erdik, E., & Sarıkaya, Y. (1991). *Temel üniversite kimyası* (5. Baskı). Ankara: Hacettepe-Taş Kitapçılık Ltd. Şt.
11. Ergül, S. (2006). *Genel kimya*. Ankara: Anı Yayıncılık.
12. Hakdiyen, İ. (1960). *Genel ve teknik kimya*. İstanbul: Teknik Okulu Yayınları.
13. Hazer, B. (1997). *Genel kimya*. Trabzon: Akademi Ltd. Şti.
14. İrez, G. (2002). *Temel kimya-1*. Muğla: Muğla Üniversitesi Yayınları.
15. Öncel, M. F. (1974). *Genel kimya notları-1*, Ankara.
16. Öncel, M. F. (1976). *Deney ve problemleri ile modern genel kimya-1*. Ankara: Fen Yayınevi.
17. Özcan, M. (1998). *Modern temel kimya-I* (Genişletilmiş 2. Baskı). Balıkesir: Vipaş Yayınları.
18. Pamuk, F. (1984). *Genel kimya*. Ankara: Gazi Üniversitesi Yayınları.
19. Saracoğlu, A. S. (1983). *Temel kimya* (3. Baskı). İstanbul: Çağlayan Kitabevi.
20. Saraç, A.S., Güvençoğlu, A., & Soydan, A. B. (1983). *Modern genel kimya ve çözümlü problemleri*. İstanbul: Murat Matbaacılık.
21. Soydan, B., & Saraç, A.S. (1998). *Genel üniversite kimyası ve modern uygulamaları* (2. Baskı). İstanbul: Seç Yayın Dağıtım.
22. Şenvar, C. (1989). *Temel kimya*. Ankara: Hacettepe Üniversitesi Yayınları.

23. Tosun, F. (1969). *Genel kimya, prensipler*. Trabzon: Karadeniz Teknik Üniversitesi Yayınları.
24. Tunalı, N. K., & Aras, N. K. (1977). *Kimya temel kavramlar* (11. Baskı). Ankara: Başarı Yayınları.
25. Ün, R. (1967). *Genel kimya (Genel ve anorganik)*. Trabzon: Karadeniz Teknik Üniversitesi Yayınları.
26. Ünal, S. (1992). *Genel kimya*. İstanbul: Marmara Üniversitesi Yayınları.
27. Yavuz, O. (1978). *Genel kimya*. Erzurum: Atatürk Üniversitesi Basımevi.

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Chapter 11
An Analysis of Standards-Based High School Physics Textbooks of Finland and the United States

Do-Yong Park and Jari Lavonen

Introduction

This study examines how the curriculum is in alignment with the reform standards using the questioning style and level of inquiry activities, which are key components of the National Science Education Standards [NSES], in terms of the inquiry milieu (National Research Council [NRC], 1996). Two countries' textbooks were chosen for analysis in this study: *Physica* (meaning physics in Greek) of Finland and *Active Physics* of the United States' high school physics, which are products of reform efforts in science education. In 2003, Finland undertook a major change in the curriculum at the national level, which produced the "National Core Curriculum" (FNBE, 2003), whereas the United States went through a major reform in science education in the past decade, which produced the "National Science Education Standards" (NRC, 1996). *Physica* of Finland was developed as a high school physics textbook based on the National Core Curriculum for Science Education, and *Active Physics* of the U.S. high school curriculum was developed based on the National Science Education Standards. The United States developed a new curriculum based on the national standards as an alternative to the traditional curriculum. Finnish *Physica* was developed based on a "traditional" national level curriculum, which includes aims for upper secondary physics and short descriptions of core content

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(FNBE, 2003). However, a study of how those particular curriculums have met the visions espoused by the National Science Education Standards is yet to be studied.

Around the world, science education has recently gone through reforms at various levels in each country. One of the reform efforts is a curriculum change in K-12. As seen in several reform documents, including the effective learning and teaching of *Science for All Americans* (American Association for the Advancement of Science [AAAS], 1989), the curriculum and content of *National Science Education Standards* (NRC, 1996), and the research base of *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993), the importance of a curriculum is described, reiterated, and infused in teaching and learning and in the development of educative materials (Davis & Krajcik, 2005; Schneider & Krajcik, 2002). In today's classrooms, the curriculum influences how content is delivered in teaching (Association for Supervision and Curriculum Development [ASCD], 1997; NRC, 1996, p. 22) to meet the needs of all students in learning (AAAS, 1989). In other words, the curriculum provides the way content is structured, organized, balanced, and presented in the classroom so that all students learn with equal opportunities (NRC, 1996). When one considers the fact that curriculum can be a powerful tool for impacting teachers' teaching practice and subsequently improving student learning (Ball & Cohen, 1996), the curriculum is critical to the school education accountability.

Often a science textbook is considered as curriculum; yet, a science textbook is just a part of the curriculum that teachers use as tool and guidebook to guide their instruction. To many teachers, a textbook becomes an important part of their instruction, including how their subject matter is delivered and what is assessed. So a textbook serves as a method and assessment of teachers' teaching, which often becomes inseparable from their everyday routine in the school curriculum. A textbook is a key concern and interest to educational constituencies including parents, school districts, students, and teachers as they get involved in the selection process of a textbook and its use. Thus, selecting and evaluating a quality textbook is critical in operating school curriculum. One of the essential steps in evaluating curriculum materials is to examine how curriculums align with national standards (Kulm, Roseman, & Treistman, 1999). A significance of evaluating a quality textbook is multiplied with the fact that over 90 % of all science teachers traditionally tend to rely entirely on textbooks for their teaching (Park, 2005). The centrality of textbooks in teachers' instruction has been documented in the corpus of literature (Harms & Yager, 1981; Shymansky & Kyle, 1992; Stake & Easley, 1978; Strangman & Hall, 2003; Weiss, 1978; Yager, 1983, 1992). Ironically, these documents alerted that too much dependence on textbooks may create problems in (a) stating learning goals that meet the need of schools and students at the local, school district, and state level and also (b) delivering the key components of science. Furthermore, the overdependence on textbooks has been blamed for a failure of reform efforts in science education called "the essence of the current crisis" (Yager, 1980). However, there have been several curriculum reform efforts to help decrease the overdependence of textbooks in teachers' science instruction (Hurd, 1994; Kahl & Harms, 1981). One of such efforts was to develop a new curriculum with new pedagogical perspectives and learning theories with topics that are phenomena of what students experienced in their own communities and everyday lives. *Active Physics* (Eisenkraft, 1998) of the Unites States is a new national curriculum funded in part by the National Science Foundation, which was developed in association with the American Association of Physics Teachers (AAPT) and the American Institute of Physics (AIP). (What was developed in association? The National Science Foundation or the national curriculum?) Unlike the traditional physics textbooks, *Active Physics* was developed with the pedagogy that strictly reflected the visions of the National Science Education Standards. *Physica* (Hatakka, Saari, Sirviö, Viiri, & Yrjänäinen, 2005) of Finland was developed with the key recommendations of the National Core Curriculum in which the concept of "inquiry" was explicitly introduced in Finnish national curriculum (FNBE, 2003), although it has been used occasionally in schools. The textbook design was started through analyzing the core concepts introduced in the national level curriculum and then allocating these concepts to courses or separate volumes and then to chapters of each volume. The design was, therefore, content oriented in the beginning. However, the authors designed also inquiry activities parallel with the designing of the content (Viiri, 2011, Personal communication with one of the authors of *Physica*). Inquiry orientation is emphasized in the national level curriculum (FNBE, 2003), "The starting points for physics instruction are the students' prior knowledge, skills, and experiences, and their observations and investigations of objects and phenomena in the nature. … The purpose of the inquiry orientation is to help the students both (i) to perceive the nature of science and (ii) to learn new scientific concepts, principles, and models; (iii) to develop skills in experimental work and (iv) cooperation; and (v) to stimulate the students to study physics (interest)." Although Finnish *Physica* is information oriented as is often seen in traditional curricula, the inquiry activities were designed according to the national level curriculum. The aims of the national level curriculum emphasize scientific skills, such as the formulation of questions and making of observations and measurements. Moreover, the aims emphasized planning and carrying of scientific investigations, evaluating the reliability of the research process and results, as well as using of various graphs and algebraic models in explaining natural phenomena, making predictions, and solving problems.

This study of textbook analysis was conducted to present evidence how congruent these two curricula are in terms of inquiry-based science with the visions of reform provided by the NSES. The *Active Physics* curriculum claimed that the NSES recommendations regarding content, teaching, assessment, and professional development were to have been evident and embedded throughout the *Active Physics* materials. In the process of textbook analysis in this study, we particularly used the questioning style and level of inquiry laboratory activities that are key reform recommendations of the NSES (NRC, 1996) as two indicators for determining the congruence between the recommended standards of the NSES and the *Active Physics* materials. The Finnish high school physics textbook was chosen because of two reasons: (a) Finnish school students have recently received much attention from around the world due to high achievement scores in science, according to the PISA international studies (Organization for Economic Cooperation and

Development [OECD], 2005, 2007, 2010), and (b) the Finnish science curriculum introduced the concept of "inquiry" in the national curriculum (FNBE, 2003). Therefore, a scientific analysis of textbooks across the countries should add significant interests and findings to the literature of curriculum studies, especially when both *Active Physics* and *Physica* were analyzed by the inquiry pedagogy in regard to the national standards.

Theoretical Framework

Curriculum and the Textbook as Reform Tool

Along with Benchmarks for Science Literacy (AAAS, 1993), the U.S.'s National Science Education Standards [NSES] (NRC, 1996) were noted as one of the major curriculum reform movements in science education that influenced the way science curriculums were developed for schools. The NSES's visions were infused into the new curriculums, which included Earth Systems Science in the Community (EarthComm) and *Active Physics*. One of the central concepts in the curriculums is *inquiry* of NSES (FNBE, 2003; NRC, 1996, p. 23) that provides a framework for ideas to be organized into a textbook. The topics included in the textbook exemplified the recommendations of National Science Education Standards that influenced its philosophy, teaching, learning, professional development, assessment, and content (Park, Yager, & Smith, 2005). A change of the curriculum is followed by new content, new structure of content, and new pedagogical philosophy including learning theories and assessment. The science textbook is a part of the curriculum that had long been a key component in education reform. As a number of studies have reported, the revamping of textbooks impacts teachers' choices of concepts and the way they teach, which may be deemed as a "dictation" of what to do for teachers (Stake & Easley, 1978). Concerning the overdependence of textbooks, teachers are misled to believing that textbook teaching can guarantee to produce knowledgeable students (Yager, 1983) and that students perceive textbooks as the only authoritative source of knowledge (Stake & Easley 1978). However, regarding the current science textbook trends, three shortcomings are noted (Stinner, 1995): (a) the overdependent belief of textbooks tacitly produces the empiricist-inductivist view of science in which scientific knowledge including laws and theories is created through scientific observation, (b) teaching textbooks is guaranteed to produce non-disputable knowledge for students, and (c) most textbooks do not focus on inquiry-oriented experiments but are content oriented. Several studies recommended key knowledge to be addressed for future textbooks by emphasizing the inclusion of curriculum goals and content that reflects the contemporary learning theories (Chiappetta, Fillman, & Sethna, 1991; Renner, 1972; Staver & Bay, 1987). One of the contemporary content and conceptions is inquiry, which is addressed and incorporated in textbooks (NRC, 1996).

Inquiry

Inquiry is one of the key visions of National Science Education Standards. By adopting the "inquiry" concept (NRC, 1996, p. 23), *Active Physics* was developed to construct and organize the content and topics in the high school physics curriculum. Inquiry-oriented approach with a constructivist learning theory influenced the way content was presented. *Active Physics* is a curriculum using the thematic approach in which each thematic unit has three chapters and each chapter has nine activities or so. Inquiry approach played a dominant role in constructing the content of *Active Physics* that is all activity driven with little reading. Each chapter started with a challenging scenario to engage students into a topic called "scenario driven," which sets the stage for the learning activities followed by exploring the activities with fundamental physics principles, deepening the understanding of identified principles, explaining observed phenomena with theories and concepts done through cooperative groups, and expanding their learning and assessing authentically. The course of both *Active Physics* and *Physica* apparently utilized what was presented as inquiry in NSES (NRC, 1996, p. 23). That is, "inquiry is a multifaceted activity that involves making observations, posing questions, … planning investigations, … using tools to gather, analyze, and interpret data, and proposing answers, explanations, … and communicating the results." This definition provided a framework for students to find solutions to real world problems through a process of investigations including formulating questions (Bereiter & Scardamalia, 1989), planning investigations (Schauble, Glaser, Duschl, Schulze, & John, 1995), using tools to gather and analyze data (Vellom & Anderson, 1999), interpreting and proposing answers and explanations (Chinn & Brewer, 1993), and finally communicating with findings. Although such a procedure is deemed important to scientists, these activities may not necessarily occur in any way that is predetermined in real school settings. When the reform recommendations apparently influence the way the curriculum is constructed, the study of textbook analysis is supposedly rooted in the contemporary learning theories and inquiry conceptions recommended by the reform document.

Questions

Scientific inquiry often begins with a question; specifically, it is to be a set of good questions that are relevant, answerable, and scientifically meaningful (Marbach-Ad & Sokolove, 2000). The type and the level of questioning can determine how effective discussions are (Rowe, 1986). If questioning only targets the knowledge, recall, and comprehension level of Bloom's taxonomy, then the science would be a limited relevance to students. Questions should stimulate students to think as if they were scientists to reduce the notion that science should only be reserved for a particular group. If questions ask for simple knowledge and facts, then students remain not critically thinking and assessing. However, questions that ask for analysis, synthesis, and evaluation in Bloom's taxonomy would require critical thinking and assessment (Beatty, Gerace, Leonard, & Dufresne, 2006). Thus, the level of questioning becomes critical during the instructional process of inquiry activities and learning goals. Regarding this particular issue, Lowery and Leonard (1978a) developed an instrument to analyze the type of questions in textbooks. They argued that the questioning style can be a good predictor of textbook quality that may help teachers expand their horizon of selection criteria when examining a textbook for their schools or school district. Question type and level of inquiry activities can be one legitimate evaluation tool to examine how congruent a textbook is in terms of what National Science Education Standards presented about inquiry, since inquiry and question type are closely integrated, to move forward when solving a problem in scientific investigations.

Methodology

Sample

The two textbooks were used for analysis. One was *Active Physics* (Eisenkraft, 1998) of the United States, a new textbook developed in association with the American Association of Physics Teachers (AAPT) and the American Institute of Physics (AIP). Unlike the traditional physics textbooks, *Active Physics* was developed with the pedagogy that reflected the visions of the National Science Education Standards. The other one was *Physica* (1,442 pages in total) (Hatakka et al., 2005) of Finland, a new national textbook developed with the visions of National Core Curriculum (FNBE, 2003). However, Finnish high schools redevelop their own local curriculum materials as in the USA to maximize the relevance of textbook contents in a local context, but they still use a textbook designed in line with the national level curriculum. These two textbooks were selected to compare for questioning style and level of laboratory activities in each book. Recommended by Lowery and Leonard (1978a), the following samples pages are used in this study: A random sample of 10–15 % of the total pages to represent a text of 300–500 pages and 5 % of the total text with over 500 pages. Based on the suggestion of Lowery and Leonard, 52 pages of the entire text of *Active Physics* (1,036 pages in total) were randomly sampled for data analysis and 72 pages from the Finnish physics textbook (a total of 1,442 pages). A random number generator was used to obtain the precise number of pages as the recommended percentage. The random number selected was skipped if the sentences on a given page comprised less than half the page. The next page number was then selected.

U.S. Active Physics

A new high school physics curriculum was developed and published in 1998. The entire book of *Active Physics* was comprised of seven themes, and each theme had three chapters, except for one theme, "light up." The purpose of the thematic approach was to continually revisit fundamental physics concepts after the unit was completed. The content was developed around seven different themes that are relatable to students' everyday lives: (a) communication, (b) home, (c) medicine, (d) prediction, (e) sports, (f) transportation, and (g) light up, which offers knowledge and skills in physics. Each chapter consisted of 6–10 activities from beginning to end, and there are 19 chapters and 163 laboratory activities in total. The pedagogy applied in *Active Physics* thoroughly reflected the central visions of the National Science Education Standards. Each chapter began with an engaging scenario or project assignment that challenged the students and prepared them for the subsequent learning activities and chapter assessments. With a constructivist approach and authentic assessment, the chapter setup followed the "less is more" curriculum and an integrated high school curriculum using cooperative grouping strategies.

Finnish **Physica**

Following the recommendations of the National Core Curriculum that used the word "inquiry" explicitly, a new high school physics curriculum named *Physica* was developed in 2005. The entire textbook was comprised of eight units (volumes), and each volume had eight chapters with 12–37 laboratory activities, not including one chapter, "Matter and Radiation." The content was constructed around the traditional physics knowledge systems: (a) physics as a natural science, (b) heat, (c) laws of motion, (d) waves, (e) rotation and gravitation, (f) electricity, (g) electromagnetism, and (h) matter and radiation. As the Finnish science curricula increased the inclusion of inquiry-based activities, *Physica* incorporated the recommendations of the National Core Curriculum, which ended up with increased amount of lessons to teach in the textbook.

Analysis Form of Textbooks

Two major factors of Analysis Form were employed to analyze the selected samples of *Active Physics* and *Physica*: (a) general features and (b) level of openness of inquiry activities. The general features we adopted for analysis included the number of units, total pages, topics, and questions and sentences in each textbook. The level of inquiry openness included the four levels of inquiry activities following the scheme of what Heron suggested (1971), which offers a practical structure of inquiry activities in textbooks. These characteristics representing the structure of a textbook are of significant assistance for educational constituencies to understand how subject matter knowledge is combined with the practices of contemporary curriculum and instruction (AAAS, 1989; Park, 2005). The Analysis Form was simply designed to locate the differences between the two textbooks. The compared features were recorded on the form for all pages of each of the two textbooks. Descriptive statistics was applied to explain the results of the comparisons.

Questioning Style

Textbook Questioning Strategies Assessment Instrument (TQSAI) was used in this study, which was developed by Lowery and Leonard (1978a) with funding from the National Science Foundation. The purpose of using TQSAI was to examine textbooks in terms of styles and possible effectiveness of the questions and processes used in textbooks (see Appendix). Before analysis began, two authors in Finland and the USA met face-to-face for this study and discussed, clarified, and cleared confusions about each item of TQSAI until they agreed 90 %. Several samples were excerpted from each book and examined one by one to see if it matched the definition of TQSAI items. After the "initial training meeting [ITM]," the authors trained other raters in the way that was done at the ITM in each country. Two trained science educators – one with a Ph.D., the other a high school teacher – performed the examination to produce an agreement rate for each question of TQSAI. The two raters examined *Active Physics* curriculum artifacts against *Physica* for the type of questions and the science learning processes in each country. Raters evaluated each question by using two-dimensional grids upon which items could be tallied from a random sample of pages from each textbook. Since two books were over 500 pages, 5 % of the textbooks' total pages were then randomly sampled to establish the inter-rater reliability. Two raters independently examined the categorization of all questions included in the sample pages of each book and then checked for agreement. The agreement reached for the question categories was 0.89 (*Active Physics*) and 0.90 (*Physica*), which is deemed as high (Ericsson & Simon, 1993). The evaluation results provide useful information for teachers, parents, and school district administrators to select quality textbooks.

Level of Inquiry Activities

A level of openness was used to analyze the inquiry activities included in *Active Physics* and *Physica*. The presentation of inquiry activities (known as laboratory activities in school science textbooks) uses a certain level of openness according to a classification scheme designed by Schwab (1962) and further elaborated by Herron (1971). There are four different levels of laboratory activities to be used as criteria: levels 0–3. Each level is determined by the openness of question, procedures, and solution. For instance, in a level 0 laboratory activity, all three learning processes including questions, procedures, and solutions are given. Table 11.1 shows Herron's level of openness of laboratory activities.

Heron's scheme is useful especially when discussing the level of inquiry activities because inquiry itself is multifaceted in understanding and performing. Similar to the questioning style studies, rating training continued until 90 % of agreement between the raters was reached. The inquiry activities were chosen and counted with 5 % of sample pages from each of the two curricula. Two raters read the activities and determined the level of openness based on the descriptions of classification.

Table 11.1 Level of openness of laboratory activities

Level	Problems	Procedures	Solutions
0	Given	Given	Given
1	Given	Given	Open
2	Given	Open	Open
3	Open	Open	Open

Table 11.2 Comparison of general features for all pages included in the two selected high school physics textbooks

	Active Physics (1,036 pages)		Finnish *Physica* (1,442 pages)	
Features	Number	Percent[a] (%)	Number	Percent[a] (%)
Units	7	0.7	8	0.6
Chapters	19	1.8	64	4.4
Laboratory Activities	163	15.7	170	11.8

Unit consists of chapters, for instance, Sports (unit), Physics in Action (chapter), and Defy Gravity (laboratory activities)

[a]Demonstrated percentage means only a portion per page of each book. For instance, units of *Active Physics* are 7. The percentage of 0.7 % for *Active Physics* Unit is calculated as follows: (7/1,036) × 100 = 0.7 %. This method is used to compare features of each curriculum. Thus, the percentage does not necessarily come to 100 % in total because it represents only a ratio of a portion of each feature

A comparison in percentages was made between the two textbooks. Two raters independently assessed the level of laboratory activities for each of the two curricula. The agreement of the raters was used to provide the inter-rater reliability, which turned out to be 100 % for the two textbooks used in this study.

Results

General Features of Textbooks

A comparison of the general features of the two textbooks illustrates their differences in structure and organization. Table 11.2 shows the results of the comparison. The percentage represents the occurrence of the feature per page in each textbook. Both textbooks were big volumes: as seen in Table 11.2, U.S. *Active Physics* had seven different units (volumes) and 1,036 pages overall, while Finnish *Physica* had eight units and 1,442 pages. The most noticeable difference was that *Active Physics* presented a greater number of laboratory activities (15.7 %) than Finnish *Physica* (11.8 %), whereas *Active Physics* included fewer chapters (1.8 %) than Physica (4.4 %). As all seven volumes of *Active Physics* together consisted of 163 laboratory activities, the difference of chapters between two textbooks demonstrates that *Active Physics* follows an inquiry-oriented curriculum with less information, which is line with the AAAS recommendation of "less is more." It seems that *Active Physics*

Table 11.3 Comparison of percentages of questions per sentence and percentages of experiential questions included in the sample pages of two textbooks

Textbooks with sample pages	Number of questions	Number of experiential questions	Number of sentences	Percentage of questions per sentence (%)	Percentage of experiential questions (%)
Active Physics	107	46	728	14.7	43.0
Finnish *Physica*	92	31	864	10.6	34.2

encourages greater understanding of the concepts through inquiry activities about the natural world rather than focusing on knowledge transmission.

Questioning Style

Using the definitions of Textbook Questioning Strategies Assessment Instrument (TQSAI), we compared the question type included in the sample page of the two textbooks. The question type is important in physics education as it is heavily emphasized in the NSES. Data was analyzed to determine the degree to which each item met the vision outlined in the NSES. Lowery and Leonard (1978a) provided the definition of each questioning style in TQSAI (see Appendix). As mentioned before, the sample pages were randomly selected according to the suggestions of the TQSAI developers, which varied depending on the total pages of each textbook. The results are presented in Tables 11.3, 11.4, and 11.5.

Frequency of Experiential and Non-experiential Questions

Table 11.3 showed the results of comparisons regarding the number of questions and the percentage of questions to sentences. *Active Physics* included more questions per sentence (14.7 %) than *Physica* (10.6 %). In addition, Active Physics has more experiential questions (43 %) than the Finnish physics textbook (34.2 %). Experiential questions are questions that ask what student experienced in the laboratory activities. For instance, an example of experiential question is “From the data you gathered, are there students in your class who can reach the same speed as the make 1,500-m record holder?” In addition, an example of non-experiential question is “What is a force?” or “What is center of mass?” The percentages of experiential questions are presented in Table 11.3.

On the other hand, the percentages of non-experiential questions for the total numbers of questions included in the sample pages of each textbook are shown in Table 11.4. The two textbooks presented a similar percentage of questions in each question type. In *Active Physics*, direct-information question type was predominant (41.4 %), followed by open-ended question type (19.3 %). Likewise, Finnish *Physica*

Table 11.4 Comparison of the types of non-experiential questions included in the sample pages of two textbooks

Textbooks with sample pages	Rhetorical (%)	Direct information (%)	Focusing	Open-ended (%)	Valuing (%)
Active Physics	8.1	41.5	0.0	19.3	0.0
Finnish *Physica*	9.2	43.4	0.0	11.8	0.0

Table 11.5 Comparison of the types of experiential questions in percentages included in the sample pages of two textbooks

Science/learning process	*Active Physics (%)* (5 % pages)	Finnish *Physica* (%) (5 % pages)
Observing	27	23
Communicating	0	0
Comparing	10	15
Organizing	1	4
Experimenting	31	27
Inferring	27	23
Applying	4	8

included mostly direct-information question type (43.4 %) followed by the open-ended question type (11.8 %). Focusing and valuing question types were not found in the selected sample pages of both textbooks.

Ebel and Frisbie (1991) classified experiential questions into a hierarchy of the science/learning processes, including lower-order (observing, communicating, comparing, and organizing) and higher-order (experimenting, inferring, and applying) processes. This study analyzed the experiential questions by using Ebel and Frisbie's scheme. The results were summarized in Table 11.5. Percentages were calculated for the number of questions in each cell compared to the total number of questions included in each textbook. Both textbooks showed a similar pattern with dominating types of several areas. *Active Physics* has observing (27 %), experimenting (31 %), and inferring (27 %), while Finnish *Physica* includes observing (23 %), experimenting (27 %), and inferring (23 %). Communicating questions are not found in any sample of the two textbooks. Organizing question types resulted in two small numbers to analyze in both textbooks.

In summary, both U.S. curriculum *Active Physics* and Finish curriculum *Physica* have more than 1,000 pages. Per the general features of the textbooks, *Active Physics* contains more laboratory activities and fewer chapters than *Physica*. While *Active Physics* has more experiential questions, the two textbooks have a similar pattern with regard to non-experiential questions, the majority of which involve direct-information and an open-ended question. According to the science and learning process scheme (Ebel & Frisbie, 1991), the observing, experimenting, and inferring question types were common in both textbooks.

Discussions and Implications

Evaluating textbook alignment is one way to assess the congruence between a curriculum and visions of reform, i.e., the National Science Education Standards. The alignment requires coherence of science content and themes in the textbook to support student leaning. This study was particularly interested in how the NSES reform standards played a role in impacting the way contents were structured and the type of questions that were asked in high school physics textbooks. In this study, curriculum alignment refers to the extent to which the structure, content, and assessment of a curriculum coherently aligned with the standards and visions of reform to promote and advance students' learning and to meet the goals and objectives of education at the district, state, and national levels. Coherence of curriculums is important to students' effective learning (National Research Council [NRC], 2007). Since the visions and recommendations of reform are many and multileveled, textbook alignment evaluation may well be performed with different number of components in the reform. Science education reform movements (AAAS, 1993; NRC, 1996) recommended standards that explicitly promote more emphasis on inquiry-based science instruction to develop students' deep understanding of science concepts. The new framework of science education expands and advances inquiry-based science teaching by incorporating engineering and mathematics components into science instruction (National Research Council [NRC], 2011) within the full inquiry framework (NRC, 1996, p. 23). These standards require a significant shift as to what and how science is delivered to K-12 classrooms. Yet, inquiry is one of the key concepts among the reform documents that challenge and advance science learning and instruction of K-12 science education. Therefore, inquiry has been adopted as a key component as the reform efforts committed to impacting the development of new science curricula, including the textbook, instruction, and assessment, across the nations over the last two decades (Minner, Levy, & Century, 2010).

General Features of Two Textbooks

Compared to Finnish *Physica*, American *Active Physics* includes more laboratory activities while having fewer chapters (see Table 11.2). This textbook trend supports one of the emphases of science curriculum reforms, "less is more," as envisioned in *Science for All Americans* (AAAS, 1989) and Iowa SS&C (Yager, 1996). The chapter consisted of topics, and the topics consisted of concepts. So the more chapters included in a textbook, the more concepts may be taught. Fewer chapters may mean that the teaching focus is not on the quantity but on the quality if both textbooks have a similar number of pages to be taught in the same period of time. This message becomes important in K-12 science education as the national reform standards emphasized what all students should know and be able to do in science by the certain grade levels, i.e., *Benchmarks for Science Literacy* (AAAS, 1993), which gives a detailed and key idea for designing a curriculum. *Active Physics* has fewer pages (1,036 pages) and chapters (1.8 %) to teach than *Physica* with 1,442 pages and more chapters (4.4 %). The ratio of the number of chapters included in *Active Physics* versus *Physica* was 1: 4. Thus, the Finnish *Physica* has more than four times the percentage than that of *Active Physics*. However, both textbooks included similar amount of laboratory activities: *Active Physics* (15.7 %) and *Physica* (11.8 %). It seems that both new curricula emphasized the importance of inquiry-based activities in physics. On the other hand, *Active Physics* focuses on teaching fewer chapters in order to teach in depth. Project 2061 recommended that teachers should "introduce ideas gradually, in a variety of contexts, reinforcing and extending them as students mature by concentrating on fewer topics" (AAAS, 1989, p. xviii). By the time students get to high school, they tend to deepen their knowledge on fewer topics. Therefore, the instructional message of "less is more" is to allow students to develop deep understanding of scientific concepts through inquiry-based investigations than the "more concepts to teach" environment in which students are demanded to memorize decontextualized knowledge and facts. Interestingly, Finnish students topped on the PISA tests three times in a row (OECD, 2005, 2007, 2010), while *Physica* seemingly places emphasis on meaning making of various physics concepts, and yet it encourages understanding through many opportunities of laboratory experiments. Lavonen and Laaksonen (2009) analyzed Finnish students' opinions about science and science studies using PISA 2006 Scientific Literacy Assessment data, and they concluded that Finnish science students' high achievement on PISA tests is strongly related to two main factors, which are context variables and the national educational policy. One of the context variables has to do with how teachers operate a curriculum in classrooms, while the national educational policy demands a curriculum to align with "knowledge based society, educational equality, devolution of decision power at the local level, and teacher education" (Lavonen and Laaksonen, p. 922). The societal environment is an important factor to consider when interpreting students' achievement outcomes as Martin, Mullis, Gregory, Hoyle, and Shen (2000) pointed out, "the home background of students and the affluence of the communities in which they reside remain powerful predictors of science and mathematics. This relationship is pronounced and persists across international contexts" (p. 97). Therefore, the curriculum developer(s) considers these factors in the development of various curricula.

Level of Laboratory Activities

Of two high school physics textbooks, all of the experimental activities (100 %) examined in this study were determined at the level 1 in which problems and procedures are given with solutions left open (see Table 11.1). None of the two textbooks

Active Physics and *Physica* provided higher-level activities of levels 2 and 3. This result is not surprising as we have seen in other studies regarding the openness of a laboratory activity (Chiang-Soong, 1988; Park, 2005). Park (2005) examined the openness level of activities included in three high school earth science curricula in which one was an NSF-supported reform-oriented curriculum and two were traditional ones. His study concluded with the same result that level 1 dominated in all of the examined lab activities. In addition, the science textbooks examined in Chiang-Soong's study demonstrated that more than 80 % (100 % for some textbooks) of the laboratory activities were at levels 0 and 1. Findings of this study indicated that none of the textbooks provided higher-level activities that promote inquiry science and problem-solving skills, though it is the "acknowledged" reality of teaching school science curriculums. However, when we admit the fact that curriculum can be a powerful tool for impacting teachers' teaching practice and subsequently improving student learning (Ball & Cohen, 1996), the characteristics of current science curricula leave room for further development to meet what research says about the laboratory activities in teaching science.

Tamir (1976) reported that if students do not understand the concepts embedded in the scientific investigation processes, then they will fail to learn problem-solving skills that are a key component of learning through laboratory activities. Tamir's study suggests that many laboratory investigation opportunities should be given for students to practice and acquire problem-solving skills. When instructing laboratory activities, teachers often used textbooks and laboratory manuals in science laboratory classes (Bryant, 2000). From this view, textbooks can be a good leverage to implement problem-solving skills in science classes so that students are able to acquire the ability of scientific investigations. Although the laboratory activities were presented as level 1 in both *Active Physics* and *Physica*, this study found that students were continuously provided opportunities to practice inquiry problem-solving skills throughout the course of experiments including using tools to gather, analyze, and interpret data and proposing solutions, explanations, and predictions and communicating the results (NRC, 1996, p. 23). This aspect is congruent with the recommendations of NSES. These skills are acquired only when students engage in "active inquiries" as frequently as possible (NRC, p. 145). Specifically, the NSRS visions regarding laboratory activities recommended that students actively participate in scientific investigations and actually use the cognitive and manipulative skills during the course of scientific explorations. However, as observed in the current science curricula including *Active Physics* and *Physica*, the level of laboratory activities turned out to be low. In other words, when the problems and procedures are provided in detail for students to follow, students are then likely deprived of a chance to commit to formulating/identifying questions that guide scientific investigations and to demonstrating appropriate procedures, which are a critical part of inquiry process (NRC, p. 175). As defined in the NSES, inquiry skills such as "making observations; posing questions; examining and reviewing what is already known; planning investigations; using tools to gather, analyse, and interpret data; proposing answers, explanations, and predictions; and communicating the results to others" (NRC, p. 23) are all important to promote high school students' higher-order thinking. Yet these concepts are not easy to understand or acquire. Therefore, many opportunities ought to be offered to students to practice so that they can understand and acquire problem-solving skills as required in scientific investigations of high school physics.

Questioning Type

Regarding the number of questions per page included in both textbooks (see Table 11.3), the results showed that *Active Physics* (14.7 %) included a similar number of questions as *Physica* (10.6 %). As recommended in the reform documents, both *Active Physics* and *Physica* provided many questions pertaining to what students would ask to find as a solution in inquiry-based investigations. Also, the number of experiential questions between *Active Physics* (43.0 %) and *Physica* (34.2 %) was similar. This result is in good contrast with what the literature says. Lowery and Leonard (1978b) reported opposite indications with what we found in this study in terms of the number of experiential questions. In Lowery and Leonard's investigation, the Biological Sciences Curriculum Studies (BSCS) curriculum had more than twice the percent that Modern Biology had. In another study of NSF-funded curricula, BSCS biology presented 5.9 % experiential questions, while Modern Biology had no experiential questions (Chiang-Soong, 1988). In addition, Physical Science Study Curriculum (PSSC) included 12.0 % experiential questions, while Modern Physics used no experiential questions (Chiang-Soong, 1988). Little to no inclusion of experiential questions in a curriculum is not supported by what research suggested in science learning. Piagetian research, for instance, continuously indicates that direct and active experiences become more effective to students' meaningful learning than indirect and passive experiences (Lawson & Renner, 1975; Piaget, 1964; Stavy, 1990). The notion from this research suggests that textbooks incorporate more experiential questions than non-experiential questions into presenting and delivering subject matter knowledge. Regarding an analysis of non-experiential questions found both in *Active Physics* and *Physica,* results again showed a similar pattern in which the type of direct-information questions and open-ended questions dominated throughout the textbooks (see Table 11.4). However, none of the books included the type of focusing and valuing questions at all.

According to the study of Lowery and Leonard (1978b), the percentage of questions used for science and learning processes (Ebel & Frisbie, 1991) is skewed to "communicating" and "applying" questions with the absence of "observing" questions in the NSF-supported curricula. In addition, the NSF-sponsored curricula mostly used low-order type questions for science/learning processes (Chiang-Soong, 1988). In contrast, both *Active Physics* and *Physica* showed a balance in using questions between lower-order questions (observing, communicating, comparing, and organizing) and higher-order questions (experimenting, inferring, and applying) in the hierarchy of science/learning processes (see Table 11.5). In scientific inquiry, science begins with formulating/posing questions that guide investigations. Formu-lating different questions would lead to different investigations. When students are engaged in investigations, they should be offered many opportunities to develop the ability to formulate and refine questions into one that explains and predicts about the natural phenomena through scientific investigations (NRC, 1996). In inquiry, the questions that students formulate should be incorporated with scientific concepts. Since formulating inquiry questions is not as easy as it looks, students should actively be involved in it. Kleinman's study (1965) indicated that "active involvement" in formulating questions helps increase scope and depth of student thinking. Student thinking can even further be developed when students work with teachers, textbooks as instructional materials, and their peers (Pizzini & Shepardson, 1991; Zoller, 1987). Especially, teachers who received training in teaching higher-order thinking can be a good facilitator to promote students' thinking. Activities of hands-on performance tasks in instructional materials are also a good tool to facilitate students' thinking. Students' collaborative learning experiences with their peers improve their thinking process and help increase their performance to ask, investigate, collect data, interpret, apply, and revise information (NRC, 2011). From this view, it is suggested that textbooks should include more questions that promote students' active involvement in higher-order thinking skills. Martin's study (1979) supports the idea that questions that require higher-order thinking help increase students' higher cognitive responses. Such ideas of the questioning type, including how to promote active involvement and how to increase students' higher-order thinking, deserve a consideration in the process of curriculum development across all levels. As envisioned in the NSES, questioning in scientific inquiry should provide students with many opportunities to increase their investigation performance by utilizing higher-order thinking skills, such as "experimenting," "inferring," and "applying" questions. As shown in Table 11.5, *Active Physics* and *Physica* used many higher-order thinking questions, including "experimenting" and "inferring" questions. Though these questions are in line with what the reform documents envisioned, the NSES specifically emphasized the relevance and authenticity of questioning in inquiry science as seen in "inquiry into authentic questions from student experiences is the central strategy for teaching science" (NRC, 1996, p. 31). In fact, each inquiry activity of *Active Physics* begins with a challenging scenario to engage students in identifying their issues and concerns in the topic, which initiates the stage for the learning activities. In sum, at least from the perspective of inquiry science and questioning type, both textbooks consistently aligned with the NSES visions.

Appendix: Textbook Questioning Style Assessment Instrument (TQSAI)

A. Not experiential

1. Rhetorical	2. Direct information	3. Focusing	4. Open-ended	5. Valuing

B. Experiential

	2. Direct information	3. Focusing	4. Open-ended	5. Valuing
a. Observing				
b. Communicating				
c. Comparing				
d. Organizing				
e. Experimenting				
f. Inferring				
g. Applying				

Definitions of Types of Questions

On the TQSAI, the question categories are sequenced along a horizontal dimension. The categories are defined as follows:

Rhetorical questions: Questions that do not expect some participation by the reader. Such questions never require the student to do anything, thus non-experiential, and are tallied in a special cell on the TQSAI.

Direct-information questions: Questions that ask the reader to recall or recognize specific information (concepts, principles, laws, and so on) read, heard, or previously discussed.

Focusing questions: Questions that contain clues that suggest what the expected response is to be. Such questions guide the student toward an answer that the author wants to be developed in the student's own terms.

Open-ended questions: Questions that do not indicate one expected answer. Such questions invite exploration of relationships and consideration of meaning or implications.

Valuing questions: Questions that ask the reader to make a cognitive or an affective judgment or to explain the criteria used in an evaluation.

The science/learning processes are sequenced along a vertical dimension on the TQASI. They are defined as follows:

Observing: Questions that ask the reader to look, listen, touch, taste, smell, and the like. Such questions may ask the reader how she/he felt or what thoughts were elicited.

Communicating: Questions that ask the reader to verbalize, write, picture, and the like. Such questions may ask the reader to furnish a name, offer a descriptive term, or verbalize a rule. They may ask the reader what was hopeful or to identify the words that elicited a feeling.

Comparing: Questions that ask the reader to compare lengths, weights, capacities, or times. Such questions may ask the reader to identify similarities, to measure, to count parts, or to state a preference and the reason for the preference.

Organizing: Questions that ask the reader to seriate, order, sequence, group, or classify. The reader may be asked to sort into groups, to identify the basis for a grouping, or to provide criteria for a grouping.

Experimenting: Questions that ask the reader to hypothesize or to control and manipulate variables. The reader may be asked to identify conditions necessary for results or whether and when to change his/her attitudes on the basis of new evidence.

Inferring: Questions that ask the reader to synthesize, abstract, analyze, recognize patterns, predict, generalize, or to formulate a theoretical model. The reader may be asked to furnish a reason for an occurrence, provide a conclusion, or to identify the generalizations that apply.

Applying: Questions that ask the reader to use his/her knowledge or to invent. The reader may be asked to embark upon a course of action based upon a choice of alternatives.

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Chapter 12
A Qualitative Method to Determine How Textbooks Portray Scientific Methodology

Ian C. Binns

Textbooks play an important role in science classrooms. In the large majority of science classrooms, textbooks become the curriculum and determine what is taught and learned about science (Chiappetta, Ganesh, Lee, & Phillips, 2006). Science textbooks are an important resource for teachers because they provide detailed explanations of the topics taught. Yager (1983) found that over 90 % of all science teachers used textbooks 95 % of the time. More recently, Weiss, Banilower, McMahon, and Smith (2001) showed that over 95 % of 9–12 teachers rely on textbooks to organize and deliver instruction and assign homework. Additionally, Weiss, Pasley, Smith, Banilower, and Heck (2003) reported that textbooks were the second most common influence on the content that teachers teach after state and district standards.

Teachers and students naturally assume that information in textbooks is accurate. Due to the fact that an overwhelming majority of teachers rely on textbooks, students most likely learn about scientific methodology from science textbooks. If textbooks present science as a static endeavor where investigations invariably lead to theories and are always experiments, then students may assume that all scientists conduct science in such a manner (Reiff, Harwood, & Phillipson, 2002). Some have even suggested that the notion of a single, scientific method is most likely caused by science textbooks (Bauer, 1994; Bybee, 2004; McComas, 1998). While textbooks are not the only reason that students hold inaccurate understandings of scientific methodology, textbooks do convey a great deal of the scientific information students receive. It is therefore critical to determine how well textbooks represent scientific methodology.

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Literature Review

Previous research reveals that science textbooks do not provide a complete and accurate picture of the ways that scientific knowledge is developed. For example, Chiappetta and his colleagues along with others found that textbooks place little emphasis on the nature of science, including scientific methodology (Chiappetta & Fillman, 2007; Chiappetta, Fillman, & Sethna, 1991a; Chiappetta, Sethna, & Fillman, 1993; Lumpe & Beck, 1996; Phillips & Chiappetta, 2007; Vesterinen, Aksela, & Lavonen, 2012; Wilkinson, 1999). Each of these investigations was based on the analytical technique that focused on the balance of four scientific literacy themes developed by Chiappetta, Fillman, and Sethna (1991b/2004). In each investigation, textbooks focused more on science as a body of knowledge than on the other three aspects of scientific literacy: science as a way of investigating, science as a way of thinking, and the interaction of science, technology, and society.

Research has also shown that when textbooks do address scientific methodology, they present it as a stepwise procedure, typically referred to as "the scientific method" (Abd-El-Khalick, Waters, & Le, 2008; Blachowicz, 2009; Chiappetta et al., 1993; Gericke & Hagberg, 2010; Gibbs & Lawson, 1992; Irez, 2009; Knain, 2001; Niaz & Maza, 2011; Reiff et al., 2002; Spiece & Colosi, 2000; Vesterinen et al., 2012). Additionally, researchers found that textbooks tended to emphasize experiments as the primary approach to scientific investigations (Alshamrani & McComas, 2009; Decker, Summers, & Barrow, 2007; Knain, 2001).

Finally, several investigations determined that textbooks inadequately represent how scientists have developed scientific knowledge. Niaz and colleagues analyzed how a variety of topics are addressed in either chemistry or physics textbooks through the history and philosophy of science perspective including atomic structure (Niaz, 1998; Rodriguez & Niaz, 2002), covalent bonds (Niaz, 2001b), kinetic molecular theory of gases (Niaz, 2000), laws of definite and multiple proportions (Niaz, 2001a), the oil drop experiment (Rodriguez & Niaz, 2004), the periodic table (Brito, Rodriguez, & Niaz, 2005), and the photoelectric effect (Niaz, Klassen, McMillan, & Metz, 2010). Additionally, Guisasola, Almudi, and Furio (2005), who analyzed the theory of magnetic field, based their research on the methods established by Niaz and colleagues. The overarching theme that emerged from each of these investigations is that textbooks inadequately presented *how* scientists throughout history developed the current understanding of the particular concept, thus giving teachers and students an inaccurate picture of scientific methodology. In each case, the textbooks missed the opportunity to use the history of science to illustrate the various ways that scientists have developed scientific knowledge.

Although it appears that several investigations have already addressed the way textbooks present scientific methodology, there are several concerns. First, previous research included scientific methodology as just one aspect of the overall investigation. The majority of the literature either looked at areas such as scientific literacy (Chiappetta & Fillman, 2007; Chiappetta et al., 1991a, 1993; Lumpe & Beck, 1996; Phillips & Chiappetta, 2007; Vesterinen et al., 2012; Wilkinson, 1999) or various science concepts (Brito et al., 2005; Decker et al., 2007; Gericke & Hagberg, 2010;

Guisasola et al., 2005; Niaz, 1998, 2000, 2001a, 2001b; Niaz et al., 2010; Rodriguez & Niaz, 2002, 2004). Additionally, some investigations addressed scientific methodology as part of the overall construct of the nature of science (Abd-El-Khalick et al., 2008; Alshamrani & McComas, 2009; Irez, 2009; Niaz & Maza, 2011).

To date, very few investigations have specifically focused on how scientific methodology is represented in textbooks (Blachowicz, 2009; Gibbs & Lawson, 1992; Reiff et al., 2002; Spiece & Colosi, 2000). However, in each investigation, the research on textbooks was just one part of the investigation. Gibbs and Lawson (1992) also described the work of two scientists, and Reiff et al. (2002) interviewed scientists with the goal of developing their own version of scientific methodology called the inquiry wheel. Spiece and Colosi (2000) were more interested in students' understandings of scientific methodology. Finally, while Blachowicz (2009) specifically focused on scientific method in textbooks, his analysis came from a philosophical perspective, not from a science education perspective.

Another area of concern is that Vesterinen et al. (2012) was the only study that analyzed the entire textbook. Either specific chapters or a percentage of pages were randomly selected for analysis for the other investigations. Finally, several studies focused only on *whether* the textbooks addressed scientific methodology, not *how* the textbooks addressed scientific methodology (Chiappetta & Fillman, 2007; Chiappetta et al., 1991a, 1993; Lumpe & Beck, 1996; Phillips & Chiappetta, 2007; Vesterinen et al., 2012; Wilkinson, 1999). Thus, it is necessary for the development of more thorough analysis procedures to address these gaps in the literature. The present investigation fills this gap. This investigation specifically focused on the representation of scientific methodology and analyzed all chapters of the text. Thus, the purpose was to develop a valid and reliable method that considers not only *whether* but *how* the textbooks addressed scientific methodology.

Method

Sample

Selection of the secondary science textbooks in this study was based on the market shares for textbook publishers within the United States. Two sources were used to gather this information: the *Report of the 2000 National Survey of Science and Mathematics Education* (Weiss et al., 2001) and *Print Publishing for the School Market 2007–2008* (Mickey, Meaney, & Agostino, 2006). The report by Weiss et al. (2001) indicated that two publishers held 51 % of the market in terms of secondary science textbook sales: McGraw-Hill/Glencoe and Holt, Rinehart, and Winston (now Holt McDougal). The report by Mickey et al. (2006) revealed that the same two publishers controlled 58.1 % of the market.

Using the information on the market shares for textbook, publishers gave a sample size of two secondary science textbooks (see Table 12.1). While additional textbooks were analyzed, one book from each publisher was chosen to illustrate the way the

Table 12.1 List of textbooks included in this investigation

Author(s)	Title	Publication year	Publisher
DeSalle & Heithaus	*Holt Biology*	2008	Harcourt/Holt, Rinehart & Winston
Zitzewitz et al.	*Physics: Principles and Problems*	2009	McGraw-Hill/Glencoe

rubric designed for this investigation was utilized. Electronic versions of the most recent teacher editions for each textbook were used in this study.

Data Collection

The data collection for the text analysis included data from the student text and teacher text. Student text was any text found in the student edition of the textbook. This included running narrative, assessments, and reviews but did not include text from the activities and image captions. The one exception was the figure outlining scientific methodology found in the introduction chapter. Teacher text was any text found in the teacher edition of the textbook, typically located in margins of the textbook. The collection of data for the text analysis used the "text analysis sheet" specifically designed for this study. The page number, subsection title, score, and notes were recorded for the data. The notes column included quotes from the text, summaries of the text, and an explanation for the score of that particular subsection.

The unit of analysis for the text analysis was the individual subsections (referred to as an excerpt in this study). Subsections are part of the natural organization of the chapter for each textbook. Each chapter was divided into individual sections which were further separated into subsections. Each subsection was organized by content. In other words, content within each subsection was related to the title for that particular subsection.

To identify the subsections that pertained to scientific methodology in the introduction chapter, I carefully read the entire chapter. I also conducted a word search using an extensive list of words that could refer to scientific methodology, i.e., scientist, biologist, chemist, physicist, geologist, observation, investigation, experiment, etc., to ensure that all possible data was collected. Finally, to identify the subsections that pertained to scientific methodology in the rest of the textbook, I skimmed each of the chapters and conducted the same word search.

Data Analysis

Content analysis is defined as a "research technique for making replicable and valid inferences from texts to the contexts of their use" (Krippendorff, 2004, p. 18). This type of content analysis is traditionally quantitative in nature. A qualitative approach to content analysis, ethnographic content analysis (Altheide, 1996), was used in this investigation. Ethnographic content analysis is defined as the reflexive analysis of documents and aims to provide a systematic and analytical, but not rigid, approach to content analysis (Altheide). Both quantitative and ethnographic content analysis can be used to make inferences from all kinds of data: verbal, pictorial, symbolic, and communicative. However, in quantitative content analysis, data collection begins with predetermined codes and categories, whereas in ethnographic content analysis, data collection begins with few predetermined codes and categories. In ethnographic content analysis, "categories and variables initially guide the study, but others are allowed and expected to emerge throughout the study, including an orientation toward constant discovery and constant comparison of relevant situations, settings, styles, images, meanings, and nuances" (Altheide, p. 16).

Data analysis included two primary tasks. The first analytical task focused only on the section where scientific methodology is introduced, typically found in the introduction chapter of the textbook. The second task focused on the remainder of the textbook. In each case, only the text was included in the analysis and used the detailed rubric that was developed for this study (Fig. 12.1). Initially, the rubric came from science education reform documents and the nature of science literature. These sources emphasized that there is no single scientific method and that experiments are not the only type of scientific investigations (American Association for the Advancement of Science [AAAS], 1993; Lederman, 2004; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Matkins & Bell, 2007; McComas, 1998; National Research Council [NRC], 1996).

Preliminary analyses helped to further refine the individual levels of the rubric. The rubric is separated as traditional and broad. This was further separated as explicit or implicit. The traditional view emphasized that scientists follow a stepwise procedure referred to as "the scientific method," scientists must test hypotheses, or scientists only conduct experimental research. The broad view emphasized that scientists use a variety of methods to conduct their work and that there are multiple types of research, including descriptive research, correlational research, epidemiological research, and experimental research.

Figure 12.2 is a list of characteristics of the traditional and broad views of scientific methodology.

Text that explicitly promoted the traditional view of scientific methodology stated that there was one way of doing science, all scientists follow a set order of steps, scientists must test hypotheses, or that scientists only conduct experimental research. This text could also have "the scientific method" as a section title, included figure outlining steps that scientists follow, or included a section on experimentation without discussing other types of scientific investigations. Other explicit references to the traditional view included instances when the text referred to "the scientific method" in the discussion, assessment questions, or teacher text.

An example of an implicit reference to the traditional view of scientific methodology was if the text described experiments or experimental design (hypothesis testing, controlling variables, control groups, etc.) without specifically stating that there is one way of doing science. Another implicit reference to the traditional view was

-5	• Excerpt includes text that *explicitly* presents the traditional view* of scientific methodology. • Excerpt includes *implicit* references to only the traditional view of scientific methodology. • Excerpt includes no reference to the broad view** of scientific methodology.
-4	• Excerpt includes text that *explicitly* presents the traditional view of scientific methodology. • Excerpt includes NO *implicit* references to scientific methodology.
-3	• Excerpt includes text that *explicitly* presents the traditional view of scientific methodology. • Excerpt includes *implicit* references to the broad view of scientific methodology.
-2	• Excerpt includes text that *explicitly* presents BOTH the traditional view and the broad view of scientific methodology. • Excerpt includes *implicit* references to only the traditional view of scientific methodology.
-1	• Excerpt does NOT include text that *explicitly* presents scientific methodology. • Excerpt includes *implicit* references to only the traditional view of scientific methodology. • Excerpt includes no reference to the broad view of scientific methodology.
0	• Excerpt includes text that *explicitly* presents BOTH the traditional view and the broad view of scientific methodology. • Excerpt includes NO *implicit* references to scientific methodology. - OR - • Excerpt does NOT present or describe scientific methodology.
1	• Excerpt does NOT include text that *explicitly* presents scientific methodology. • Excerpt includes *implicit* references to the broad view of scientific methodology.
2	• Excerpt includes text that *explicitly* presents BOTH the broad view and the traditional view of scientific methodology. • Excerpt includes *implicit* references to the broad view of scientific methodology.
3	• Excerpt includes text that *explicitly* presents the broad view of scientific methodology. • Excerpt includes *implicit* references to only the traditional view of scientific methodology.
4	• Excerpt includes text that *explicitly* presents the broad view of scientific methodology. • Excerpt includes NO *implicit* references to scientific methodology.
5	• Excerpt includes text that *explicitly* presents the broad view of scientific methodology. • Excerpt includes *implicit* references to the broad view of scientific methodology.

Fig. 12.1 Rubric used for the text analysis

if the text organized the introduction of scientific methodology in an order similar to the steps of the traditional scientific method (i.e., ask a question, form a hypothesis, collect the data, analyze the data, and report conclusions). A third implicit reference included text that described the work of a scientist and only referred to

*The "traditional view" of scientific methodology features one or more of the following components:

- The "scientific method"
- Steps of the "scientific method"
- Experimental research ONLY
- Components of experiments (hypothesis-testing, controlling variables, etc)
- Laboratory work

**The "broad view" of scientific methodology features one or more of the following components:

- Multiple methods
- "No single scientific method"
- "not a set of sequential steps"
- "not rigid, step-by-step outlines"
- Various types of scientific research:
    - Observational/descriptive research
    - Field studies
    - Correlational research
    - Epidemiological research
    - Experimental research
- Serendipitous discoveries

Fig. 12.2 List of characteristics of the traditional and broad views of scientific methodology

experiments in that discussion. Assessment questions that required the reader to design an experiment, evaluated the experimental work of a scientist, or asked about different parts of experiments were also implicit references to the traditional view.

Text that explicitly promoted the broad view of scientific methodology stated that there are many ways of doing science, there is no single scientific method, or scientists do not follow a set of sequential steps. This text could have also included a section describing scientific investigations other than experiments, phrases such as "scientific methods" or "systematic approaches," or statements such as "scientific inquiry is a process rooted in observations and experimentation" (Biggs et al., 2007, p. 11).

Implicit references to the broad view of scientific methodology included text that described multiple methods, such as observational/descriptive research, correlational research, epidemiological research, and experimental research, without specifically stating that there are many ways to do science. Other implicit references to the broad view of scientific methodology included text that described scientists' nonexperimental research or assessment questions that asked the reader to evaluate scientists' nonexperimental research.

For the first task, the text rubric was used to assess how science textbooks initially described scientific methodology in the introduction chapter. This analysis only focused on the section of the introductory chapter that specifically described scientific methodology. This primarily included just the student text, but there were also some references in the teacher text. For the second task, the text rubric was used to assess if the examples in the rest of the textbook, including the rest of the introduction chapter, were consistent with its initial description of scientific methodology. As noted earlier, an extensive list of words were used to ensure that all references were included in the analysis.

Reliability and Validity of the Rubric

Two types of reliability were used in this study. The first type of reliability was intracoder reliability, also called stability (Altheide, 1996; Krippendorff, 2004). To establish intracoder reliability or stability, I reanalyzed the same text after a certain amount of time (test-retest design). A second analysis of several randomly selected excerpts showed a high level of agreement at 87 % for the text analysis.

The second type of reliability was interrater reliability, also called reproducibility. To establish interrater reliability, multiple coders were first trained in how to use the rubric. The coders then independently analyzed and scored the practice excerpts and activities. Each score was to be supported by any relevant quotes and explanations. Next, the coders discussed their findings as a group. Differences were addressed to refine the rubric and enhance interrater reliability. Interrater reliability was only established for the rubric using percent agreement, sufficient for this ethnographic content analysis (D.L. Altheide, personal communication, March 11, 2008). Interrater reliability was not established for the overall data analysis. Prior to discussions, the coders reached an agreement of 83 %. The differences were resolved through negotiation among the coders.

The author-developed rubric used for the text analysis was initially guided by the *Benchmarks for Science Literacy (Benchmarks)* (AAAS, 1993), the *National Science Education Standards (NSES)* (NRC, 1996), and the nature of science literature. These sources provided the general structure of the rubric. Preliminary analyses of sample text served to refine the rubric and ground it in the data. Face and content validity were provided by a panel of experts. Initially, one expert voiced concerns over the likelihood that the text rubric would be reliable and valid. As noted earlier, interrater reliability for the text rubric was established with three additional coders.

Results

As indicated earlier, the results for two textbooks, *Physics: Principles and Problems* and *Holt Biology*, are used to illustrate how the rubric designed for this investigation was utilized. Results from additional textbooks can be found in Binns (2009) and

Table 12.2 Score for the initial description in the student text and the teacher text

Book	Student text	Teacher text
Holt Biology	Broad (+2)	Traditional (−8)
Physics: Principles and Problems	Traditional (−3)	Neutral (0)

Binns and Bell (2010). I first provide the results illustrating how the textbooks initially described scientific methodology and then provide examples found throughout each textbook to show how the examples align with the initial descriptions.

Initial Descriptions of Scientific Methodology

The two textbooks used in this study presented mixed views of scientific methodology in their initial descriptions. The initial description in the student text in *Physics: Principles and Problems* placed more emphasis on the traditional view than the broad view, while the description in the teacher text sent a strong mixed message (Table 12.2). The initial description in the student text in *Holt Biology* placed more emphasis on the broad view than the traditional view, while the description in the teacher text sent a strong message supporting the traditional view (Table 12.2). The student text was one excerpt for each textbook, while the teacher text had multiple excerpts for each textbook. The score for the teacher text was added together for each book.

Physics: Principles and Problems. The initial description in *Physics: Principles and Problems* sent mixed messages, placing more emphasis on the traditional view. This section, titled "scientific methods," included explicit references to only the traditional view and implicit references to the broad view, presenting a mixed message and receiving a score of −3 on the text rubric (Table 12.2). The two explicit references in the teacher text contradicted each other, sending a strong mixed message to the teacher. The following examples provide support for why the description in the student text received a score of −3 and why the references in the teacher text received a score of 0 and sent a mixed message.

An example of an explicit reference to the traditional view in the student text came in the first sentence of the "scientific methods" section. The text stated that "in physics class, you will make observations, do experiments, and create models or theories to try to explain your results or predict new answers" (Zitzewitz et al., 2009, p. 8) and referred to this statement as "the essence of a scientific method" (p. 8). The text continued this discussion stating that "all scientists, including physicists, obtain data, make predictions, and create compelling explanations that quantitatively describe many different phenomena" (p. 8). The remainder of this section emphasized that "scientists conduct experiments" (p. 8) without mentioning other types of scientific research. At no point did the textbook include a statement explaining that scientists do not have to follow a scripted scientific method.

Even when the student text had the opportunity to introduce other types of scientific research, it continued to emphasize experiments. For example, the implicit reference to the broad view in the "scientific methods" section was a discussion about how scientists' observations of Mars changed due to the development of better instruments. The purpose of this example was to illustrate how scientific models and theories change as scientists are able to make more observations using better instruments. However, instead of using this opportunity to explicitly introduce other types of scientific research, the student text again emphasized experiments, stating that "if the new data are born out by subsequent experiments, the theories have to change to reflect new findings" (Zitzewitz et al., 2009, p. 9). Obviously, scientists did not control or manipulate any variables when making these observations of Mars, but the text failed to emphasize this point, continuing to promote the traditional view.

The two references to scientific methodology in the teacher text that accompanied the initial description in the student text sent a mixed message to the teacher. One excerpt explicitly promoted the broad view, and the other explicitly promoted the traditional view. For example, the excerpt that promoted the broad view emphasized that scientists do not follow a common series of steps and suggested that the teacher "inform students that scientists approach and solve problems with imagination, prior knowledge, and perseverance" (Zitzewitz et al., 2009, p. 8). However, next to this comment was a chart titled "a scientific method." The chart, which the textbook suggested the teacher share with students, included the list of steps that are commonly associated with the traditional scientific method, i.e., "state the problem, gather information, form a hypothesis, test the hypothesis, analyze data, draw conclusions" (p. 8). The chart indicated that after drawing conclusions, scientists either repeat the experiment several times if the hypothesis is supported or modify the hypothesis if it is not supported. The emphasis was on scientists following a stepwise approach when conducting research.

Holt Biology. The initial description of scientific methodology in the student text placed more emphasis on the broad view. This section, titled "scientific methods," included explicit references to both the broad and traditional views and implicit references to the broad view, presenting a conflicting message and giving it a score of 2 on the text rubric (Table 12.2). There were two references to scientific methodology in the teacher text, both of which contradicted the message in the student text. The following examples provide support for why the description in the student text received a score of 2 and why the references in the teacher text received a score of −8 and contradicted the student text.

The explicit reference to the broad view was a discussion of studies that do not include experiments under the title "study without experimentation," stating that "there are often cases in which experiments are not possible or not ethical" (DeSalle & Heithaus, 2008, p. 11). The example used to illustrate this point was a study in which researchers tried to determine if the bacteria that caused dental plaque also contributed to heart disease. The text emphasized that it would not be ethical to ask a group of people to not brush their teeth, stating that "researchers look for connections in data gathered from patients who have heart disease" (p. 11). Although the

Table 12.3 Frequency of excerpts at each level of the text rubric, total number of excerpts, and total score for each textbook for student text and teacher text

Book	Text Location	−5	−4	−3	−2	−1	1	2	3	4	5	# of excerpts	Total score
Holt Biology	Student text	0	1	1	1	55	123	0	0	0	2	183	69
	Teacher text	0	1	0	0	23	51	0	0	0	0	75	24
Physics: Principles and Problems	Student text	0	2	0	0	77	55	1	0	0	0	135	−28
	Teacher text	1	0	0	0	29	21	0	0	0	0	51	−13

student text failed to explicitly refer to this study as a correlational study, the emphasis was still on the fact that not all science research is experimental, explicitly and implicitly promoting the broad view.

An explicit reference to the traditional view in the "scientific methods" section was the figure that illustrated scientific methodology. The figure emphasized experiments and a linear process, including many of the steps found in the traditional scientific method (i.e., questions, hypotheses, experimentation). The caption read "scientists build theories from questions, predictions, hypotheses, and experimental results" (DeSalle & Heithaus, 2008, p. 13). Additionally, as with *Physics: Principles and Problems*, the student text did not include any statements indicating that scientists do not have to follow a scripted scientific method.

An example of an implicit reference to the traditional view was the organization of the section on scientific methodology: "making observations," "formulating a hypothesis," "scientific experiments," "analyzing results," and "drawing conclusions and verifying results." This order follows the traditional steps of the scientific method. Although the text did not explicitly state that these headings were steps that scientists follow, this organization implied that scientists follow a set order of steps in their research.

The two references in the teacher text did not align with the message in the student text in that they explicitly supported only the traditional view. Each excerpt explicitly referred to "the scientific method" and steps. For example, one excerpt suggested that the teacher "have students perform the following activity and identify the stage of the scientific method at each step" (DeSalle & Heithaus, 2008, p. 12). The other excerpt was a formative assessment for the teacher and stated that "according to the scientific method, what should you do after you state a question" (p. 13). The teacher text included four possible choices with "make predictions and hypotheses" (p. 13) as the correct choice.

Examples in the Text

The second part of the text analysis focused on any examples in the textbook except for the section on scientific methodology and used the established rubric described earlier. Table 12.3 shows the frequency of excerpts found at each level of the text rubric for the student and teacher text, excluding the initial description. It also shows the total number of excerpts as well as the total score for each textbook in the student and teacher text. The scores were added together in order to get an overall picture of how the textbook presented scientific methodology. The textbooks are organized according to the total score for the student text.

The results revealed that an overwhelming majority of excerpts in both the student and teacher text for each textbook implicitly promoted either the broad view (1 in the text rubric) or the traditional view (−1 in the text rubric). Additionally, the scores for the textbooks revealed that the examples in the student text and teacher text in *Holt Biology* placed more emphasis on the broad view, whereas the examples in the student text and teacher text in *Physics: Principles and Problems* placed more emphasis on the traditional view.

The following examples illustrate the types of excerpts at each level of the text rubric (Table 12.4). The examples with a ST after the citation are from the student text and the examples with a TT after the citation are from the teacher text. The examples are organized from the most traditional to the least traditional.

While the majority of the excerpts from each textbook implicitly promoted either the traditional or broad view, it is interesting to note that both textbooks included explicit excerpts outside of the initial description (Table 12.4). For example, *Physics: Principles and Problems* had three excerpts that explicitly promoted only the traditional view in either the student or teacher text. Two of these excerpts were definitions of scientific method, one at the end of the first chapter and one in the glossary (Level −4 in Table 12.4). The only difference between these two excerpts was that at the end of the first chapter, the text referred to "the scientific method" (Zitzewitz et al., 2009, p. 23), while the glossary just referred to "scientific method" (p. 925).

Holt Biology also had several excerpts that explicitly promoted the traditional view. One found in the teacher text in the chapter on DNA offered additional information for the teacher to potentially share with students (Level −4 in Table 12.4). The purpose of the statement was for the teacher to explain how scientific knowledge builds on the work of other scientists, but the emphasis was that scientists do this "utilizing the scientific method" (DeSalle & Heithaus, 2008, p. 293).

Each textbook also included excerpts that explicitly promoted both views while implicitly promoting one view over the other. It is interesting to note that in each excerpt, the text included statements indicating that scientists do not have to follow a stepwise method. As shown earlier, each textbook failed to do this in the initial description found in the student text. One example in *Holt Biology* was in the section on science skills in the appendix (Level −2 in Table 12.4). The purpose was to provide a more thorough explanation of experimental design than what was offered in the initial description. A key difference between this section and the initial description was that this section included a statement indicating that scientists do not always follow a stepwise method. While this is an improvement, the emphasis was still on experimentation as the only way to do science. In an end-of-chapter assessment, *Physics: Principles and Problems* included a question asking if scientists have to follow specific steps when conducting research (Level 2 in Table 12.4).

Table 12.4 Representative textbook excerpts corresponding to the levels of the rubric

Level	Representative quote or example
−5	Scientific method – The graph of a runner's motion can be thought of as the result of a scientific investigation. The hypothesis might be that the distance the runner covers as the time increases. The mass of the runner and the velocity of the runner are called the controlled variables because they do not change. If the measurements of position are made at equal intervals of time, time is called the independent variable since the experimenter determined the interval. The distance is called the dependent variable. It is customary to plot the independent variable on the horizontal axis and the dependent variable on the vertical axis. (Zitzewitz et al., 2009, p. 39) – TT
−4	This section explains the contributions of Griffith, Avery, Hershey, and Chase, which led to the conclusion that DNA, not a protein was the molecule of heredity. It is a good example of how science builds on the work of other scientists, utilizing the scientific method. (DeSalle & Heithaus, 2008, p. 293) – TT
	Scientific method: A systematic method of observing, experimenting, and analyzing to answer questions about the natural world. (Zitzewitz et al., 2009, p. 925) – ST
−3	Q1. Summarize the processes that scientists often use when beginning scientific investigations
	Q2. Describe two ways that scientists test hypotheses
	Q3. Analyzing methods: Provide one example of a case in which an experiment would not be possible and one example in which an experiment would not be ethical. (DeSalle & Heithaus, 2008, p. 13) – ST
−2	Scientists conduct experiments in order to explore and better understand the world around us. A key element of scientific experiments is that they address very specific questions. Scientists first ask the questions, then propose answers, and then test these possible answers using objective methods that can be repeated by other scientists
	This scientific method, as it is called, is often thought to consist of a rigid set of steps and related rules. In fact, the ways that experiments are carried out do not always fit this mold. Nevertheless, experiments must be done and explained in such a way that other scientists can repeat the procedures and obtain the same results. Producing consistent results between trials of the same experiment allows scientists to verify their conclusions. (DeSalle & Heithaus, 2008, p. 1052) – ST
−1	In 1666…Newton performed experiments on the colors produced when a narrow beam of sunlight passed through a glass prism….he believed that particles of light were interacting with some unevenness in the glass to produce the spectrum. To test this assumption, Newton allowed the spectrum from one prism to fall on a second prism. If the spectrum was caused by irregularities in the glass, he reasoned that the second prism would increase the spread in colors. Instead, the second prism reversed the spreading of colors and recombined them to form white light. After more experiments, Newton concluded that white light is composed of colors, and that a property of the glass other than unevenness caused the light to separate into colors. (Zitzewitz et al., 2009, p. 440) – ST
1	Sometimes, comparing fossils and living beings reveals a pattern of gradual change from the past to the present. Darwin noticed these patterns, but he was aware of many gaps in the patterns. For example, Darwin suggested that whales might have evolved from a mammal that lived on land. But at the time, no known fossils were "in between" a land mammal and a whale. Darwin predicted that intermediate forms between groups of species might be found.…the hypothesis that all vertebrates descended from a common ancestor is widely accepted. Observations of the anatomy of both fossil and living vertebrates support this hypothesis. When modern vertebrates are compared, the difference in size, number, and shape of their bones is clear. Yet the basic pattern of bones is similar. In particular, the forelimbs of many vertebrates are composed of the same basic groups of bones. This pattern of bones is thought to have originated in a common ancestor. (DeSalle & Heithaus, 2008, pp. 382–384) – ST

(continued)

Table 12.4 (continued)

Level	Representative quote or example
2	Q31. Describe a scientific method. (Answer given: Identify a problem, gather information about it by observing and experimenting, analyze the information to arrive at an answer)
	Q48. Is a scientific method one set of clearly defined steps? Support your answer. (Answer: There is no definite order of specific steps. However, whatever approach is used, it always includes close observation, controlled experimentation, summarizing, checking, and rechecking)
	Q65. Mars-Explain what observations led to changes in scientists' ideas about the surface of Mars. (Answer: As telescopes improved and later probes were sent into space, scientists gained more information about the surface. When the information did not support old hypotheses, the hypotheses changed)
	Q96. Design an Experiment-How high can you throw a ball? What variables might affect the answer to this question? (Answer: mass of ball, footing, practice, and conditioning) (Zitzewitz et al., 2009, pp. 24–28) – ST/TT
3	No examples from either textbook
4	No examples from either textbook
5	Scientific research typically involves asking very specific questions and then designing studies to collect answers to these questions. There are two broad styles of scientific research: experimental and observational
	In an experiment, some aspect of an organism, an object, or part of the environment is deliberately changed. The researcher then observes the effects of this change. For example, a scientist might study the effects of adding different amounts of nitrogen fertilizer to the soil in which a crop is grown
	Sometimes, it is not possible or desirable to perform an experiment. Observational research uses the senses, such as sight and hearing, to take in information. Scientific observation may also make use of instruments such as microscopes that allow us to see small things and balances that weigh objects. During scientific observation, a scientist observes but usually does not disturb or change his or her subject. For example, for a study of bird song, a scientist might quietly observe birds by recording their songs to be analyzed later in a laboratory. (DeSalle & Heithaus, 2008, p. 1050) – ST

What makes this different from the example in *Holt Biology* is that while the excerpt in *Holt Biology* emphasized experimentation, the assessment in *Physics: Principles and Problems* included questions on experiments and observations, implying that there are multiple ways that scientists conduct research.

Holt Biology also included excerpts outside of the initial description that explicitly promoted only the broad view (Level 5 in Table 12.4). In this example, the emphasis is on the notion that there are multiple ways scientists conduct research, stating "there are two broad styles of scientific research: experimental and observational" (DeSalle & Heithaus, 2008, p. 1050). The text then provides examples of both types of research, a key requirement to be classified at level 5 of the rubric.

Finally, it is important to clarify the two examples used in Table 12.4 to illustrate the types of excerpts that implicitly promoted either the traditional or broad view. The example of Newton and his experiments with light (Level −1 in Table 12.4) accurately described Newton's work. However, this example is representative of the majority of excerpts to scientific methodology that implicitly promoted experiments throughout *Physics: Principles and Problems*. This same argument applies to the

Table 12.5 Alignment between the initial descriptions of scientific methodology and the score of the examples in the rest of the textbook

Textbook	Initial description in student text	Initial description in teacher text	Score of examples in student text	Score of examples in teacher text
Holt Biology	Broad (+2)	Traditional (−8)	69	24
Physics: Principles and Problems	Traditional (−3)	Neutral (0)	−28	−13

example in *Holt Biology* that focused on the different types of evidence that Darwin used to support his theory (Level 1 in Table 12.4). The example implies that scientists can and do use techniques to gather evidence other than experiments. The purpose here is not to indicate that these two excerpts are inaccurate. It is to indicate what types of excerpts were considered to be level −1 or level 1 of the rubric.

Summary

These two textbooks illustrate how the instrument developed for this investigation can be used to look at the quality of a textbook's initial description of scientific methodology as well as the examples in the rest of the textbook. Both textbooks presented mixed messages in their initial descriptions of scientific methodology. *Physics: Principles and Problems* placed more emphasis on the traditional view in the student text and sent a strong mixed message in the teacher text. *Holt Biology* placed more emphasis on the broad view in the student text and strongly supported the traditional view in the student text. These mixed messages make it difficult for the teacher to get an accurate understanding of scientific methodology.

The analysis of the examples in the textbook revealed that the scores for the examples in the student and teacher text in *Holt Biology* were consistent with the textbook's initial descriptions of scientific methodology in the student text (Table 12.5). For *Physics: Principles and Problems*, the student text's initial description emphasized the traditional view as did the scores for the examples in the student text and teacher text. However, the scores for the examples in the student text and teacher text were not consistent with either textbook's description of scientific methodology in the teacher text. These results showed that while *Holt Biology* placed more emphasis on the broad view than *Physics: Principles and Problems*, each still presented a mixed view of scientific methodology throughout the text.

Discussion and Conclusions

This investigation focused on the development and use of a rubric to qualitatively evaluate how textbooks present scientific methodology. As noted earlier, much of the literature focused on *whether*, not *how*, textbooks present scientific methodology

(Chiappetta & Fillman, 2007; Chiappetta et al., 1991a, 1993; Lumpe & Beck, 1996; Phillips & Chiappetta, 2007; Vesterinen et al., 2012; Wilkinson, 1999). While I agree this type of analysis, quantitative content analysis, is needed to determine if textbooks even address scientific methodology, qualitative content analysis can address the accuracy of how textbooks address scientific methodology. As in, the analysis used in this investigation makes it possible to determine how textbooks address scientific methodology. Results from two textbooks, *Holt Biology* and *Physics: Principles and Problems*, illustrate how the rubric designed for this investigation was utilized.

Results from previous studies indicated that textbooks did not place strong emphasis on scientific methodology (Chiappetta & Fillman, 2007; Chiappetta et al., 1991a, 1993; Lumpe & Beck, 1996; Phillips & Chiappetta, 2007; Vesterinen et al., 2012; Wilkinson, 1999). Others found that textbooks typically presented science as following a stepwise approach, sometimes referred to as "the scientific method" (Abd-El-Khalick et al., 2008; Blachowicz, 2009; Chiappetta et al., 1993; Gibbs & Lawson, 1992; Irez, 2009; Knain, 2001; Niaz & Maza, 2011; Reiff et al., 2002; Spiece & Colosi, 2000; Vesterinen et al., 2012), or that textbooks emphasized experiments as the primary approach to scientific investigations (Alshamrani & McComas, 2009; Decker et al., 2007; Knain, 2001). Finally, textbooks inadequately represent how scientists have developed scientific knowledge (Brito et al., 2005; Gericke & Hagberg, 2010; Guisasola et al., 2005; Niaz, 1998, 2000, 2001a, 2001b; Niaz et al., 2010; Rodriguez & Niaz, 2002, 2004).

Some results from the present study support these earlier findings. For example, neither textbook placed much emphasis on scientific methodology, supporting the results from Chiappetta and colleagues. Additionally, as Niaz and colleagues showed, both textbooks inadequately represented how scientists have developed scientific knowledge in that for the most part, neither textbook included information on how scientists have developed scientific knowledge.

Nevertheless, there are some differences between the results from the present study and earlier research. Both textbooks analyzed in this study portrayed scientific methodology as a stepwise procedure. Additionally, neither of the two textbooks explicitly stated in the introductory portion of the student text that scientists do not follow a stepwise procedure, supporting Abd-El-Khalick et al.'s (2008) findings. However, both textbooks did include explicit statements in other portions of the textbook. *Physics: Principles and Problems* included a statement in the introductory portion of the teacher text, while *Holt Biology* included a statement in the appendix, contradicting Abd-El-Khalick et al.'s (2008) findings. Although this portrayal may create confusion for the reader, this finding suggests that these textbooks are beginning to show signs of improvement in how they address scientific methodology.

Results also showed that only *Physics: Principles and Problems* emphasized experiments as the primary approach to scientific investigations in the introductory section and throughout the text. *Holt Biology* explicitly stated that scientists cannot always conduct experiments, promoting the broad view. The text also placed more emphasis on the fact that there are multiple ways that scientists conduct research throughout the textbook.

Other than the introductory section, the majority of the rest of each textbook reviewed in this study implicitly promoted either the traditional or broad view. Regardless of how textbooks portrayed scientific methodology, they primarily did so implicitly, which is consistent with the findings in the Abd-El-Khalick et al. (2008) study. However, unlike previous research, the findings from the present study also showed that explicit references to scientific methodology do exist outside of the introductory section, even though most promoted the traditional view. Earlier studies did not report this most likely because they did not analyze the entire textbook. What makes this finding important is that research has shown that for understandings of the nature of science, including scientific methodology, to improve, one must experience explicit instruction (Abd-El-Khalick, Bell, & Lederman, 1998; Bell, Blair, Crawford, & Lederman, 2003; Bell, Mulvey, & Maeng, 2012; Kfishe & Abd-El-Khalick, 2002; Scharmann, Smith, James, & Jensen, 2005). While I am not arguing that just because textbooks have a few explicit references students will learn more, it does indicate that a more thorough analysis of the entire textbook is necessary to determine the full message presented to the reader.

While the results from the present study clearly illustrate how the rubric developed for this investigation was utilized to evaluate how textbooks present scientific methodology, more research is necessary. For example, results of the analysis of additional textbooks need to be shared (Binns, 2009; Binns & Bell, 2010). This will allow for a comparison of how other science textbooks, including additional biology and physics textbooks, present scientific methodology. Next, the rubric developed for this investigation should be used to evaluate additional instructional materials. Textbooks are not the only source that teachers use in the classroom, thus making it more important to also determine how other instructional materials present scientific methodology. Finally, efforts need to be made to contact authors and publishers about their materials. Encouraging the textbook publishing industry to improve how textbooks portray the work of scientists is a necessary part of this research. This not only includes how the textbooks introduce scientific methodology, this also includes the examples in the rest of the textbook. The goal for textbook authors and publishers should be to include a broad representation of the scientific endeavor, while the rest of the textbook includes an appropriate mix of explicit messages that there is not just one way of doing science.

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Chapter 13
Science and Science Teaching

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Introduction

Science is a term that has been used to describe both the body of knowledge (product) and the processes that are being used for developing and validating this accumulated knowledge. Processes and knowledge are necessarily integrated, because scientists use inductive and deductive processes to formulate laws, generalizations, and regularities that constitute the product of science. Both psychologists and science educators have been interested both in the product, or the individual knowledge about scientific concepts, and the processes that are being used to foster this knowledge acquisition and continuous revision. It is however unanimously concluded that learners' individual knowledge about science concepts and processes are necessarily influenced by the ways science teachers teach. These ways of teaching science have also impact and important implications on learners' lifelong abilities to educate themselves and solve real-life problems.

It is also acknowledged that science textbooks have important implications on the ways science is taught (i.e., inquiry-based or teacher-directed) and on the type of the classroom learning environment that is usually created (i.e., student- or teacher-centered) as well as on the ways that science knowledge is being assessed. From this perspective, the true manifestation of successful schooling is not how well learners perform in school-based assessments (Shymansky & Kyle, 1992), but rather the extent to which they develop scientific reasoning skills during the school years. The past decades have witnessed an increasing research on the development of learners' scientific reasoning skills that has been the goal of many reform efforts in science education. Scientific reasoning refers to the mental processes used when reasoning about the content of science or engaged in typical scientific activities and

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to specific types of reasoning that are frequently used in science (Dunbar & Fugelsang, 2005). Reasoning skills are also closely linked to attitudes towards science teaching and science in general.

Learners of any age develop their scientific reasoning skills when they are involved in inquiry tasks, such as scientific investigations. A scientific investigation broadly defined includes numerous procedural and conceptual activities, such as, theory generation, experiment design, hypothesis testing, control of variables, data interpretation, coordination of theory and evidence, evaluation of evidence, use of apparatus, statistical computations, modeling, and argumentation (Keys, 1995; Schauble, Glaser, Duschl, & Schulze, 1995; Zachos, Hick, Doane, & Sargent, 2000; Zimmerman, 2007). Due to this complexity, science educators had limited their scope by giving attention either on the procedural or on the conceptual aspects of scientific reasoning.

Klahr and Dunbar (1988; Klahr, 2000), on the other hand, developed an integrated model that incorporates domain-general strategies with domain-specific knowledge. This model conceives scientific reasoning as problem solving that is characterized as a guided search and information gathering task. The model is known as the Scientific Discovery as Dual Search (SDDS) model. According to this model, scientific discovery is a kind of circular or repetitive attempt and it is accomplished by a dual search process. The search takes place in two related problem spaces, namely, the hypothesis space and the experimental space. Searching the hypothesis space involves the process of generating new hypothesis based on some knowledge about the domain either as prior knowledge or as knowledge through experimentation. Searching the experimental space involves the performance of experiments that will yield interpretable results. Search in the two spaces is however mediated by a third process, the evidence evaluation process. Evaluation assesses the fit between theory and evidence, and guides further research in both the hypothesis and the experimental spaces. Although the original descriptions of SDDS model highlighted the "dual search," more recent descriptions acknowledge the coordination and integration of all three components as well as the blend of inductive and deductive processes (Klahr, 2000; Klahr & Li, 2005).

As a consequence, more recent research studies engaged students in all three phases of scientific activity (Keselman, 2003; Papageorgiou & Valanides, 2010; Schauble, 1996). This new paradigm of research in conducting scientific investigations is well known in the literature as self-directed experimentation research (Zimmerman, 2000, 2007). In self-directed experimentation research, individuals learn about a multivariable causal system through activities initiated and controlled exclusively by them. The results of these studies showed that science teaching should engage students in all three phases of scientific activities.

In the center of any scientific investigation is of course the ability to design fair and informative experiments by applying the control-of-variables strategy. Klahr and his colleagues (Chen & Klahr, 1999; Klahr & Li, 2006; Klahr & Nigam, 2004; Masnick & Klahr, 2003; Toth, Klahr, & Chen, 2000; Triona & Klahr, 2003) examined and compared the effects of different kind of instructions on the development of the control-of-variables ability. For example, the Chen and Klahr (1999) study examined the effect of direct and indirect instruction on the control-of-variables strategy (CVS). The results indicated that direct instruction was more effective in developing children's ability to design informative experiments. The results of the Klahr and Nigam (2003) study also favored direct instruction in order to help students develop the ability to design fair tests and to master the control-of-variables strategy. Klahr and Li (2005) explained that the terms direct instruction and discovery learning do not involve a difference between "active" and "passive" learning. In these studies and in both conditions, students were actively engaged in the design of their experiments and the physical manipulation of any necessary apparatus.

It is also unanimously acknowledged that the way children learn implies active participation by them so that they continuously identify effective connections among the new concepts and prior understandings or prior knowledge that already exist in the long-term memory. This is the basic principle of analogical reasoning and constructivistic learning as well. For example, in analogical reasoning, the learner maps a well-known domain (base) to a new one (target) by keeping their structural relationships. In other words, analogies are used to make the unfamiliar familiar. Gentner (1998) stated that theories of analogy distinguish the following processes when analogical reasoning takes place:

(a) As soon as a new concept is presented in the working memory, a similar or analogous example saved in the long-term memory is *retrieved*.
(b) While both cases are processed in the working memory, *mapping* of the common structures occurs.
(c) The effectiveness of the analogy is *evaluated*.
(d) The analogy is used in order to construct an *abstract structure* common to both analogs.
(e) One or both representations are *re-represented* in order to improve the match.

Any new concept can be characterized as an external situation to the brain that should be understood. According to Newton (2003), in order to understand a new concept (target), first it must be transformed into a mental representation. If the target is directly manipulated, then the results may not be the expected ones, so it is better to map it onto a mental representation of the analogous situation that already exists in the long-term memory. Then, a subsequent state of the analogous situation is generated, which may help the learner to better and correctly understand the new concept (Fig. 13.1).

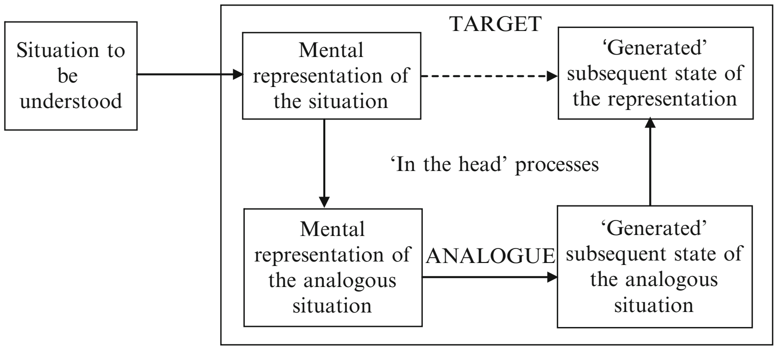

Fig. 13.1 The process of analogical reasoning (Newton, 2003, p. 354)

Analogies are used to help understanding of different kind of concepts across the curriculum. For example, Goswami (1986, 1988) tried to identify whether pupils can create their own analogies in order to pronounce correctly words with common syllable sequence. Hughes (1986) used Dienes cubes to help young pupils connect abstract concepts, such as addition and subtraction, with real items. Hewitt (1987) proposed that the flow of water in a pipe can be a very effective analogy for understanding the flow of electricity in wires. Rigas and Valanides (2008) investigated how verbal and pictorial analogies can promote learning of biological concepts, such as photosynthesis, the function of white blood cells, and the function of the animal cell, and concluded that the combined effect of textual and pictorial analogies contributed significantly to primary school pupils' comprehension of abstract scientific concepts. Although research emphasizes that the use of analogies in many subjects can facilitate learning, there is little evidence that analogies are presented in textbooks and especially in science textbooks (Newton, 2003).

Similarly, constructivistic teaching/learning emphasizes learners' prior understandings and active involvement in the process of learning. Accordingly, learners "*construct rather than absorb their ideas and they actively generate meaning from their experience*" (Bell, 1995, p. 23). This means that pupils construct their own meaning of what they receive via their senses by generating links between their preexisting knowledge and the new phenomena they attend to. So, science should be taught in whatever way to engage active involvement of learners, as this is most likely to make them feel willing to take on the serious intellectual work of reconstructing meaning and resolving any consequent cognitive disequilibrium (Gilbert, Osborne, & Fensham, 1982). In other words, learners should have opportunities to experience learning as conceptual change in order to modify, extend, or exchange their own ideas with the appropriate scientific ones. Driver, Guesne, and Tiberghien (1993) pointed out that pupils' ideas interact with information from the environment, and the new ideas, according to Piaget's theory, are assimilated by the learners. Then, these ideas interact with the cognitive structure that is already present in their minds, and, as a result, the structure is changed. This radical form of conceptual change is called accommodation and its product is a more advanced cognitive structure.

Apart from the use of analogies and constructivistic teaching/learning, recent studies also put a growing emphasis on the role of argumentation in science education (Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002; Erduran & Jimenez-Aleixandre, 2008). Argumentation should be a central process in science education, since it can help pupils to understand the epistemological bases of scientific practice. But, the production of arguments is not a natural process. According to Kuhn (1991), learners need to be taught through appropriate instructional interventions, task structuring, and modeling in order to produce appropriate and meaningful arguments. Even though learners may produce arguments in social settings, they usually find it difficult to do that in a science class, because they lack sufficient knowledge about science topics. So, science teaching must become a social activity, where learners of different age must learn how to defend their opinion by using valid arguments. By using arguments, learners develop their communication skills, metacognitive awareness, critical thinking, and understanding of the culture and practice of science and scientific literacy (Cavagnetto, 2010). So, In other words, learners should be educated through scientific and mainly socio-scientific argumentation to improve their social skills and acquire habits of mind, which can help them face problems in various cases of their everyday life, as future citizens of really democratic societies.

It should be also stressed that science is directly linked with technology and has important implications on modern society. Consequently, pupils should be able to use technological tools and to integrate ICT in class in order to reinforce their learning and understand, to a certain extent, the role of science and technology in transforming our globalized world. The use of ICT in learning was examined by many studies and a strong relationship between pupils' learning and use of ICT was found (Cox & Webb, 2004). This implies that if the right pedagogical approaches are used for integrating ICT in the learning environment, then learning can be supported and improved.

In science teaching, ICT may be used as a tool to access data, as a modeling or simulation tool, and as a communication tool (Webb, 2005). Science teaching needs to be reinforced either by using real evidence, i.e., by observing or interpreting the results of an experiment, or by simulating the microworld where scientific concepts can be found. According to Steinberg (2000), simulations are used only when conducting a real experiment is not possible or it is impractical. So, even though the use of ICT is well stressed, it is important to state that they should be used only when it is impossible to observe the real world. For example, when learning about the human circulatory system, the only way to explore it is by using simulations. Nevertheless, the integration of ICT in teaching/learning should be used for transforming the learning environment in ways that invest on tools affordances and manifest the added value of technology in teaching/learning, especially when ICT tools are employed by learners as cognitive tools (Angeli & Valanides, 2009). The effective use of ICT in science learning is evident in the results of international tests, such as PISA, where pupils whose ICT activity was connected with the educational process achieved higher scores (Kubiatko & Vlckova, 2010).

Textbook Analysis

Aligned with this framework, the present chapter investigated to what extent science textbooks in the Cyprus school curriculum adopt design principles that support the inquiry-based learning environments by emphasizing also objectives that are beyond subject-matter coverage and can foster the development of nature-of-science objectives and learners' epistemological and cognitive development. More specifically, the present textbook analysis focused on the set of science textbooks (teacher's book, textbook/worksheets, and evaluation sheets) for the sixth grade of the primary school. The analysis was however restricted to mainly investigate whether the specific set of textbooks emphasize effective and productive experimentation, the use of analogies and constructivistic teaching/learning approaches, the integration of ICT in the learning environment for fostering exploration, evidence-based argumentation, collaboration and communication, and to what extent the teaching/learning approaches invest on tools affordances that signify their added value in teaching and learning. More specifically, the following questions were systematically investigated, although, in some cases, only few of these questions were dealt with, depending of the specific content:

- Do textbooks encourage self-directed experimentation strategies or do they only propose totally structured experiments to verify existing knowledge?
- Do textbooks consider investigation as a combination of processes (a circular process), where the pupils are engaged in inductively formulating and deductively verifying hypotheses based on experimental results?
- Do textbooks foster the development of investigation skills, such as, the formulation of hypotheses and predictions, the use of apparatus, observations and collection and analysis of data, and evidence evaluation?
- Do textbooks promote pupils' understandings concerning fair testing by systematically applying the control-of-variables strategy?
- Do textbooks employ analogies where pupils may construct meaning of scientific concepts by identifying relationships with well-known familiar phenomena and concrete conceptualizations?
- Do textbooks offer opportunities for pupils to be engaged in evidence-based argumentative discussions concerning scientific or socio-scientific phenomena and processes?
- Do textbooks encourage the effective and efficient integration of ICT and their relevant affordances in the teaching/learning environment in science?

Science Textbooks in Primary Schools

The science textbooks presently used in primary schools in Cyprus were designed and developed during the years 1990–1997 by a group of primary school teachers with the help of secondary school teachers, who were recruited with the help of science teaching supervisors. The process was guided and continuously scaffolded by an expert in primary science from abroad (professor in Texas A&M University). The attempt also took into consideration the results of international studies, such as TIMSS (1995), and the need to emphasize objectives beyond content knowledge. Thus, the new books should pay enough attention to scientific reasoning skills, such as, observation, interpretation of observation, hypothesis formulation, identification and control of variables, experimental design, and interpretation of results, in order to help the pupils enrich their skills to solve problems. The attempted reform also put emphasis on the nature and processes of science and the way scientists work and defend their own ideas. Thus, the guidelines of the reform specified that the textbooks should emphasize inquiry teaching/learning and cooperative learning, where pupils are expected to be actively engaged in hands-on and especially minds-on activities, by doing science, instead of talking about science and insisting on one-way dissemination of information by the teachers themselves.

For each class, a set of three textbooks has been finally made available having the label "First steps in science." The idea was to have books where integrated science is presented, instead of different subject areas, as it is the case in the secondary school, where Physics, Chemistry, and Biology are taught as separate topics. The set of textbooks that has been made available for each class consists of:

(a) *Teachers' textbook*: It delineates a timetable to help the teacher organize the time he/she needs to teach each chapter, describes in detail all the activities and suggests answers to possible questions, provides valuable content knowledge for the teacher, and gives guidelines how to promote scientific reasoning skills. Special emphasis is given to the way experiments should be carried out (it provides information and alternative ways of how the materials can be used and how the experiments can be carried out).
(b) *Textbook/worksheets*: This is designed in the form of worksheets and the pupils can detach the specific worksheets that address the chapter that they specifically study. It contains questions or problems that should be answered or solved, respectively, and usually provides guidelines and instructions of how to carry out specific experiments by using specific materials. In some cases, the results of these experiments are connected with everyday life.
(c) *Evaluation sheets*: These are specifically designed for summative evaluation of the basic knowledge and the skills that are linked to each chapter. There is no reference of formative evaluation in any of the three textbooks.

According to the Ministry of Education and Culture of Cyprus (1996), science education must help pupils "(a) develop their inquiring mind and scientific approach in order to solve problems, (b) acquire scientific knowledge in order to comprehend themselves and the world that surrounds them, and (c) develop attitudes for proper appreciation of their environment in order to actively participate in activities that promote its preservation and improvement" (p. 145). The content knowledge that should be taught at the sixth grade includes heat, human muscular system, acids and alkalines, air pressure, lenses, human circulatory system, pressure, electricity, energy, human respiratory system, sound, and man in space.

For the purpose of the present analysis, only a sample of chapters from the books was used. The chapters in the selected sample represented concepts on Physics, Chemistry, and Biology. More particularly, the chapters concerning heat, acids and alkalines, the human circulatory system, and pressure were sampled for the analysis. In addition, the analysis was mainly guided by the previously stated questions and was extended to the set of materials from the three different sources of information, namely, the teachers' textbook, the worksheets, and the evaluation sheets. More specifically, the analysis initially focused on the teachers' textbook where there exist specific and detailed suggestions on how to teach the specific chapter in terms of time, sequence of activities, and involvement of both the teacher and the pupils themselves. The way of implementing these specific suggestions corresponds to the activities that are clearly described in pupils' textbooks (or the worksheets) that correspond to any specific chapter. The analysis was then extended to the evaluation sheets, as a way of confirming the extent to which different objectives have any priority at the expense of some other objectives.

Results

Pressure

The teachers' textbook clearly states that the chapter on pressure is designed to be covered in two 80-min teaching sessions. It also specifies that, during the first session, the factors that affect pressure should be investigated, while, during the second session, the concept of hydrostatic pressure will be similarly investigated by rather "structured" deductive approaches. Thus, the teachers' textbook proposes that the session should begin by asking a pupil to crack a walnut using his/her hands and then to crack two walnuts simultaneously. Following the specific approach, all the pupils are really expected to realize that it is easier to simultaneously crack two walnuts instead of one, provided that pupils can only use their own hands.

As a second step in this session, the teacher herself proposes to the pupils that they should consequently investigate the following question: "*Which factors affect the pressure of a solid body on a plane surface?*" Indirectly, the specific question tends to imply that all pupils, after the completion of the proposed activities and teacher's suggestions and clarifications, very easily and quickly can develop a correct conceptualization of pressure, and that they have the readiness to move on and investigate the factors that affect this totally abstract concept (pressure). Nevertheless, the textbook itself proposes the materials that should be used and provides detailed description of the activities that the pupils should perform.

More specifically, the pupils' worksheets instruct the pupils to use a matchbox filled with plasticine and a bigger container full with flour. They are then specifically guided to place the matchbox on the prepared plane surface of the flour. The pupils are also guided to estimate the "*amount of pressure*" that the matchbox exerts on the plane surface of the flour, by examining the depth of the imprints that appear on it. Later, the pupils are also explicitly instructed to add extra weight on the matchbox and compare the imprints on the plane surface of floor, with or without the extra weight on the matchbox. The students are consequently instructed to change the area of the same matchbox that touches the surface of the flour by changing its orientation, instead of adding additional weight, and comparatively examine the imprints that appear on the plain surface of the flour in each of the three cases. Then, pupils are asked to recognize which two factors they "*investigated*" and whether and how these factors affect the pressure of a solid (geometrical) body on a plane surface of flour, by just comparing the observable imprints on the flour surface. The pupils are then guided to summarize their conclusions and specify the two factors (the weight of the body and the area of the touching surfaces) and to write their appropriate conclusions in their worksheets. They are also guided to conclude that the pressure is proportional to the weight and inversely proportional to the area of the touching surfaces.

At the end of the lesson, some examples from everyday life, in the form of comics, are provided to the pupils, and they are asked to explain any observable results by applying the conclusions that they copied in their worksheets or the conclusions that are stated by the teacher or written by her on the blackboard. Specific visual comics present a camel that can easily walk in the dessert, while a horse cannot, or how someone equipped with skies is not sinking in the snow. For correctly answering these questions, only the application of "*memorized knowledge*" is needed. This does exclude any possibility for pupils to clarify their understandings and provide more credibility to their "*stated*" conclusions, while they may be also involved in some kind of evidence-based argumentation by defending their answers and attempting to reach commonly accepted answers.

The presented approach and the sequence of activities that pupils perform indicate a teacher-centered instruction, where the teacher controls everything and allocates activities to specific students, who, later on, through teacher questioning or suggestions, should reach a specific conclusion that they may report to the class, or the teacher may report and clarify the expected outcome, by clearly introducing the concept of pressure and the factors that implicate changes in the "*amount of pressure,*" depending on her own knowledge and understandings.

The same approach is adopted for introducing the concept of hydrostatic pressure. For example, the teacher textbook suggests to use a metallic tin (open from both sides), while, at its bottom, a balloon with no neck is tightly attached. Then, water is poured into the tin, and the pupils are expected to observe that the balloon is progressively inflated, due to the increasing hydrostatic pressure as more and more water is poured into the tin. Pupils are consequently asked to predict what will happen if the teacher continues to pour more water into the tin. The experiment is then demonstrated by the teacher, and pupils can observe and contrast their observations and their predictions. A consequent discussion among the pupils and the teacher is followed, where the teacher guides the pupils to conclude that water, as well as any other liquid, exerts pressure due to its own weight. Finally, the teacher explains to her pupils that the balloon is inflated, because water, and any other liquid, exerts pressure due to its weight. This pressure is subsequently named as hydrostatic pressure, without any further attempt to clarify its meaning and even justify why it is called hydrostatic.

Then, the teacher demonstrates successively two experiments that are described both in the teacher textbook and the pupils' worksheets. These two experiments are demonstrated by the teacher because, in the teachers' textbook, it is explicitly stated that both experiments cannot be easily performed by the pupils themselves. For the first experiment, a plastic bottle having three small and equal size holes along one of its vertical sides is used. The three holes are tightly closed with plasticine, and, then, water is poured into the bottle until it is full of water (Fig. 13.2). Then, the teacher removes the plasticine from the holes and students are expected to observe and compare how far the water is out-floating from each hole. The teacher facilitates a consequent discussion among the pupils and guides them, so that they finally conclude that the nearer the hole is to the bottom, the farther the water reaches as it outflows from each hole. The smaller the distance of the hole from the bottom of the bottle should be finally connected to higher hydrostatic pressure, due to the increasing amount of water and its weight above each hole.

In the second demonstration, the teacher uses two plastic funnels, with two balloons that each is attached at the mouth of the funnels (Fig. 13.3). Then, in each funnel,

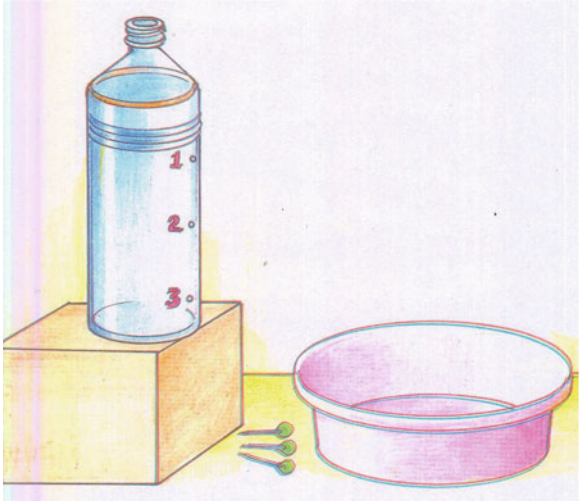

Fig. 13.2 The smaller the distance of the hole from the bottom, the higher the hydrostatic pressure is (Cyprus Ministry of Education and Culture (1997b, p. 52))

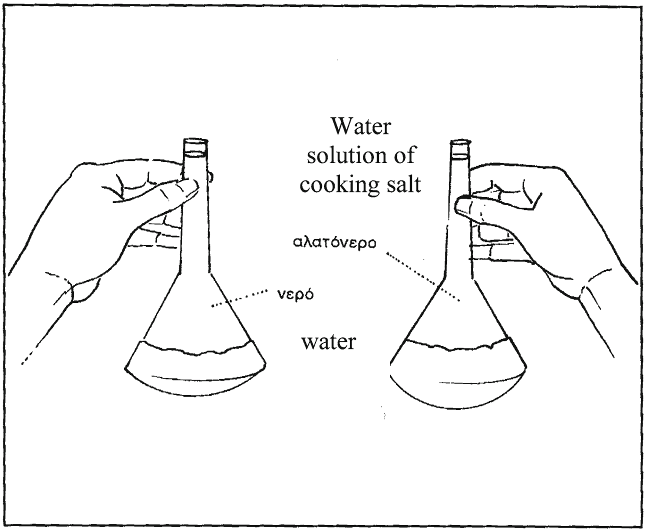

Fig. 13.3 One of the balloons is more inflated than the other (Cyprus Ministry of Education and Culture (1997a, p. 183))

a different water-like liquid is poured into, so both funnels are full of the water-like liquid. One of the liquids is water and the other one is a solution of salt into water, but this information is not given to the pupils. Pupils are expected to first observe that one of the balloons becomes more inflated than the other. Then, the teacher, based on the instructions from the textbook, invites the pupils to taste the water-like liquids and conclude that one of them is a water solution of cooking salt.

Then, the teacher moves on and performs the following experiment. She pours water in one glass container and water solution of cooking salt in another glass container, and then she puts an egg in each glass container (Fig. 13.4). The pupils observe that the egg floats in the water solution of cooking salt and the egg in the other glass, containing just tap water, sinks. The teacher involves the pupils in a consequent discussion, where she guides them to connect the two experiments and to reach the conclusion that the two liquids are different (their density is different) and that different liquids exert as well different "*amount*" of hydrostatic pressure, at the same depth inside the two funnels, due to their different density.

For controlling variables, the teachers' textbook instructs the teacher to use the same volume of the two liquids, but no discussion in the classroom, about the control of variables, is expected to take place. Then, the teacher herself guides, scaffolds, or even dictates the final conclusion that is always stated, almost verbatim, as follows: "hydrostatic pressure at a certain point in a liquid is affected by the density of the liquid and the depth of the specific point," or in a more explicit way, "*hydrostatic pressure in the liquid is proportional to the depth in the liquid and proportional to its density*." It is interesting to note that the phenomenon of sinking and floating is taught at the third grade, without using the concept of buoyancy and with experiments that use only tap water. Furthermore, the pupils have not been taught anything about the concept of density. These clarifications and the totally abstract concept of "*density*" indicate that the "*conclusions*" are simply stated by the teacher herself, and constitute rather a piece of declarative and inert knowledge.

Pupils are then guided to add liquid soap in a transparent glass half-filled with water and continue to stir it with a straw. They are consequently instructed to turn the straw upside down and to put it in a taller transparent glass full with water and confirm that a bubble is formed at the top side of the straw. Pupils are then instructed to vertically

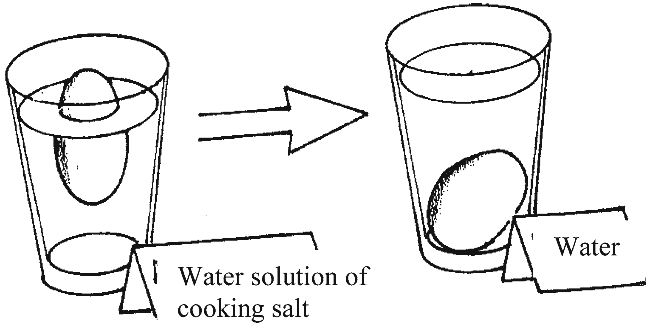

Fig. 13.4 The same egg floats only in one of the glass containers (Cyprus Ministry of Education and Culture (1997a, p. 184))

move the straw inside the glass and observe and compare the size of the bubble at different positions of the lower part of the straw (closer or farther from the bottom). The pupils are somehow guided to apply what they earlier "*learned*" and conclude that the size of the bubble is becoming smaller, the closer to the bottom of the taller glass, the lower point of the straw is, because the pressure is proportional to the depth inside the same liquid, since the density of the liquid does not change (Fig. 13.5).

At the end of the lesson, the teachers' textbook proposes two optional experiments, which are usually performed by the teacher. The first experiment shows that hydrostatic pressure is exerted in all directions. For this purpose, a balloon, which has several small holes, is applied on the mouth of a plastic bottle half-filled with water (Fig. 13.6). Then teacher turns over the bottle, and by pushing the bottle with her hands, pupils can observe that water outflows from the balloons' holes in different directions. The teacher, in a consequent discussion, attempts to explain that hydrostatic pressure is exerted not only on the bottom, but also on every point of the container in touch with water.

The second experiment helps pupils to understand that hydrostatic pressure at a certain point is not necessarily affected by the amount of liquid that there is above this specific point. For this experiment, two plastic bottles, similar to the one that was used in the previous experiment, are used. The bottles differ in their diameter, but not in height, and each of the bottles have one equal size hole at the same distance from the bottom. Both holes are closed with plasticine and then water is poured into them until they are full of water. Obviously, the bottle with the bigger diameter contains more water above its hole than the other bottle. Then, the teacher places the two bottles side by side and removes the plasticine from the holes. Pupils, probably contrary to their own expectations, observe that the water floats out at the same distance from the two holes. Prior to performing

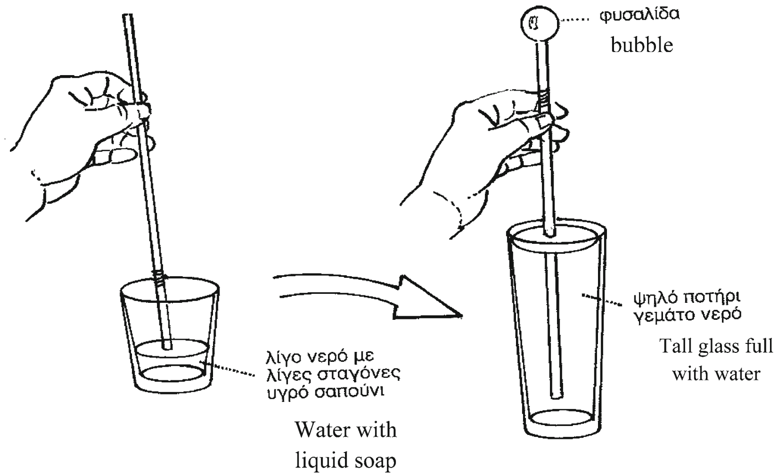

Fig. 13.5 The size of the bubble varies depending on the position of the lower point of the straw (Cyprus Ministry of Education and Culture (1997a, p. 186))

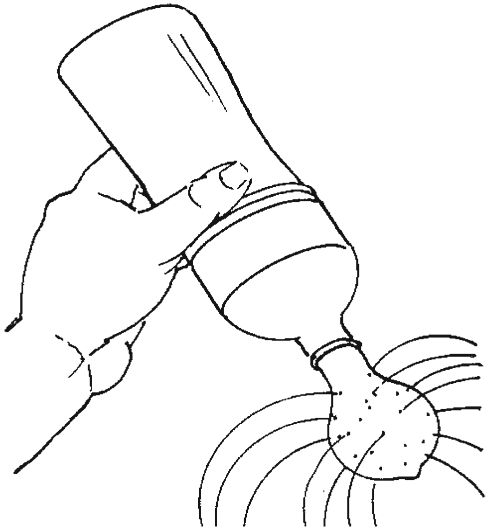

Fig. 13.6 The water outflows from the holes in different directions (Cyprus Ministry of Education and Culture (1997a, p. 186))

this experiment, pupils are not necessarily instructed to express orally their predictions, but the teachers' textbook provides suggestions for instructing the pupils to do so.

This is however the only point where there are suggestions for asking the pupils to state their ideas (predictions) prior to performing the experiment. Depending on pupils' ideas and their observations after the demonstration, a situation of cognitive conflict can be induced. Pupils may believe that hydrostatic pressure depends on the "*amount of water*" that exists above the hole, depending on the width of the bottle. Moreover, the examination of any factors (independent variables) that may affect hydrostatic pressure should be investigated with the other two factors, in order to help the pupils understand that only some variables are causal and can affect the hydrostatic pressure (the dependent variable).

At the end of the second lesson, pupils are expected to answer (complete) the evaluation sheets. All the questions demand pupils just to retrieve from their long-term memory what they "*learned*" about pressure and hydrostatic pressure, without any provisions to test for pupils' understanding. In the evaluation sheets, there is only one question that examines students' ability to perform a "*fair test*" by controlling variables. More particularly, three plastic bottles, similar to the ones that were used for the previous experiments, are presented on paper. The first two bottles have a hole at the same position from the bottom and the third one has a hole at a different position. In all cases, the holes are tightly closed with plasticine. In the relevant question, pupils have to decide which two of the bottles they should choose if they wanted to examine whether the position of the hole affects the outflow of water, as soon as they remove the plasticine that closes each of the three holes. In a second question, pupils have to decide which two bottles, among the three available, they should choose in order to investigate whether the diameter of any hole does not affect the outflow of water when they open it by removing the plasticine.

Acids and Alkalines

This chapter is also designed to be covered in two 80-min teaching sessions. During the first session, pupils are expected to be able to differentiate water solutions and categorize them as being either an acid or alkaline, by just using chemical indicators, and to justify the use of acids and alkalines in everyday life. Initially, the teacher invites the pupils to think and propose ways that can be employed for identifying the kind of liquid inside a container on the teacher's desk. Then, the teacher, after dividing the class into small groups, asks the pupils to place some water solutions and liquids in different transparent containers and instructs them to collaborate within their groups and put all the liquids into two discrete categories, by just using their senses of taste and touch. As soon as the pupils complete the specific task, the teacher initiates a discussion where all the pupils report and contrast their results, so that they finally agree upon the criteria they used.

Later, the teacher distributes to the groups pieces of litmus papers (blue and red), and following the detailed instructions of the relevant worksheet, pupils attempt to find out whether they can have the same two categories of liquids by using the changes in color of the litmus paper, when a piece of it is inserted in each liquid. After completing the specific activity, they are also instructed to answer the following question: "*What is the color of litmus solution after being inserted either in a sour liquid or in a slippery liquid?*" (Cyprus Ministry of Education and Culture, 1997b, p. 20). Pupils are always asked to follow step by step the sequence of instructions that are detailed in the relevant worksheets. The aim of this totally "*structured inquiry*" is to finally label any sour liquid as an acid and any slippery liquid as an alkaline. By the end of the first session, the teacher describes the use of the two categories of substances in everyday life and instructs the pupils to examine how an acid interacts with a piece of chalk and how an alkaline interacts with a small amount of butter. Finally, pupils are guided to prepare at home their own indicator (based on the relevant worksheet, the color of the indicators may vary, since different kind of flowers can be used), and how to use it for identifying a liquid as being either an acid or an alkaline.

At the beginning of the second session, the pupils are invited to present the indicator that they prepared at home prior to the session. Then, the teacher divides the class into small groups and invites the pupils to use their own indicator and realize that the color of the indicator changes depending on whether it is put into any acid or into any alkaline solution. During the second session, the pupils are also expected to use a liquid indicator and specify that when an acid and an alkaline come into contact, then a chemical change is occurring where the two substances interact between each other producing completely different products (neutralization) that also have quite different properties from the two initial substances, including how these affect the color of any chemical indicators. They can observe the changes in color as they are adding progressively drops of an acid into an alkaline solution containing a liquid indicator. For example, the pupils may be invited to answer the following question: "*What will happen when an alkaline solution is added drop by* *drop or little by little into an acid?*" (Cyprus Ministry of Education and Culture, 1997b, p. 23). The teacher distributes the necessary materials to every group of pupils and instructs them how to carry out the specific experiment.

The specific activity aims to help the pupils realize that when an acid is added in an alkaline, or vice versa, then they interact with each other and produce a totally new substance with quite different properties. The pupils can also realize that there may be either an excess of acid or alkaline by using their indicator and observing the color changes. The teacher describes then to the pupils that, in reality, a bee sting contains an acid and, consequently, an alkaline solution can be used on a bee sting to cancel its consequences, because of a consequent neutralization reaction. In a similar way, the teacher also explains why antiacid products (alkaline solutions) are used to overcome stomach sourness. The last worksheet describes a story of a girl who accidentally drank a dangerous alkaline that caused her many health problems. This manifests a clear attempt to sensitize the pupils of the dangers that are always associated with the use of unknown liquid, solid, or gaseous substances.

The teachers' textbook guides the pupils to be engaged in hands-on activities, but they are not encouraged to simultaneously be engaged in minds-on activities, by reflecting and even questioning the way they work and the conclusions they reach. More emphasis is put on justifying certain conclusions that are needed for providing correct answers to the questions of the evaluation sheets. Most questions in the evaluation sheets emphasize the memorization of content knowledge and neglect to mainly evaluate any of the many processes that should be used and the reasoning skills of the pupils. For example, pupils are asked to memorize some liquids as being either an acid or an alkaline, and they are also asked to state definitions associated with the concepts of indicators, acids, or alkalines. Pupils are also trained to describe a way of finding out whether an unknown liquid is an acid or an alkaline, by just memorizing the use of indicators and the changes in their color, depending on whether they are put into an alkaline or acid solution.

Heat

The chapter on "heat" is also designed to be taught in three 80-min sessions and the first session deals with the transfer of heat by conduction. At the beginning of the session, the teacher holds a metallic spoon close enough to the flame of a burning candle and asks the pupils to predict what will happen in a few minutes, and then also explain how and why the other end of the spoon is heated, although the flame is close to its other end.

The teacher does not make any suggestions or comments to the pupils' expectations, but she just informs them that they will understand that heat travels in solid bodies. Following that, the pupils read specific instructions listed in the relevant worksheet and perform the following activity. They use a tin and they stick a strip of copper on it, holding it in a horizontal direction (Fig. 13.7). Then, by using vaseline, they hang along the wire two pins in different distances from the tin.

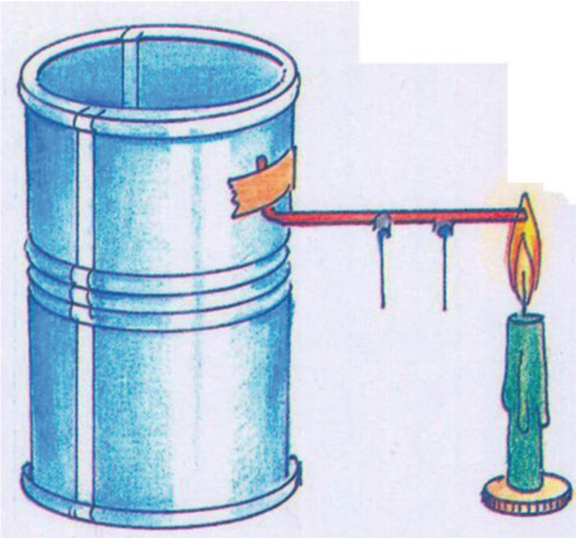

Fig. 13.7 The lesser the distance of vaseline from the heating source, the quicker it melts (Cyprus Ministry of Education and Culture (1997b, p. 6))

They then heat the wire using a candle, which is placed under the other end of the wire. Following that, they repeat the same experiment by adding now hot water inside the tin, instead of using the candle.

After observing the two experiments and collecting evidence of the way pins drop from the copper wire, the teacher initiates a discussion among the pupils to explain and justify their observations. More specifically, pupils are guided and challenged to justify why the two pins drop from the copper wire in a different sequence during the first and second experiment. The answer relates to the distance of the vaseline that holds the two pins from the heating source. The lesser the distance of the Vaseline is from the heating source, the quicker it melts and frees the attached pin. Pupils conclude that heat somehow travels via the solid wire in a different direction starting always from the source of heat. The teacher involves the pupils in a consequent discussion, where she guides them to realize the "*travel of heat*" across the solid wire, while the teacher offers the term "*conduction*" of heat. According to teachers' textbook, the heat transfers from point to point inside a solid body, moving always from the warmer to a less warm point and this is called "*conduction of heat*." After completing the previous tasks, the pupils are called upon to decide "*Which materials are good conductors of heat*." They are then guided to perform another "*structured experiment,*" using the same tin from the previous experiments.

Pupils are given detailed instructions stating that they should stick more materials at different positions around the tin, namely, a nail, a tooth stick, a plastic stick, a steel wire, a chalk, a cardboard strip, and a strip of aluminum foil (Fig. 13.8). They are also specifically guided to hang one pin on each material, by using the same amount of Vaseline at the same distance from the tin for each material, so that their results will be comparable. The pupils pour into the tin hot water and they observe the outcomes of the specific experiment. They are also involved in a discussion,

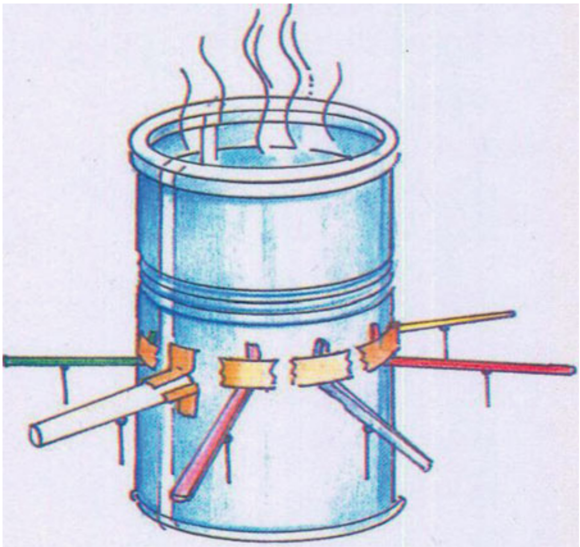

Fig. 13.8 Testing for good and bad thermal conductors (Cyprus Ministry of Education and Culture (1997b, p. 8))

dominated by the teacher, in an attempt to categorize the materials into good conductors and insulators (bad conductors) of heat. Pupils are then asked to find an appropriate answer to the following question: "*Among the good conductors, which materials allow the heat to travel faster or which of them are better conductors than the others?*" This is the only case where the pupils are expected to propose their own ways of experimenting, and design and perform an experiment by themselves. Nevertheless, the teachers' textbook clearly suggests that the pupils are only expected to use the same experimental device that was used earlier and to hang similar pins only on those materials that were identified as good conductors. The textbook and consequently the teacher guides the pupils to also measure the time needed for each pin to drop from the different materials.

At the end of the session, several objects usually used in everyday life activities are presented and the pupils are asked to comment about the substances (materials) they are made of, and mainly provide appropriate and informed justifications for the choice of the specific material in each case. For example, why the handle of a pan is made of a plastic, or wooden material, while the whole pan is made of a metallic substance (material).

This specific lesson also follows a "structured" investigation, where the pupils are only expected to follow step-by-step instructions, and perform experiments that are predetermined and can lead only to the confirmation of specific generalizations or well-accepted "truths." The only deviation from this orientation relates to the last experiment, where pupils are expected to take some initiative and propose their own experiments and ideas, although the teachers' textbook specifies and restricts the way pupils can perform. Moreover, the description of the specific lesson suggests that pupils should be involved in a discussion relating to the need and importance of identifying and controlling variables in any experiment, in order for any conclusions to be valid. Nevertheless, it seems that pupils are not engaged in minds-on reflections and applications of the specific ability. All the relevant suggestions, and, in most cases, without justifications, are offered by the teacher, while, in some cases, relevant variables are not taken into consideration or are totally ignored. For example, the dimensions (size) of the different materials that are stacked on the tin are not even discussed (Fig. 13.8).

The second 80-min session concerning heat is titled "*how heat is transferred in liquids and gases*." Pupils are again expected to perform another experiment following step-by-step instructions that are explicitly described in their worksheets and the teachers' textbook. They are thus guided to use a glass tube half-filled with water and to add some sawdust in the water. Then, they are instructed to heat the bottom of the tube by using the flame of a candle. The pupils are also guided to observe the movement of the pieces of sawdust in the water and connect it to the movement of the water inside the tube. They are also guided to repeat the experiment with another similar tube, but they do not heat the bottom of the tube, but they instead heat the tube closer to the surface of the water. By comparing their observations, pupils realize that they cannot observe the same movement of the floating pieces of the sawdust. The teacher again initiates a consequent discussion, where the pupils are similarly guided to explain their observations, and reach at the expected and clearly stated conclusion in the teachers' textbook. The teacher is mainly responsible for stating and justifying the conclusion, by explaining that as the water becomes hotter, it also becomes lighter and moves up, while cold water moves down, so that there is a constant movement inside the tube from the bottom to the surface and from the surface to the bottom. The moving water carries the pieces of sawdust, so that these participate in the same constant movement. This constant movement depends on whether we continue heating the bottom of the tube, so that the temperature of the water next to the bottom is kept higher than the corresponding temperature of the water at the surface of the tube. The discussion between the teacher and the pupils focuses on understanding that hot water from the bottom moves upwards to replace cold water, which consequently moves downwards. Thus, the moving water carries as well heat from the bottom to the surface, or the other parts, of the tube, while this way of transferring heat is termed convection of heat.

Finally, the evaluation sheets include evaluation items where the pupils are just expected to remember and use certain definitions or necessary rules. For example, students are only expected to select the appropriate terms from the following written statement and delete those terms that do not fit an appropriate and correct explanation. This written statement is as follows: "*When the water is heated, it becomes heavier/lighter, and it goes up/down…*" The pupils are expected to just delete the words heavier and down, so that they provide the correct answer. Interestingly, the book proposes the idea that by heating, the water becomes lighter, without even clarifying the real meaning of the specific statement. This statement may become the source of several alternative conceptions among young pupils, including the misconception among primary school pupils, who usually believe that a container full of a liquid becomes lighter after increasing its temperature. Obviously, in this specific lesson, the concepts of weight and density are not totally differentiated, and, especially for pupils at this age, this can become a source of relevant misconceptions.

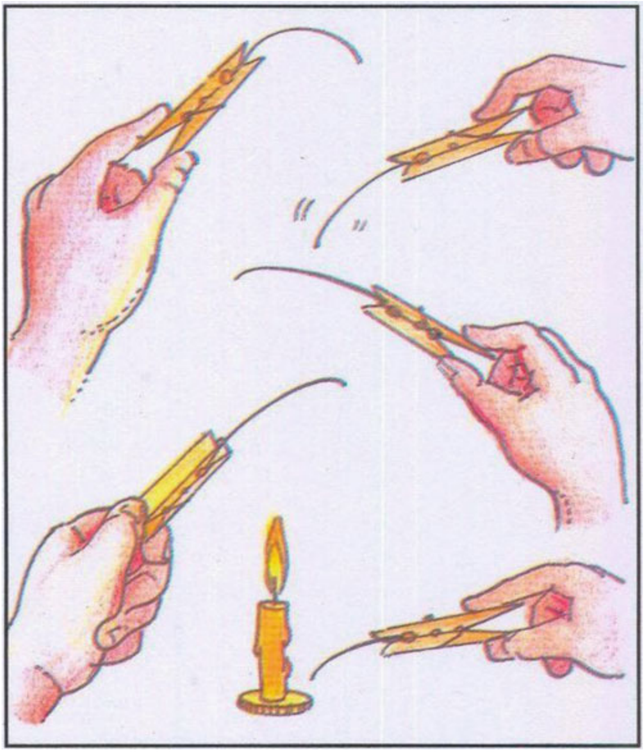

Fig. 13.9 The movement of air around the flame of the candle (Cyprus Ministry of Education and Culture (1997b, p.11))

In the teachers' textbook, another very specific experiment is also proposed, for studying how heat is transferred in the air. Pupils use a candle and each of them holds a thin strip of aluminum foil held by a clothespin in different positions around the flame of the candle (Fig. 13.9). The moving hot air causes the aluminum foils to move. The pupils may notice the intense movement of foils (the air) above the area of the flame and nearly no movement on its sides. In a consequent discussion, the teacher should guide the pupils to connect the movement of the air with the movement of water in the previous experiment and, by one way or another, to conclude that the moving air also transfers heat by convection.

The teachers' textbook also provides instructions for the teacher on how to demonstrate and explain the transfer of heat by radiation. Thus, the teacher lights up a lamp covered by a lampshade and the pupils by approaching the lamp with their hands may feel the heat from the lamp in any direction around it. Then, they are again guided to discuss and conclude that heat is also transferred around the lamp, not only above it, where the air is moving upwards, since they are instructed not to touch any part of the lamp. The teacher finally provides the information that this time heat transfers by radiation. The pupils are consequently guided to connect radiation with the way heat from the sun reaches the earth and that, in the case of radiation, heat can be transferred even through space that does not include any material substance (vacuum).

The third and final session allocated for the study of heat relates to the thermal insulating properties of different materials. Based on instructions in the teachers' textbook, the teacher initiates a discussion about winter and summer clothes, and the pupils are guided to realize why winter clothes prevent, to a certain extent, the heat of the human body to escape by somehow "*trapping*" it, and the term "*thermal insulating materials*" is offered as a label for such materials. Then, the teacher presents to the class several materials and the pupils are instructed to identify among them the one having the best thermal insulating properties. These materials, based on the instructions in the teachers' textbook, are synthetic fabric, wool fabric, newspaper, aluminum foil, cotton, and napkins. The teacher divides the class into small groups and each group is instructed to use a tin and wrap it with one of the materials mentioned above, so that each group of students uses a different material. Then, the teacher herself pours hot water in each of the tins and, using a thermometer, the pupils are instructed to measure the temperature of the water inside the tin, both as soon as the teacher pours the hot water in it and after 15 min. Prior to these experiments, the teacher initiates a discussion by inviting the pupils to think and propose different factors (variables) that may affect the transfer of heat from the tin to the environment. The teacher guides the pupils to realize that the results cannot be valid and comparable, unless they control other variables, such as, the initial temperature of the water, the amount of water, and the thickness of the material, that may influence the final temperature inside the tin.

Following the specific experiments, the teacher finally presents a picture of a house that is thermally insulated, and asks the pupils to propose and explain various ways that can help to reduce the energy loss from any house. At the end of the lesson, pupils play a relevant board game, where all the players have a pawn and they move forward using a dice and the numbers on it, which indicate how many steps one should move on. On the board, there are white, green, and red numbered squares. When a player reaches a white square, he/she has to wait for the next round; when the player reaches a red square, she/he has to answer a question from a red card; and when the player reaches a green square, she/he has to answer a question from the green cards. On each red card, an object, such as "oven mitts" or a material, such as "silver," is written and the pupils have to decide whether the specific object or material is either a conductor or an insulator of heat. On each green card, there is a sentence that describes one of the three ways of heat transfer and the pupils have to provide the right answer. For example, on a green card is written that: "*This is the only way that heat transfers in vacuum*," and the pupils have to recognize that this sentence describes the transfer of heat by radiation, in order to continue playing. For any wrong answers, the player loses its turn and has to wait his/her next turn to continue playing.

This can be considered as an enjoyable game that can be used for evaluation purposes, although it mainly requires recall of previously stated information or specific knowledge. This is also obvious and for the evaluation sheets, where there are questions that require only recall of information. There exists however only one question where they have to apply the knowledge in an everyday life context. This specific question requires from the pupils to decide which of two materials (aluminum foil or a napkin) is the best for wrapping a hot sandwich in order to keep it as warm as possible.

Human Circulatory System

The time allocated for the human circulatory system is also scheduled for two 80-min teaching sessions. During the first session, pupils study the structure of the heart, how it is functioning, and its role for the human body. Initially, the teacher guides the pupils to identify on their body the approximate position of the heart and to also identify the heart on a diagram of the human body. Then, they are also asked to examine whether they can feel their pulse in other parts of their body beyond their chest. The teacher consequently guides them to locate other areas of their body where they can also feel their pulse, such as, their wrist, their neck next to their jaw, and their ankle. As an extension to the previous activity, pupils are then invited to answer the following question: "*Since the heart is situated in the area of our chest, why can we feel our pulse in other areas of our body?*" (Cyprus Ministry of Education and Culture, 1997a, p. 153).

The pupils are successively guided to examine and feel their pulse around their wrist and then to justify how the heartbeat can be felt to several areas of their body. They are thus guided to identify some blood vessels (veins), which can be easily recognized under their skin, as a way of helping them to provide an appropriate answer. The next activity relates to the size of human heart. The teacher presents the drawings of three hearts that differ in size stating that each one is from a different animal. Pupils are thus expected to be involved in a consequent discussion and finally connect the size of the heart to the size of the body of each animal. Then, the teacher informs the pupils that the size of the human heart is approximately equal to the size of the fist of the respective person, while she presents a drawing of the model of the heart. Pupils are instructed to carefully study the different parts of the heart using the information that is accompanying a diagram of the heart in their worksheets (Fig. 13.10).

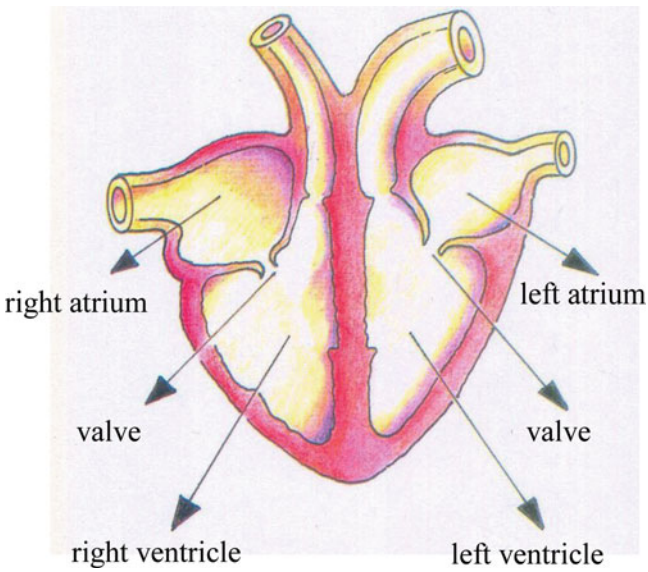

Fig. 13.10 The different parts of the heart (Cyprus Ministry of Education and Culture (1997b, p. 43))

Then, the teacher presents and clarifies the relevant information using an appropriate plastic model of the heart, where pupils can observe all the different parts of the real human heart. At the end of the session, the pupils working in groups are guided by the teacher to draw the heart on the outline of a real human body that was drawn using the body of one of their classmates. The main purpose of this activity is to finally guide the pupils to draw the heart on the correct position of the body and recognize its relevant size.

In the second session, the pupils focus on the pulmonary circulation and the systemic blood circulation. The teacher tries to help the pupils recognize how the blood is transferred from the heart to every single part of the body and then back to the heart, and how this continuous movement of the blood is supported by the heart (Fig. 13.11). At the same time, pupils are also introduced to the different substances in the blood and examine their specific role in the human body. Initially, the teacher uses one of the previously prepared drawings in order to remind the pupils about the correct position of the heart in the human body and its relevant size. The teacher also informs them that they will continue examining the crucial role of the heart for the circulation of the blood in the human body and why the blood circulation is vital.

Immediately after these introductory activities, the teacher asks the pupils to think and answer a very specific question: "*How many times does the heart beat in one minute?*" (Cyprus Ministry of Education and Culture, 1997a, p. 157). Then the pupils are guided to move on and have appropriate measures so that they finally recognize that the heartbeat of children is faster than the heartbeat of any adult. The pupils should also somehow be sensitized and recognize that the heart never stops functioning, except in the case of death. The teacher introduces then an analogy concerning the functioning of the heart, by stating that the heart's functioning resembles a water pump, and helps them to understand how the heart circulates blood to every single part of the body. Later, using the relevant worksheets from their textbooks, pupils are guided to differentiate and understand the role of different blood vessels (arteries, veins, and capillary).

The teacher then instructs the pupils to use their relevant worksheets that represent and describe in a form of a diagram the systemic circulation of the blood (Fig. 13.11). In the diagram, there is information describing how the blood rich in oxygen travels from the heart to the body and how the same blood rich in carbon dioxide returns to the heart. The teacher guides the pupils to realize that some vessels in the diagram are colored blue and others are colored red. Pupils by just studying the relevant information on the worksheet that provides information about the pulmonary circulation of the blood should be able to connect the two colors to arteries and veins. The teacher then provides additional explanations concerning the difference between the red and the blue vessels (the red vessels carry blood rich in oxygen from the lungs and the blue vessels carry blood rich in carbon dioxide to the lungs), and clarifies any gaps in pupils' understandings through a relevant discussion guided by teachers' questioning.

The pupils are guided to study several additional worksheets, and consolidate their knowledge and understanding concerning the following specific information, namely, (a) red blood cells carry oxygen to every single part of the body and carbon

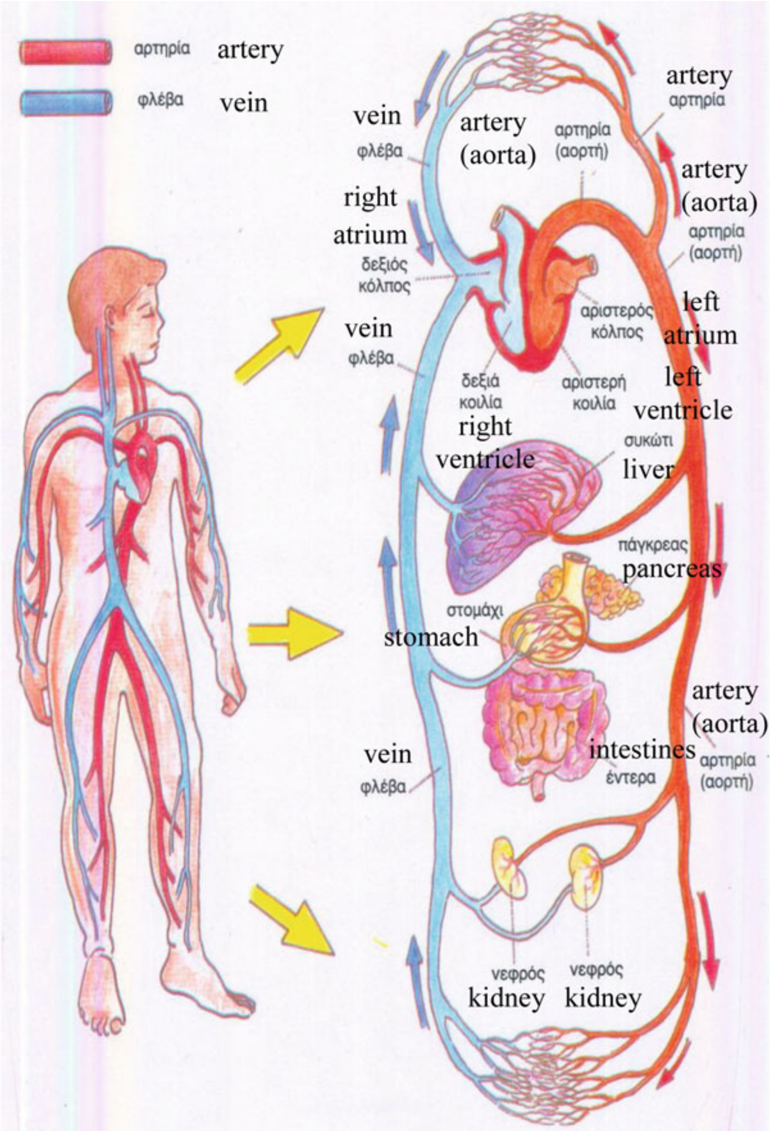

Fig. 13.11 The systemic circulation of the blood (Cyprus Ministry of Education and Culture of Cyprus (1997b, p. 45))

dioxide to the lungs, where it is extracted outside the body; (b) white blood cells fight germs that invade the body; (c) platelets help blood to clot; and (d) blood carries nutrients to every part of the body.

During the next activity, the teacher presents to the whole class a diagram representing two blood vessels, where, in the inner surface of only one of them, a lot of fat has been accumulated. The teacher uses the diagram and, guiding a discussion among the pupils, helps them to realize that the modern way of living (excessive eating and absence of physical exercise) may affect the human circulatory system, causing several and severe health problems. Lastly, the teacher instructs the pupils to draw the main parts of the pulmonary and the systemic circulation of the blood on the diagram of the whole body that was prepared earlier and later present the information in the class.

It is obvious that the chapter is not aligned with a constructivistic way of teaching/learning. Pupils' ideas are not investigated in order to use them to construct the new unknown concepts. The teacher is expected to behave as an instructor and not as a mediator of knowledge. All the concepts are given to the pupils without giving them the opportunity to test and modify their existing knowledge and understandings.

It is noticeable that the teachers' textbook suggests the use of a relevant software concerning the circulatory system, but there are no indications or instructions of how the software should be used. This suggestion seems to indicate a welcome initial response to the political demand for integrating ICT in the teaching/learning environment, and the associated investment on buying and installing of both the necessary hardware and the accompanied software as well. It does not however indicate any significant institutional and professional changes compatible with the idea of transforming the educational system by investing on ICT-rich affordances.

In the evaluation sheets, the pupils are expected to fill in a diagram where the parts of the heart are presented, to fill in some sentences concerning the pulmonary and systemic circulation of the blood, to identify whether certain eating habits are healthy or unhealthy for the human circulatory system, and finally to write the basic functions of blood substances. It is obvious that only the content knowledge is evaluated, while there is no reference on evaluating any kind of investigation or other kind of skills.

Conclusions and Discussion

The descriptive textbook analysis of the specific random sample of chapters was not restricted to the teachers' textbook. On the contrary, it included both the main activities that are presented and clearly described in the pupils' worksheets and the questions/problems that appear in the evaluation sheets. The attempt was guided by some a priori questions and a coordinated effort to somehow triangulate the results and find out any correspondence among the three sources of information that were available (i.e., the teachers' textbook, the students' worksheets, and the evaluation sheets).

The accumulated evidence from the present analysis clearly indicates that the presently used textbooks were guided by an innovative reform policy, but, contrary, to the any expectations, they did not trigger real reform in the teaching of science at the primary school. More emphasis is given to rather delivering information instead of developing other important objectives. All the information in the teachers' textbooks provides guidelines and useful information of "*how to teach pupils*" and mainly promotes teacher-centered or teacher-directed approaches. The content of these textbooks, in conjunction with the worksheets and the evaluation sheets, does not take into consideration "*how children learn*," while it does address the need to develop pupils' reasoning and investigation skills. Pupils are involved in some kind of very "*structured*" experiments, where they are just expected to follow detailed and step-by-step guidelines, and mechanistically perform the proposed "*experiments*." Pupils are not also offered any opportunities to even discuss or comment on the whole experiments or parts of them, and reflect on how and why they follow certain approaches.

The performed hands-on activities do not encourage pupils' initiative, creativity, imagination, and epistemological development and are mainly restricted to experiments that can only deductively confirm existing knowledge and "*truths*," as these are exemplified by the teachers' textbook or stated by the teachers themselves. The different "*experiments*," as they are presented in the textbooks, do not provide opportunities for the pupils to inductively formulate and deductively verify hypotheses, based on evidence from experimental tests proposed by pupils themselves. Communication among the pupils is nonexistent and pupils are not provided opportunities to express and experimentally test their ideas about the phenomena they study. Thus, the learning environment does not invest on pupils' initial ideas, and pupils are rarely involved in argumentative discussions and consequent experimentation for collecting relevant evidence concerning their preconceptions and claims. On the contrary, they are guided, for example, to implicitly apply the control-of-variables strategy and perform experiments that are exclusively prearranged for them. They are not also offered any opportunities to negotiate and construct meaning and clear understanding from the activities that are mechanistically performed by themselves or demonstrated for them. Finally, any conclusions seem to be arbitrarily stated "*truths*" that pupils need to memorize and remember them for correctly answering the questions included in the evaluation sheets. These activities do not foster the development of any objectives aligned with the nature of science and pupils' reasoning and investigation abilities. Papageorgiou and Valanides (2010) examined fourth- and sixth-grade pupils' investigation abilities and problem-solving strategies. The results of this recent study indicated that both fourth- and sixth-grade pupils could not effectively apply the "*control-of-variables*" ability; they did not exhibit advanced ability to coordinate their hypotheses (theory) with evidence; they were usually performing random experiments, only few of them conducted experiments for testing previously stated hypotheses; and they rarely changed their hypotheses when they had contradictory data.

Furthermore, the analysis of the books shows that pupils' thinking, imagination, creativity and initiative are not called upon, while every group and every individual pupil should follow prespecified rules and perform identical experiments, and should always reach the same conclusions at exactly the same time period. They are thus restricted to only observe under restricted circumstances, and it is not clear whether they really appreciate the value of any careful and selective observation and how the evidence from their observations can be recorded and organized in order to reach certain tentative generalizations or conclusions. The described experiments provide always expected outcomes and pupils collect mainly confirming evidence, leading to unanimously accepted and unchanged "truths," contrary to the real nature of science and its associated activities.

The implied teaching approach is slightly different from the one-way dissemination of canned knowledge and understanding, but deviates from both the guidelines of constructivistic teaching/learning approaches and the real nature of science as well. Obviously, there are no suggestions for even investigating pupils' initial knowledge and understandings about the scientific concepts, or how the scientific concepts are used in everyday language and communication among people. Moreover, the emphasis on memorized knowledge that is divorced from real understanding and correct conceptualization, which are associated with the active construction of meaning by the learners themselves, is clearly shown in the evaluation sheets where there are mainly questions that require recall of knowledge and information.

The integration of ICT in the teaching/learning environment does not seem to be a priority, and there are no signs indicating when, how and why teachers may invest on tools and their affordances for scaffolding pupils' thinking and construction of meaning and understanding. Some concepts in the science curriculum cannot be investigated using real materials and experimentation, and constitute totally abstract concepts that primary school children face difficulties to correctly conceptualize them, and teachers face difficulties to teach them. These abstract concepts or phenomena can be better presented by investing on tools' affordances (i.e., using simulations, models, and other visualizations). This is a real challenge that textbooks do not tap on. This challenge does not just relate to textbooks but the teachers themselves, since the presently used textbooks implicitly consider teachers to be digital immigrants, if not digitally illiterate as well.

Textbooks, worksheets and evaluation sheets seem to put emphasis on the one-way delivery of information and well-known truths, or inert knowledge, by emphasizing coverage of subject matter and neglecting the nature of science and other important objectives, such as, the development of pupils' reasoning and the acquisition of argumentative skills and analogical reasoning to construct meaning. Teaching analogies are not frequently employed, while, on the other hand, when analogies are employed, for example, the function of the human heart resembles a water pump, they are not appropriately and efficiently used to promote learning and understanding. Rigas and Valanides (2008) provide evidence indicating that the use of appropriately selected and exemplified analogies can promote better learning and understanding. For example, white blood cells can be presented as soldiers who defend their country, when an invasion occurs. The soldiers fight the enemy (germs) and defend their country (human body), and, in case of a stronger enemy, the soldiers can even call several allies (drugs) for further help.

The use of analogies and the integration of ICT in the teaching/learning environment are not a priority, despite the research evidence supporting the use of analogies and the added value of ICT, especially for young pupils who are still in the process of continuous cognitive development and do not yet acquire the necessary reasoning skills of formal learners and the habits of mine that are closely linked to experimenting and reasoning as scientists do. Besides, when trying to teach abstract concepts, such as pressure, heat and how it is transferred, and the human circulatory system, it seems quite obvious that several analogies and ICT affordances can be easily employed to make the abstract concepts learnable, by referring to concrete and well-known analogies or by visualizing invisible concepts or phenomena.

More importantly, the analogies and ICT, coupled with hands-on and minds-on activities, and opportunities for students to express and test their own ideas and engage in debates and argumentative discussions, seem to be effective approaches for encouraging primary school children to be engaged in active learning and developing habits of mind (i.e., learning to learn, decision making, critical thinking, etc.) that promote lifelong learning and active citizenry.

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Chapter 14
Content Analysis of Diagrams in Secondary School Science Textbooks

Yang Liu and David F. Treagust

Introduction

Visualization in Science Education

Visual representations are powerful tools for providing learners with explanations of natural science phenomena. Visualizing and understanding a wide range of scientific phenomena are therefore central to facilitating the learners' biological conceptual learning. Among visual representations, diagrams were found critically important in conveying both abstract and concrete information (Pozzer & Roth, 2003; Roth, Bowen, & McGinn, 1999). Many science teachers report that they frequently use diagrams in their instruction because diagrams can greatly help build students' understanding in various ways (Pozzer-Ardenghi & Roth, 2005). Well-illustrated diagrams can help students visualize complex scientific and biological phenomena which are often hidden from their direct observations or experiences (Buckley, 2000). Diagrams reduce the amount of cognitive effort to solve equivalent science problems (Ainsworth, 2006) and they can limit the ambiguity of textual explanation of science concepts (Stenning, Cox, & Oberlander, 1995).

An earlier study of biology textbooks found that there are on average 0.55–0.78 photographs, 0.19–0.22 diagrams, and 0.18–0.23 naturalistic drawings per page (Pozzer & Roth, 2003). The interpretation of diagrams may be a demanding task for students. Pozzer and Roth reported that students may have difficulties when interpreting illustrations in biology textbooks; for example, multiple objects are always shown in one image, multiple related images are contained in one figure, and

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the color coding, arrows, or numbering are used without explanation. Recently, Cromley and her colleagues (2010) followed Roth et al.'s ontology of graphs and further investigated some particular visual representations such as naturalistic drawings, line diagrams, and flow charts in biology and geoscience textbooks. These authors also argued that different domain knowledge and conventional rules used in the images could have an impact on students' learning.

Diagrams can depict scientific phenomena and processes that are invisible to the naked eye. As one of the important representational formats used in science education, an increasing number of studies are investigating how diagrams are used in secondary science and particularly in biology teaching and learning (Tytler, Waldrip, & Griffiths, 2004). Diagrams not only show various amount of abstract information but also omit irrelevant detail of the concept being taught. It is therefore important to analyze the content and the distribution of different types of diagrams in secondary science and biology textbooks and thereby determine any uniformity of the frequency of usage.

Types of Diagrams

There are several perspectives on classifying the visual representations used in science textbooks. For example, Pozzer and Roth (2003) categorized all kinds of illustrations in biology textbooks on a continuum from least to most abstract – including photographs, naturalistic drawings, maps and diagrams, graphs and tables, and equations. *Photographs* are considered to be able to include large amounts of detail, which make them powerful representations of real-world phenomena. *Naturalistic drawings* resemble drawn versions of photographs with some detail removed. Both photographs and naturalistic drawings are isomorphic with the objects they depict (Arsenault, Smith, & Beauchamp, 2006); the representations provided by both photographs and naturalistic drawings enable their interpretation comprehensible to students and lay people. *Maps and diagrams* omit irrelevant detail but can depict objects or processes operating at a scale that would either be invisible to the naked eye or otherwise require additional interpretation by readers (Houts, Doak, Doak, & Loscalzo, 2006). Since diagrams are extremely varied, the learner is required to interpret abstract visual conventions and realistic detail correctly (Butcher, 2006). *Graphs and tables* usually show relationships between items or steps in a process. Graphs and charts also exist in various forms, such as line charts and histograms. *Equations* are useful for representing the most abstract information, for instance, the chemicals involved in chemical equilibrium and also formulas in physics. The above-mentioned diagrams also could be presented in combination when illustrating scientific concepts.

In building on the categorization of diagrams proposed by Hegarty, Carpenter, and Just (1991), Novick (2006) emphasized the importance of teaching diagrammatic literacy to improve students' learning of science concepts. Earlier, Hegarty et al. had examined the use of diagrams in scientific contexts, especially in biology teaching, and categorized scientific diagrams into three categories – *iconic*, *schematic*, and *charts and graphs*. An *iconic* diagram refers to an accurate depiction of concrete objects in which the spatial relations in the diagram are isomorphic to those in the referent object. Because iconic diagrams look like what they represent, they are effective in helping students recognize different kinds of physical systems that are not available to visual inspection (Hegarty et al., 1991). An example is the comparison of the sketches between skeletons of an Asian elephant and an African elephant. The iconic sketches provide visible outlines that could help to infer the differences of their habits of living. *Schematic* diagrams are highly abstracted from real-world entities but do not preserve the physical relationships presented in the source information; examples include electric circuit diagrams, magnetic fields, and periodic table (Lynch, 1990). *Charts and graphs* depict a set of related, typically quantitative data and numerical meanings based on the interpretation of independent variables. For instance, a line graph can depict the relation between the hours of sunshine and the rate of flowering. A pie chart can show the percentage of water that is contained in a healthy body weight. It is necessary for the reader to identify all independent variables before making an interpretation because abstract meanings and numerical data are embedded into charts and graphs.

Research Design

Content analysis in this research entails a systematic reading and categorizing of a body of diagrams, drawings, photos, and text that appeared in these school textbooks. To have a more comprehensive understanding of the textbooks' diagrammatic usage, an interpretive paradigm and quantitative non-experimental research design was incorporated in the study (Cohen, Manion, & Morrison, 2011).

Research Objectives

The first objective of the research was to examine the nature and extent of the use of diagrams in science textbooks for Years 8–10 and in biology textbooks and workbooks for Years 11–12 in Western Australia. Data from a content analysis of textbooks were used to respond to the two research questions: (1) How are different categories of diagrams distributed in science and biology textbooks? (2) What are the trends of diagrammatic usage in these science and biology textbooks?

Procedure

Nine books (seven textbooks and two student workbooks) analyzed in this study were identified by the state syllabus organization as being in current use for Western Australian high schools. The secondary science textbooks include four science textbooks for lower secondary high school (Years 8–10) and three biology books and two biology workbooks for upper secondary high school (Years 11–12). The textbooks were analyzed in three categories. Category 1 comprising *Fundamentals of Science: Books 1–4* are textbooks that contain many science subjects for students in Years 8–10 (aged 14–16 years), not only biology but also chemistry, physics, and geology. Category 2 contained textbooks for Years 11–12 (aged 17–18 years) that are used in biology teaching and learning. The biology textbooks include *Human Biology 1*, *Human Biology 2*, and *Biology: An Australian Perspective*. Category 3 comprised two biology workbooks for Years 11–12 (aged 17–18 years), which are *Student Resource and Activity Manual 1* and *Student Resource and Activity Manual 2*. Workbooks are used as complementary learning materials within which students are requested to complete the assignments as revision of their own learning. Subsequently, the diagrams contained in all these textbooks were counted and classified, and the percentages of each type of diagram were calculated. Descriptive statistics were conducted in order to provide data on how diagrams are distributed in these books.

Firstly, all the diagrams in the nine textbooks were examined and coded. The coding criterion followed the definitions of the three types of diagrams (iconic, schematic, or charts and graphs) proposed by Novick (2006). The authors and another scholar acted as independent reviewers who cross-checked the results of content analysis in order to improve the inter-rater reliability of the study. An agreement was reached about the criteria used in classifying diagrams, such as which particular features were defined so that the specific diagrammatic type could be determined. Any diagrams in dispute were examined once again. Decisions were reached when both reviewers had 95 % agreement. The accuracy of the results as shown in Table 14.1 was ensured thereafter.

Secondly, the frequency of the three diagrammatic types occurring in each book was calculated. The means of diagrams for each page of textbooks were calculated. Thirdly, any changes of diagram types in different content areas of the three categories of textbooks were investigated. A one-way ANOVA test was conducted to examine any differences between the mean diagrammatic usages in the three textbook categories. Lastly, the trends of diagrammatic use across different book categories were summarized.

Results and Discussion

Prevalence of Diagrams

Content analysis was conducted to examine the inclusion of images in the textual materials. Descriptive statistics for each textbook, including the title of the textbook, the total number of pages in the book, as well as the number and the proportion of every diagram type, are presented in Table 14.1. The three distinct types of diagrams are found in all the textbooks. However, several features are evident:

Table 14.1 Summary of content analysis of lower secondary school general science textbooks and upper secondary school biology textbooks

Number	Book	Pages	Iconic		Schematic		Charts and graphs		Total
1	Fundamentals of Science Book 1	306	480	80.19 %	97	16.26 %	21	3.55 %	598
2	Fundamentals of Science Book 2	306	399	75.18 %	115	21.74 %	17	3.08 %	531
3	Fundamentals of Science Book 3	298	250	69.89 %	98	27.31 %	10	2.80 %	358
4	Fundamentals of Science Book 4	368	291	58.6 %	160	32.32 %	45	9.08 %	496
	Total	*1,278*	*1,420*		*470*		*93*		*1,983*
	Mean diagram/page		*1.11*		*0.37*		*0.07*		*1.55*
5	Human Biology 1	320	148	56.5 %	99	37.77 %	15	5.73 %	262
6	Human Biology 2	398	209	60.1 %	121	34.77 %	18	5.13 %	348
7	Biology: An Australian Perspective	718	373	55.42 %	236	35.04 %	64	9.54 %	673
	Total	*1,436*	*730*		*456*		*97*		*1,283*
	Mean diagram/page		*0.51*		*0.32*		*0.07*		*0.90*
8	Student Resource and Activity Manual 1	394	1,041	83.48 %	132	10.59 %	74	5.93 %	1,247
9	Student Resource and Activity Manual 2	386	527	63.72 %	231	27.94 %	69	8.34 %	827
	Total	*780*	*1,568*		*363*		*143*		*2,074*
	Mean diagram/page		*2.01*		*0.47*		*0.18*		*2.66*
		3,494	3,718	69.63 %	1,289	24.14 %	333	6.24 %	5,340

1. Secondary science and senior biology textbooks contain large amount of diagrammatic illustrations. There are *5,340* diagrams in a total number of *3,494* pages of textbooks. Though there is a slight difference in the mean of the total number of diagrams per page, varying from *0.87* (*Human Biology 2*) to *3.16* (*Student Resource and Activity Manual 1*), there are on average *1.5* diagrams per page used for the explanation of scientific content.
2. The three categories of scientific diagrams (iconic, schematic, charts and graphs) have been identified in every chapter of each of the biology books. In general, the most frequently used diagrammatic type is iconic (*69.63 %* in total diagrammatic usage), whereas schematic diagrams together with charts and graphs account for *24.14 %* and *6.24 %,* respectively. Iconic diagrams have been used the most frequently in the book *Student Resource and Activity Manual 1* (*83.48 %* of the total diagrammatic usage); the book *Biology: An Australian Perspective* contains the most amount of schematic diagrams (*35.04 %*); and charts and graphs were found to be the most populous with the textbook authors of *Biology: An Australian Perspective* (*9.54 %*), whereas the lowest figure for charts and graphs was *2.8 %* as seen in *Fundamentals of Science Book 3*.

Distribution Differences

The content analysis also suggests that there are differences in the distribution of the diagram types not only between textbooks but also within the specific chapters of each book. The reason for this is that each diagram type has its own unique characteristics in demonstrating a certain type of information, and this also accords with the intended students of different age groups. Therefore, the diagrammatic distribution varies according to the content being taught and age of students as the intended learners.

As the different age groups mentioned above, other results emerged by grouping all these textbooks broadly into three categories. The amount and majority of diagram usage in these books varies between lower secondary textbooks and upper secondary level textbooks. In particular, *Fundamentals of Science Book 1–4* for lower secondary school students provide a combination of general science topics including ecology, natural science, biology, chemistry, and physics. *Human Biology Books 1–2* and *Biology: An Australian Perspective* for upper secondary students focus on biological science. *Student Resource and Activity Manuals 1–2* are mainly for students' assignment and self-evaluation purposes in Years 11 and 12. The diagrammatic distribution in the three textbook categories is depicted in Fig. 14.1.

Different types of diagrams may have different functional roles in secondary science and biology teaching and learning. In addition to that, the number of pages in each textbook was different – some books have a small number of pages, others a larger number. Therefore, the means of diagrammatic usage for each textbook category were calculated. Subsequently, a one-way ANOVA test was performed to determine if there were statistically significant differences between the mean

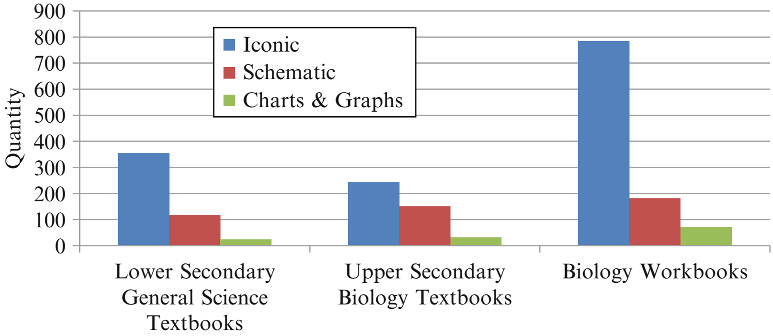


Fig. 14.1 Means of diagram inclusions in the three textbook categories

Table 14.2 Means and ranges of the diagram usage of the three textbook categories.

Textbook categories	Number of books	Iconic	Range	Sche-matic	Range	Charts & graphs	Range	Total	Range
Lower secondary general science	4	355	250–480	117.5	97–160	23.25	10–45	495.75	358–598
Upper secondary biology	3	243.33	148–373	152	99–236	32.33	15–64	427.67	262–673
Biology workbooks	2	784	527–1041	181.5	132–231	71.5	69–74	1,037	827–247

diagrammatic usages in the three textbook categories. Results indicate that the usages of the three types of diagrams differentiated significantly ($F=5.87$, $p<0.05$) between the three book categories only for the iconic diagrams. On the other hand, schematic diagrams ($F=0.95$, $p=0.44$) and charts and graphs ($F=4.34$, $p=0.07$) were not found to differ significantly in these distributions across the textbooks. The means of the diagram usage in the three textbook groups are shown in Fig. 14.1. The results for both the means and the ranges of all the textbook categories are shown in Table 14.2. Several distribution patterns are evident.

Though iconic diagrams account for the most diagrammatic usage in every textbook type, upper secondary biology textbooks contain relatively less iconic diagrams than other textbook types (*730* vs. *1420* in lower secondary general science books *and 1568* in biology workbooks) as shown in Table 14.1. From this finding, therefore, it can be assumed that beginning science learners learn from iconic diagrams more frequently, which typically bear the isomorphic relations to the concrete referent object in its graphic depiction. In other words, younger secondary school learners may depend more on iconic diagrams for visualizing what the scientific and biological entities and phenomena look like.

The largest quantity of charts and graphs can be found in the two biology workbooks (*143* in all), although the absolute quantity of charts and graphs is not as large

Fig. 14.2 Percentage of schematic diagrams in lower secondary general science textbooks

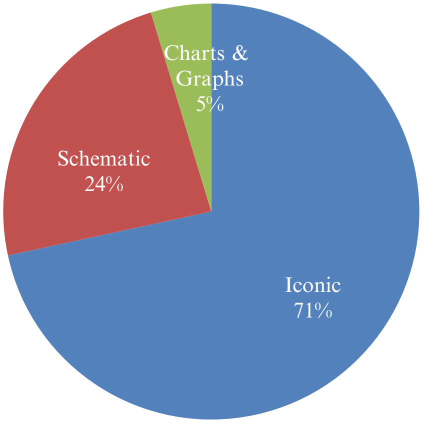
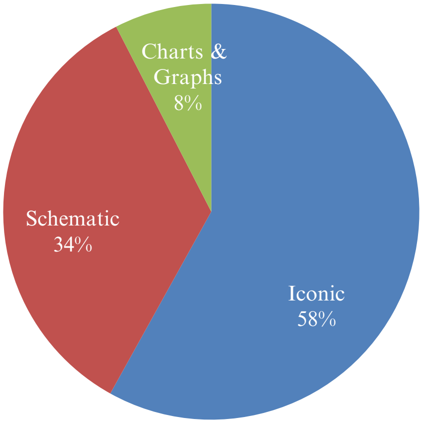


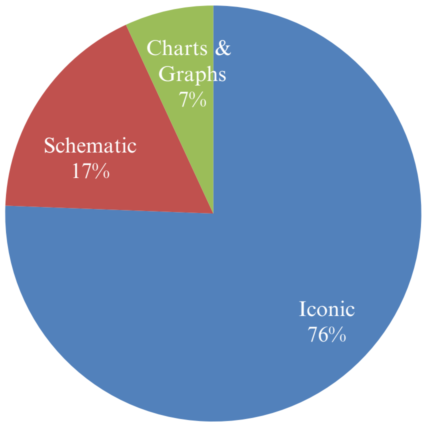
Fig. 14.3 Percentage of schematic diagrams in upper secondary biology textbooks



as the numbers of iconic and schematic diagrams. The number of charts and graphs presented in lower secondary general science textbooks and upper secondary biology textbooks are *93* and *97*, respectively (refer to Table 14.1). The charts and graphs category contains highly quantitative information that is drawn in the form of pie charts, line graphs, etc. Therefore, charts and graphs are used in the workbooks for the purpose of assessing students' learning.

Though a relatively similar amount of schematic diagrams have been used in the three textbook types (*470* in lower secondary general science textbooks, *456* upper secondary biology textbooks, and *363* in biology workbooks) shown in Table 14.1, schematic diagram types have different proportions in the total diagrammatic usage of every textbook category (see Figs. 14.2, 14.3, and 14.4). Schematic diagrams are more evident in the upper secondary biology textbooks than in the lower secondary science textbooks and biology workbooks (*34 %* vs. *24 %* and *17 %*). This is because schematic diagrams tend to help simplify complex situations by providing a concise depiction of the abstract structure to enable students to interpret those complex

Fig. 14.4 Percentage of schematic diagrams in biology workbooks



concepts more easily. Therefore, schematic diagrams have the didactic advantages for learners to figure out why and how a complex scientific mechanism functions in such a way (Lee, 2001; Tomczak, 2005).

Trends Across Textbook Types

Following the discussion of the diagrammatic compositions in each textbook category, this section reports on the differences in percentages of diagram types between the textbooks in each category. As shown in Fig. 14.5, from *Fundamentals of Science Book 1* to *Book 4*, the percentage of iconic diagrams decreased from *80.19 %* to *58.6 %*. However, the proportions of both schematic diagrams and charts and graphs peak in Book 4, reaching *32.32 %* and *9.08 %,* respectively. For diagrammatic usage between the general science textbooks used for lower secondary classes, as students progress to the next year level, the less likely they are exposed to iconic diagrams in these textbooks.

The trends displayed in Fig. 14.6 within the upper secondary human biology textbooks show that the amount of the diagram types remained almost unchanged. The percentage of iconic usage increased from 56.5 % to 60.1 %, the percentage of schematic diagrams dropped from 37.77 % to 34.77 %, and there is slight decrease in the use of charts and graphs, from 5.73 % to 5.13 %. However, overall, there are very similar percentages of use of all diagram types in both textbooks for Year 11 and 12.

The patterns for diagrams used in the upper secondary student workbooks are consistent with those in the upper secondary textbooks, even though workbooks are used mainly for the purpose of students' self-evaluation, serving as complementary learning materials to the textbooks. As shown in Fig. 14.7, the percentage of iconic diagrams drops from 83.48 % to 63.72 %, schematic diagrams increased from 10.59 % to 27.94 %, and there is a minor increase of charts and graphs from 5.93 % to 8.34 %.

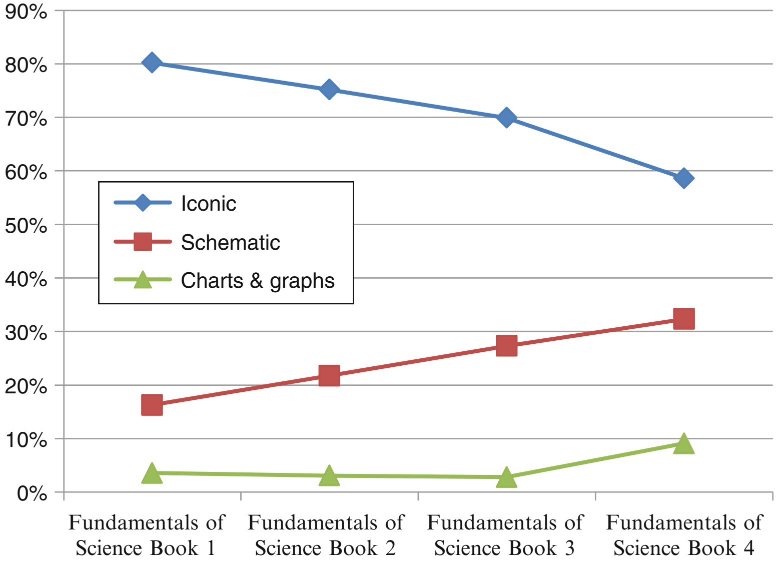


Fig. 14.5 Trends across the lower secondary general science textbooks

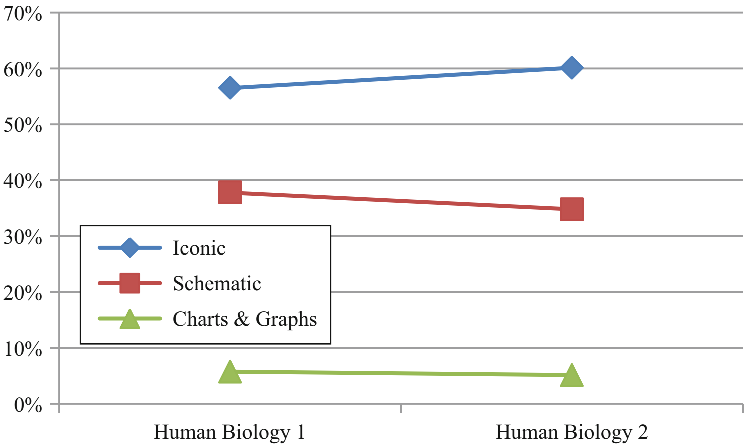


Fig. 14.6 Developmental trends within the upper secondary biology textbooks

Overall, the trends in the prevalence of the three diagrammatic types in these high school science textbooks reflect variations in the likely advantages of different diagrammatic types for learning various scientific contents. It is evident that textbook authors tend to use more iconic diagrams in the junior secondary year textbooks; however, senior secondary year textbooks appear to include schematic diagrams and charts and graphs more frequently with increased scientific content as shown in Fig. 14.8.

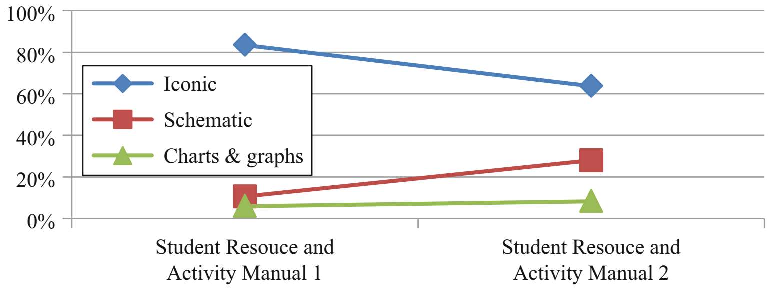


Fig. 14.7 Trends in the student workbooks

	Iconic	Schematic	Charts & graphs
Lower Secondary General Science Textbooks	↓	↑	↑
Upper Secondary Human Biology Textbooks	↑	↓	↓
Student Workbooks	↓	↑	↑

Fig. 14.8 Developmental trends in the three textbook genres

Discussion

An examination of these nine general science and biology textbooks used by Western Australian senior high school students enabled a response to the first question about the distribution of diagrams in lower secondary general science and upper secondary biology. The results of the content analysis indicated that a large amount of diagrams are included in these secondary science and biology textbooks. The textbook diagrams serve as an important teaching and learning tool to present science and biology content knowledge to the students.

The distribution of diagrams in these textbooks also showed how teachers may use different diagrams in their teaching. Each of the nine science textbooks included diagrams which can be used in the teaching for assessment and explanation of content knowledge. The following distribution features are drawn from the results:

- These secondary science and senior biology textbooks contain large numbers of diagrams. On each page, there are about 1.5 diagrams used for the illustration of the biological concepts.
- Iconic diagrams are the most frequently used diagrammatic type. Secondary school biology textbooks use a large amount of photographs and pictures that could serve as reference for students' learning natural phenomena.

- Students' workbooks tend to frequently include charts and graphs that may be used for assessing students' conceptual understanding, especially when mathematical calculations and relations are involved.
- The biology textbooks developed for senior secondary school students appear to rely heavily on schematic diagrams for the explanations of domain knowledge.
- Though iconic diagrams are always the most frequent diagrammatic type used in any book categories, schematic diagrams have a larger proportion of usage for senior-level biology learning. The same structure applies to the charts and graphs.

With regard to the trends of the diagram usage, textbooks in each category were compared so see if there are any changes in later years of science or biology learning. The results (see Fig. 14.8) suggest that all three textbook categories have similar patterns of usage, that is, iconic diagrams are included less when the textbook users become more senior, while schematic diagrams and charts and graphs are more and more important in the conceptual learning as years of schooling increase.

This study has certain limitations which could be considered in future research:

(a) Limited sample size. Though the nine textbooks were widely used in lower science and senior biology teaching, especially in state secondary schools, some other private schools in the state of Western Australia may use different textbooks and workbooks that were not sampled in the study. Moreover, the other states in Australia have their own secondary science and biology textbooks, and the designated textbooks may change year to year.
(b) There may be other methods for analyzing the diagrammatic distributions. For a better understanding of the representational roles that diagrams play in students' conceptual learning, diagrams could also be analyzed according to the science subjects/topics. For instance, the types of diagrams used in genetics topic may not be the same types as used in a physical science topic like force and motion.
(c) Specific diagrammatic conventions like arrows, circles, and coloring could also be taken into consideration in future studies. Though these conventions alone are not sufficient for students to make full use of the information in the diagrams, knowing how students refer to conventions may also provide a means of analyzing the diagrammatic usage.
(d) Textbook users' (teachers/students) opinions could have been sought in addition to the results generated from the quantitative analysis. Each of these four suggestions for future research could enhance the validity of the research findings.

Implications

Previous research into content analysis of science textbooks about diagram usage focused on characterizing the different functional features of visualizations by examining the relations among the images as well as teachers' instructional practices (Pozzer-Ardenghi & Roth, 2005; Roth et al., 1999). However, this study did not investigate how students' biological learning could be influenced by the different diagrams or the diagrams' constituents such as coloring, labels, or caption. The analysis of diagrams contained in the nine textbooks may provide science educators with some insights for understanding in what manner the diagrams have been organized in the textbooks. In this way it would be possible to highlight the fact that diagrams have been shown to be fruitful tools in portraying complex scientific phenomena. An important finding of this content analysis study is the diagrams' distributional patterns including the frequencies, trends, and methods of having science and biology content knowledge to be visualized by students.

Iconic diagrams are deemed to be effective for showing learners about what the scientific entities and phenomena look like, because they keep rich details of the content that they represent. Students therefore could have less difficulty in making sense of the information from an iconic diagram, such as photos and naturalistic drawings. As such, iconic diagrams are especially useful for the students who have limited background knowledge or before their learning proceeds to more complex phenomena. Previous studies have argued that pictorial skills and conceptual knowledge are needed for a better learning of science or biological concepts such as meiosis (Kindfield, 1993). It is therefore assumed that increasing conceptual understanding and diagrammatic reading skills enable students to efficiently interpret the abstract biological concepts. In this case, depiction provided by diagrams could lay the foundation for students' further learning.

Understanding schematic diagrams relies on effective diagrammatic reading skills (Novick, 2006). The learners need to specify the embedded information from the various graphic elements and rules of mapping these elements. Being familiar with these reading conventions can enable the readers to see the diagram as a representation of an abstract structure. Students have to move from the recognition of the phenomena to the development of mental models communicating the underlying domain-specific knowledge and the diagrammatic representations. In science and biology textbooks, schematic diagrams are more used for explaining the concepts for students at later levels of secondary schooling.

In contrast to the other two types of diagrams, charts and graphs are the most intellectually demanding type because knowledge of conventions is necessary but not sufficient for comprehending graphs (Mevarech & Stern, 1997). The difficulty for learning with charts and graphs is that students have to interpret how science and/or biology domain knowledge, mathematical knowledge, and graphic composition are integrated. For example, independent variables and dependent variables are written on the X-axis and Y-axis, respectively. Students need to understand the science and biology domain knowledge by figuring out how the two variables are related to each other.

The research raises questions about the pedagogical value of diagrams included in science textbooks. Our future studies will investigate (a) the relationships between different types of diagrams and other representational modes such as text, (b) the conceptual understandings that students develop when reading different types of diagrams, and (c) how teachers use different diagrams in classroom settings to provide a more holistic view on the instructional use of diagrams.

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Part IV
Conclusion

Chapter 15
Analysis of Science Textbooks for Instructional Effectiveness

Myint Swe Khine

Introduction

Science educators unanimously agree that textbooks play an important role in teaching and learning process (Clement, 2008; Koppal & Caldwell, 2004). For this reason, numerous research studies have been conducted in science textbook analysis in the past several decades. In 1941, Graham noted that "The textbook is an old instrument in learning and teaching processes" and traced the origin of the textbook that can be dated back to the Greek classical era. With the invention of the printing press, textbooks became omnipresent in every school. Since the textbooks are being used as a major source of information in teaching a particular subject, the quality and accuracy of the content is crucial for their educational effectiveness.

International organizations such as UNESCO formulated comprehensive strategy and guidelines on textbook research. In the UNESCO guidebook, Pingel (2010) states the complexity of textbook research and outlined the considerations that need to be taken in the process. The guide book provides practical advice for textbook reviewers in using both quantitative and qualitative methods. Some of the criteria for analysis include types of texts and mode of presentations such as the use of illustrations, photos, maps, and tables and exercises to practice the knowledge that the students just learned. The content analysis in terms of factual accuracy, completeness, and errors is also considered as important criteria. It was also suggested to examine the proportion of facts and views and their interpretation.

The American Association for the Advancement of Science (AAAS) Project 2061 was launched to meet the challenge of science literacy. One of the projects is to develop analysis protocols to evaluate the instructional effectiveness of science

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textbooks. Science educators observed that when the students learn science topics, there is a need to emphasize deep conceptual understanding rather than factual recalls. This requires textbooks that incorporate a wide repertoire of content-specific instructional supports that promote understanding among students from diverse backgrounds, interests, and abilities (Koppal & Caldwell, 2004).

In analyzing the science textbooks, researchers look into the balance between theoretical and practical knowledge, portrayal of minorities, women and gender fairness, treatment of socio-scientific and controversial issues, and depiction of graphical information, vocabulary load, comprehensibility, and readability at intended level, accuracy, and coherence, representation of indigenous knowledge, the role of textbook questions, dealing with misconceptions, and cultural and religious sensibility. A number of analytical tools have been constructed in recent years in the form of survey questionnaire, rubrics, grids, criteria, rating scheme and procedures using ethnographic content and reflexive document analyses, coding of the indicators, and image analysis protocols. Chapters in this book present evaluation of science textbooks using various methods of analysis.

This book is organized in four parts. While Part 1 introduces the theoretical background, criteria and protocol for evaluating the quality of science textbooks, Part 2 covers textual and language analysis of the science textbooks. Part 3 of the book presents research efforts in content analysis of the textbooks. Part 4 summaries the findings and issues presented by the international researchers.

Criteria and Protocol

Devetak and Vogrinc present the criteria for evaluating the quality of science textbooks in Chap. 1. They note that textbooks are important source for students to gain knowledge and inadequate and inconsistent science knowledge presented in the textbooks can affect students' conceptions about scientific phenomena. In learning science, the visual aspect is becoming more important since some scientific concepts are abstract and photos and graphics drawing can help understand the science text.

Numerous research related to textbooks indicate that proper combination of text, real photos and graphical representations can help student learn difficult concepts. They propose criteria for evaluating textbooks using didactic principles.

In Chap. 2 Slough and McTigue observe that in recent years school-based science textbooks are similar to the design of webpages and science trade books with photographs, table, textboxes, flow charts, drawings, and other visual representations. It seems teachers prefer these high visual-content books to traditionally formatted textbooks. They also state that while an increasing visual presence in science has been noted by many and explored in middle and high school science textbooks, the information about the graphical demands of science textbooks are not widely available. In addition there is a little research exploring how verbal and visual text compliments each other. In this chapter the authors discuss the development of a new instrument, the Graphical Analysis Protocol (GAP), based on four principles. These principles are (1) graphics should be considered by form and function, (2) graphics should help a viewer build a mental model of a system, (3) graphics and texts should be physically integrated, and (4) graphics and texts should be semantically integrated. The authors discuss three research articles that used GAP as an analytical instrument.

Textual and Language Analysis of Science Textbooks

Muspratt and Freebody, in Chap. 3, look at the textbook analysis from the point of view of language. They argue that there is systematic variation in the ways the authors of science textbooks deploy linguistic features in representing scientific knowledge. As a consequence, the texts present different ways of understanding the world. Using the results of multivariate analyses of linguistic and textual features, the authors show that there are clear and interpretable distinctions among the disciplines of science – physics, biology, chemistry, and other subjects. They note that topics on physics and chemistry, scientific knowledge is presented in terms of rules, statements, procedures, and arrangements, and the content tends to be structured around a small number of underlying and unifying concepts. But topics dealing with biology and geology are presented through description, elaboration, and persuasion. The chapter discusses the implication of textual variation for classroom practice and teacher training.

Dimopoulos and Karamanidou in Chap. 4 assert that currently the school science is presented as a static and absolute knowledge, but in reality it is dynamic and subject to negotiation in meaning making. They present the comparison between school science and science in public domain highlighting different conceptions. They introduce the use of textuality in analyzing the textbooks and suggest to include textual elements that might enhance the reflexibility of the learners. They stress on "epistemologically valid image" of school science.

In Chap. 5, MaryKay Orgill from the University of Nevada explores the use of analogies in science textbooks. She observes that science instructors and textbook authors often use oral and textual analogies with the intension of helpings students learn new concepts. It is noted that textual analogies are more prevalent learning resource that students can consult when a teacher is not available to make new information more understandable. She believes that textual analogies have the potential of being more complete and explicit than oral analogies since textbook authors can devote time and thought to constructing them. It seems that many textual analogies are not explained appropriately or in enough detail to be helpful to students. In her chapter, she reviews the research literature about the use of analogies in science textbooks that focuses on the potential learning effects of textual analogies and the factors related to effective analogy use. The chapter summarizes the methods and results of several published analyses of analogy use and presents the classroom teaching models in effective use of analogies.

Nadine Bryce discusses the textual features and language demands of primary grade science textbooks in Chap. 6. She describes that reading comprehension is a part of science teaching and learning similar to the exploration of concepts through hands-on activities in the United States. She observes that science textbooks are commonly used in the early grades, but young children struggle to read and understand them because they often contain difficult vocabulary and abstract concepts. It is noted that textbooks often present topics superficially and language use is not attractive to the young learners. Several other problematic aspects of science books include difficult vocabulary, superficial views of topics, and outdated explanations and sometimes with errors. In addition, the books are not well organized to make it user-friendly and promote reading with understanding. As a result language and literacy demands of reading science textbooks continue to challenge students. She highlights the fact that young children must first learn to read (such as stories) before they can read to learn (such as informational texts). The chapter calls for more informational texts in primary grades.

Content Analysis of Science Textbooks

A review of the Earth science content of all the science textbooks for 11–16-year-olds used in England and Wales schools is described in Chap. 7. In this study, the content of the textbooks was evaluated against the Earth science statements in the National Curriculum for Science. It was found that 453 instances of error/oversimplification were identified. In addition another 78 instances were also identified from other sources. All 531 "misconceptions" were analyzed and showed that the parts of the Earth science curriculum most prone to misconception are sedimentary processes/rocks, earthquakes/Earth's structure, and plate tectonics. The author concludes that the possible cause of the poor quality of textbook is that many science textbook writers are science teachers and they do not have background knowledge in Earth science education or education in Earth science teaching. The author provides some guidance to consider in developing the Earth science content of future science textbooks that are more appropriate and accurate.

Chapter 8 by Rillero investigates the science contents in nineteenth-century United States reading textbooks. These books are designed to help students to read and to learn about the world in this era. He reported that during those years science was not yet established as a separate subject. The chapter presents the results of the analysis that determines the quantity of science and type of science in 20-year periods during the nineteenth century. Through the analysis it was found that science content in the readers was probably the first formal science education of most students and biology content increased relative to other science subjects.

Caravita and Valente from Institute of Research on Population and Social Policies at National Research Council in Rome, Italy, present the cross-countries analysis of educational approach to environmental complexity in life sciences school manuals. In their chapter they describe the importance and concerns of educational institutions in European countries on this important issue. They found that environmental issues are oversimplified in the manuals and future scenarios are not emphasized. It was also found that students are not given opportunities to conduct project-oriented activities to explore and understand the critical issues. They conclude that the manuals do not seem to offer a great deal of contribution to help students understand the relevant issues and the model of complex environmental systems as well as its implications in their daily life.

The analysis of Turkish general chemistry textbooks based on a History and Philosophy of Science (HPS) is the topic of discussion by Niaz and Costu in Chap. 10. They state that research in science education has recognized the importance of analyzing science textbooks from HPS perspective. It is also noted that reform documents have emphasized the importance of including HPS. The chapter presents the results from the analysis of general chemistry textbooks published in Turkey based on the topics such as atomic structure, determination of the elementary electrical charge (oil drop experiment), kinetic molecular theory of gases, and origin of the covalent bond. The textbooks involved in this study were published from 1964 to 1998 and 2000 to 2006. The authors report the detail findings and concluded that the results from this study can help improve the general chemistry textbooks in Turkey and other countries. It can also help in the design and implementation of HPS perspectives to assist students' conceptual understanding.

In Chap. 11, Park and Lavonen present the study on the analysis of standard-based school physics textbooks in Finland and the United States. In this chapter, they report the differences between a curriculum based on the National Science Education Standards (NSES) in the United States and a curriculum following National Core Curriculum in Finland. High school physics curricula including Active Physics of the USA and Physica of Finland are analyzed in terms of general features, questioning style, and level of laboratory activities by two experts in science education in each country. Both curricula are supported by the standards of NSES in the United States and the National Core Curriculum in Finland. The Textbook Questioning Strategies Assessment Instrument and Herron's four levels of activities are used for the analysis. The chapter presents general features, questioning style, and level of laboratory activities contained in the books. The authors noted that their study paves way to improve physics education and lead to inquiry-based science teaching and learning.

Binns' chapter addresses the development of qualitative method to evaluate how textbooks portray scientific methodology. He notes that key aspect of scientific literacy is to have a clear understanding of how scientists work. But studies in the United States indicate that a large majority of citizens do not understand how scientists work. There are also arguments that science textbooks are one source of this misunderstanding. While the public's misinterpretation of scientific methodology could not squarely blame on textbooks, schools use textbooks as a standard resource in most classrooms. In this chapter Binns states that the majority of research in this area has utilized quantitative methods for their analyses. This chapter describes the qualitative methods and the how the instrument was used to identify the quality of a textbook's presentation of scientific methodology. He suggests that the textbook authors and publishers should consider including a broad representation of the scientific endeavor.

In Chap. 13 Valanides and colleagues report the findings from the analysis of the set of science textbooks used in Cyprus school curriculum. The set includes teacher's book, textbook/worksheets, and evaluation sheet for the sixth-grade primary classes. The study attempts to find out to what extent textbooks adopt design principles that support the inquiry-based learning and the subject-matter coverage that can foster the development of nature-of-science understanding. A number of research questions are formulated in analyzing the books and related materials. These include whether the textbooks encourage self-directed experimentation strategies, whether it considers investigation as a combination processes, and whether the textbooks foster the development of investigation skills. In addition, the team also looks into whether the textbooks promote pupils' understandings concerning fair testing, whether the textbooks employ analogies, and whether it offers opportunities for pupils to engage in evidence-based argumentative discussions. The results from the analysis indicate that although textbooks presently used were guided by the reform policy, they do not reflect real reform in teaching of science at the primary level. They also express that the content of these textbooks together with the worksheets and the evaluation sheets does not consider "how children learn." It was also found that the hands-on activities do not seem to encourage pupils' initiative, creativity, imagination, and epistemological development. Pupils involved in structured experiments following the step-by-step guidelines mechanically. The authors suggest the use of analogies and integration of ICT and encourage teachers to use tools and affordance for scaffolding pupils' thinking and meaning construction.

Much of the research described above is content analysis of textual nature. In Chap. 14, Yang and Treagust endeavor content analysis of diagrams in secondary school science textbooks. Their chapter reports on analysis of nine science textbooks used in Western Australian high schools. They scan through 3,494 pages of science textbooks and identify 5,340 diagrams as iconic, schematic, and charts and graphs. The study reveals that percentage of iconic usage is higher than other categories. The authors note that iconic diagrams are effective for showing learners about scientific entities and phenomena and students can easily make sense of the information. Conversely, understanding schematic diagrams depends on effective diagrammatic reading skills. Charts and graphs are the most intellectually demanding to understand how the information is represented and requires mathematical knowledge to make sense of relationship between variables. The authors suggest to explore deeper into the pedagogical value of diagrams and how these can help students in conceptual understanding of science subjects.

Conclusion

John Issitt (2004) once remarks that the term textbooks provokes negative response from teachers and students. There are also many criteria in science textbook analysis set by the different stakeholders and users with the variety of emphasis and what constitutes a good science textbook is an open-ended question. Textbook researchers attempt to look at the issues related to the quality of the textbook from different perspectives. Apart from the various approaches described in this book, others also evaluate the prevalence, function, and structure of graphics and photographs and inclusion of history of science, assessing comprehension demands and language structure (Bezemer & Kress, 2010), balancing gender representation, and looking at the textbook as a cultural object (Izquierdo & Gouvea, 2008). Some look at the social and political issues that are applicable in certain context (Bianchini & Kelly, 2002), inclusion of indigenous knowledges in the textbooks (Ninnes, 2000), and method to analyze the coherence of textbooks (Roseman, Stern, & Koppal, 2010).

In recent years, textbook analysis has reached another level with the use of information technology tools. It is possible to digitize the books and analyze with the use of computerized text analysis tools (Bulger, Murphy, Scheible, & Lagresa, 2011; Rockwell, 2012). Digital version of books (e-books) is also increasingly available along with the traditional printed book. But the use of e-book is still in its infancy and produces mixed results from the users. The study conducted by Woody, Daniel, and Baker (2010) indicates that the experience of reading e-books is not equivalent to reading textbooks and students do not prefer e-books over textbooks despite the fact that e-books provide hyperlinks to other resources on the web. The contributors to this volume have considered challenges and potentials in textbook analysis and presented their findings. It is hoped that this collective work will continue and lead to more rigorous attempts and establish a framework for analyzing science textbooks in the future.

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Index

A
Analogies, 79–96, 143, 261, 262, 264, 280, 284, 285, 305, 308
Argumentation, 41, 72, 74, 174, 187, 188, 194, 202, 203, 252, 260, 262–264, 267, 283–285, 307, 308
Atomic structure, 91, 150, 200–204, 240, 307

C
Cluster analysis, 37, 42, 47
Complexity, 11, 20, 21, 34, 38, 39, 102, 173–196, 205, 207, 260, 303, 306
Content analysis, 6, 7, 161–169, 242, 243, 246, 254, 287–299, 303, 304, 306–308
Covalent bond, 200, 211–214, 240, 307
Cross-country analysis, 306

D
Diagrams, 5, 7, 12, 20–24, 27, 28, 105, 111, 128, 135, 139, 140, 147, 155, 156, 279–282, 287–299, 308
Disciplinarity, 34, 54, 174, 191
Document analysis, 163, 304

E
Earth science, 24, 123–158, 164–166, 168, 175, 177, 190, 232, 306
Education, 4, 5, 9, 13, 34, 57, 67, 69, 71, 80, 86, 112, 113, 118, 123–126, 134, 157, 161–169, 173–178, 180, 191, 193, 195, 196, 199, 200, 214, 219–225, 228, 230, 231, 239, 241, 243, 246, 259, 262, 265, 268–275, 277, 279–281, 287–288, 306, 307
Environmental education (EE), 173, 175–178, 180, 190, 194, 195
Epistemology, 34, 61–76, 177, 179, 188–189, 194, 199, 262, 263, 283, 305, 308
Error, 103, 104, 114, 125, 128, 129, 132–134, 136–138, 140, 142, 144, 146, 148, 150, 151, 154, 157, 303, 306
Evaluation criteria, 3–13, 201, 204, 207, 211, 304
Experimentation, 6, 243, 245, 248–250, 252, 260, 263, 264, 283, 284, 308
Expository structures, 106, 109–111

G
Geology, 35, 40, 53, 56, 123, 125, 139, 140, 154, 156, 164, 168, 290, 305
Graphical classification, 19
Graphical representations, 18, 19, 21, 24, 304

H
History, 34, 55, 66, 71, 101, 103, 139, 154, 156, 161, 162, 168, 199–215, 240, 307, 309
History & philosophy of science (HPS), 199–215, 240, 307

I
ICT integration, 263, 264, 282, 284, 308
Inquiry learning, 107, 173, 223, 224, 264, 307, 308
Instructional effectiveness, 303–309
Instrument development, 17, 18, 19, 224, 248, 253

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K
Kinetic theory, 40, 208, 210

L
Language analysis, 33–57, 104–112, 304–306
Learning science, 4, 12, 102, 107, 288, 299, 304
Linguistic analysis, 305
Literacy, 17, 20, 33–35, 57, 101, 105, 107, 112–115, 220, 222, 231, 240, 246, 263, 288, 303, 306, 307

M
Meaningful learning, 80–81, 84, 88, 233
Misconception, 4, 8, 12, 13, 18, 81–84, 87, 92, 95, 115, 124, 125, 133, 135–142, 144, 146, 148, 150–158, 187, 276, 304, 306

N
National curriculum, 6, 7, 10, 13, 123–127, 129, 130, 134, 157, 221, 222, 306
Nature of science (NOS), 17, 64, 75, 130, 199, 200, 221, 240, 241, 243, 246, 255, 263, 283, 284, 308
Nonfiction reading in primary grades, 113
NOS. *See* Nature of science (NOS)

P
Protocol, 17–25, 163, 303–305

Q
Qualitative content analysis, 254
Qualitative research, 7

R
Readability, 102–105, 109, 114, 304
Readers, 18, 19, 22–24, 35, 41, 43–45, 50, 64, 66, 69, 70, 74, 75, 76, 102–105, 107, 109–112, 114–117, 134, 161–169, 185, 189, 195, 235, 236, 245, 254, 255, 288, 289, 299, 306

S
School manuals, 173–196, 306
School science, 4, 17, 18, 56, 61–76, 204, 226, 232, 287–299, 304, 305, 308
Science, 3–13, 17–28, 33–57, 61–76, 79–96, 101–118, 123–158, 161–169, 173–196, 199–215, 219–226, 229–235, 239–241, 243, 245, 246, 249–251, 254, 255, 259–285, 287–299, 303–309
Science analogies, 94
Science in public, 61–64, 305
Science textbook(s), 3–13, 17–28, 33–57, 61–76, 79–96, 101–118, 123–158, 190, 220, 222, 226, 232, 239, 240, 241, 245, 255, 259, 262–266, 287–299, 303–309
Science textbook analysis, 303–309
Scientific methodology, 239–255, 307
Secondary, 17, 33–35, 56, 57, 66, 83, 85, 88, 90, 92, 102, 103, 123–125, 133, 142, 157, 177, 179–181, 183, 188, 190, 194–196, 219, 241, 264, 265, 287–299, 308
Secondary biology, 293, 294, 296, 297

T
Teaching strategies, 4, 34
Textbooks, 3–13, 17–28, 33–57, 61–76, 79–96, 101–118, 123–158, 161, 163, 164, 166, 168, 173, 174, 177, 181, 182, 188, 190–194, 199–215, 219–236, 239–255, 259, 262–266, 280, 282–284, 287–299, 303–309
Textual analogies, 84–88, 94–96, 305
Textual features, 101–118, 305, 306
Textuality, 61–76, 305
Turkish textbooks, 25, 199–215, 307

V
Visual representations, 17, 18, 84, 287, 288, 304
Vocabulary demands, 102, 104, 106, 114