TOWARDS MULTISEMIOTIC LITERACY: CONSTRUCTING EXPLANATIONS IN SECONDARY SCIENCE CLASSROOMS

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Towards multisemiotic literacy:
Constructing explanations in secondary science classrooms

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

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Abstract

Constructing explanations in science classrooms is a complex science practice (Braaten & Windschitl, 2011) and can be challenging for both students and teachers (Zangori, Forbes, & Biggers, 2013). Part of this complexity lies in how scientific knowledge is made accessible to students with multimodal resources, which is an area that is under-researched. This study examines how explanations are discursively constructed in science classrooms through different modes of communication (i.e., spoken language, written language and images) adopting a systemic functional multimodal discourse analysis (SFMDA) approach.

The data comprised 162-minute video recordings of two science classrooms on the topic "applications of air pressure". Three types of data were analyzed due to their central role in constructing scientific explanations: (1) written texts (i.e., the explanations produced by the teachers and the students in writing), (2) spoken texts (i.e., the verbal interactions between teachers and their students), and (3) images (i.e., the images shown on the PowerPoint slides to represent the phenomenon of air pressure).

The data were analyzed within the framework of Systemic Functional Linguistics (SFL) which consists of three interrelated components to trace the way meaning is represented, developed and multiplied through the use of different modes. The development of meaning in the written and spoken texts was examined through Theme analysis (Halliday & Matthiessen, 2014). The representations of scientific entities and their relations in the images were examined through representational analysis (Kress & van Leeuwen, 2006) and visual linking analysis (van Leeuwen, 2005). The multiplication of meaning between visual and verbal modes was investigated via the analysis of image-text relations (Martinec & Salway, 2005).

The findings show that the development of meaning in the written texts can be schematized as three stages: Experiment Condition, Phenomena Perception and Phenomena Interpretation. The stage of Phenomena Condition explicates the condition

for the phenomena to occur; the stage of Phenomena Perception describes the perceivable features of the phenomena in question; and the stage of Phenomena Interpretation articulates the causal mechanism to account for the phenomena under investigation. While the patterns of Themes in the stages of experiment condition and phenomena perception are oriented to commonsense knowledge, those in the stage of phenomena interpretation focus on the construction of causal mechanisms, which is the vital component of a scientific explanation. To construct the written explanations, the spoken texts develop meaning around the demonstration of an experiment and the construction of an explanation. In both cases, the choices of Themes show that meaning-making in the spoken texts constantly shunts between commonsense knowledge (e.g. the topical Themes of people) and abstract scientific knowledge (e.g. the topical Themes of scientific entities). The findings highlight the important role of Themes in the spoken texts in marking a shift or a continuation in discourse.

The scientific entities are represented in the images through the co-presentation of multiple visual structures that are linked through relations such as elaboration, temporal, spatial and logical ones. To fully appreciate meaning-making in the images, students need to be able to identify their visual structures and complex interrelations, which is one crucial step towards being multisemiotically literate. In addition to appreciating the meaning in the images, being multisemiotically literate also requires the ability to connect meanings across modes. The findings about the image-text relations suggest that visual meanings are activated through cues such as pointing gestures to multiply meanings in the spoken texts, which collectively contribute to the construction of the written explanations.

Overall, multisemiotic literacy includes but is not limited to the mastering of language and scientific knowledge, the skillful tracing of the development of discourse, and a holistic appreciation of relationships (i.e., elaboration, temporal, spatial and logical relations) in images. The case studies of the two science classrooms demonstrate how scientific knowledge, such as that about air pressure, is constantly shaped and reshaped through the integration of visual and verbal meanings.

The main value of the thesis lies in its multisemiotic perspective on scientific literacy and the explication of the complexity of constructing scientific explanations in classrooms. Theoretically, this thesis provides a comprehensive account of scientific literacy, integrating Norris and Phillips's (2003, 2009) two senses of scientific literacy, Bernstein's (1999, 2000, 2001) sociological view of knowledge and a systemic functional view of language as social semiotics (Halliday, 1978; Kress & van Leeuwen, 2006). This thesis is one of the first attempts to further develop the scale of theme markedness proposed in Halliday and Matthiessen (2014), through two dimensions: topical markedness (topical Themes), and inherent/characteristic markedness (interpersonal and textual Themes). Pedagogically, this study highlights the role of multisemiotic literacy in science education and the possibilities as well as challenges that teachers may encounter when selecting, organizing and communicating visual and verbal meanings.

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Chapter 1 Introduction

1.1 Overview

This thesis intends to investigate the nexus between literacy and pedagogy by examining the construction of scientific explanations in the classroom from a functional, multimodal discourse-based perspective. This chapter presents the rationale for examining multisemiotic literacy in this study, with a focus on the construction of scientific explanations in Hong Kong science classrooms (Section 1.2), the research aims and the significance of this study (Section 1.3), and an overview of the following chapters (Section 1.4).

1.2 Rationale for the study

1.2.1 Why multisemiotic literacy?

Literacy is traditionally defined as the ability to read and write texts in the traditional format, such as print books. In today's digital age, the communication space that used to be occupied solely by traditional texts is shared by a multitude of continuously changing forms of multimedia and other electronic devices, such as Google docs, Skype, iMovie, Dropbox, Facebook, Google, Chrome, educational video games and numerous mobile apps (Leu, Kinzer, Coiro, Castek & Henry, 2017). This has brought about at least two consequences with regard to the concept of literacy. First, texts become multimodal, expanding from static traditional texts to include images, sound and symbols. To understand these multimodal texts requires not only linguistic skills but also literacy in other semiotic (meaning-making) systems. While the traditional view of literacy solely focuses on the semiotic system of language, other semiotic systems, such as images, are overlooked (New London Group, 1996). Second, the meaning of these texts becomes highly dependent on their textual environments. The text of "I am happy", when paired with an image of a smiling face, means very differently from the same text when paired with an image of a crying face. Apart from adjacent texts or images, the context where the text is produced also contributes to its overall meaning. Therefore, the conception of literacy in this new era has shifted from an acquired skill through schooling to a developing skill constantly adjusting to one's changing multisemiotic situations and contexts (Jewitt, 2008; Unsworth, 2002).

The notion of multisemiotic literacy, as used in this thesis, is informed by a social semiotic perspective (Kress, 2010). From such a perspective, meaning-making is "social, and material, and semiotic" (Lemke, 2002a, p. 23). Thus, multisemiotic literacy is multidimensional by nature: social, material and involving multiple semiotic resources. First, the social nature of literacy is reflected in the fact that any literacy practice must involve people and their social relationships. Literacy practice such as literacy learning is inevitably embedded in privileges and ideologies that are valued in a society (Gee, 2007; Cope & Kalantzis, 2000). A consideration of the context where the meaning-making occurs is crucial to understanding literacy. Given this recognition of the importance of the social aspect of literacy, the context of this study, science classroom teaching in Hong Kong, will be elaborated in detail in Section 1.2.3.

Second, literacy is material. This is because meaning is communicated through physical media in a material environment. With the advancement of educational technologies, the classroom provides a complex web of communication supported by different modes and media, such as written language in the medium of printed text, and the mixed modes of written language and images in the medium of PowerPoint slideshows. These media provide the physical conditions of communication that allow for specific ways of making meaning through modes. For instance, the medium of PowerPoint slideshows allows written language to be edited and animated, whereas it is impossible to do so in the medium of printed text. It is increasingly recognized that making sense of the information presented in various modes and their complex combinations is not effortless and self-evident (Bateman, 2017; Bucher & Niemann, 2012; Cromley, et al., 2016). Given the challenges presented by contemporary classroom communication, being literate requires skills in switching among modes to connect relevant information, which might appear “isolated and autonomous” (Jewitt, 2007, p. 261). This relates to the third dimension of literacy, that is, its multisemioticity.

Literacy is semiotic because it is through the semiotic interpretation of phenomena that an individual agent selects to engage with and transform the physical world according to their principles (Kress, 2007). Literacy is multisemiotic because it involves the use of multiple semiotic resources, such as language, images and gestures, to interpret the phenomena. Lemke (2002) points to the fact that learning is not only semiotic but multisemiotic, because meaning is seldom made by resorting to one semiotic system. This has at least two consequences for the development of literacy in today’s classroom. First, given that each mode of communication has its strengths and limitations in conveying meanings (i.e., semiotic affordance), knowing what mode is apt for expressing what meanings forms a vital component of multisemiotic literacy. For instance, language (both written and spoken modes) is organized by the logic of time; therefore, it is regarded as a robust resource for constructing temporality and logic reasoning (e.g., Danielsson, 2016). Images, on the other hand, tend to be organized by the logic of space, which results in their advantage for constructing spatial meanings (e.g., Kress & van Leeuwen, 2006). Being familiar with the affordances of semiotic resources prepares students with a better understanding of what and how meanings are made. Second, the nature of learning as a multisemiotic experience requires a skillful integration of information from multiple sources, such as recognizing the multiplication of meanings in an integration of semiotic resources, where the meanings made from such an integration are greater than the sum of the meanings in each semiotic resource (Lemke, 1998). In a case study of secondary science classrooms, Lemke (1998) points out that students need to “fluently juggle” between several semiotic resources, such as language, mathematical symbols and images, each accounting partially for, and collectively constituting to, a complex set of conventional practices in scientific meaning-making (p. 248). Each of these conventional integrations of semiotic resources should be learned as a crucial form of multisemiotic literacy.

With this understanding of literacy, the present study focuses on the ways of meaning-making in two semiotic resources: images and language (in both written and spoken modes). While the critical role of language in classroom communication is widely recognized, also becoming increasingly important are the role of images and the relation between language and images (Bateman, 2014). The present study examines the discursive construction of meaning through language (see Section 3.4.2 for analysis procedures and Chapter 4 for findings) and images (see Section 3.4.3 and Section 3.4.4 for analysis procedures and Chapter 5 for findings) as well as the multiplication of meanings between image and language (see Section 3.4.5 for analysis procedures and Chapter 5 for findings). The next section will explain why this study focuses on multisemiotic literacy in the construction of scientific explanations.

1.2.2 Why scientific explanations?

Science education aims to nurture two broad types of understanding: a qualitative understanding of how a scientific system works and a quantitative understanding of the numerical details of scientific investigations (Mayer & Jackson, 2005). While both types of understanding are important for fostering scientific proficiency, a qualitative understanding of the operation mechanism in scientific systems is often regarded as the first step (Gentner & Stevens, 1983; Halford, 1993). This qualitative interpretation of a phenomenon involves not only the identification of the phenomenon per se but also the ability to explain how or why the phenomenon exists or occurs in a specific way. While the significance of explanation formulation is highlighted in the school curriculums of most countries (e.g., Australian Curriculum Assessment and Reporting Authority, 2014; Curriculum Planning and Development Division Singapore, 2014; National Research Council, 2012), student-constructed explanations in science classrooms are often found inconsistent with the scientifically accepted explanations. Compared with the precise, abstract and evidence-driven explanations that are accepted in established science, students' explanations tend to be intuition-driven (Touger, Dufreshne, Gerace, Hardiman, & Mestre, 1995), less precise and less abstract (Heckler, 2010), and are often found incomplete (Zangori & Forbes, 2013) or inconsistent (Ozdemir & Clark, 2009).

The discrepancies between accepted scientific explanations and student-constructed ones are, at least partly if not fully, due to the fact that an explanation in its scientific sense is different from an explanation in its everyday sense. While describing an occurrence in the form of "what happened" is counted as an explanation in its everyday sense, a scientific explanation goes beyond "what is there" to address "what is not there", that is, how or why a phenomenon is observed. However, this distinction between explanation in its scientific sense and explanation in its common sense is often overlooked by students and even teachers, who tend to equate explanations with explications (Zangori & Forbes, 2013). Moreover, students are exposed to a limited number of scientific explanations as model texts (Berland, Schwarz, Krist, Kenyon, Lo, & Reiser, 2016; Jong, Chiu, & Chung, 2015; Rose & Martin, 2012), which contributes to the difficulty in constructing a scientific explanation, namely, an explanation that is evidence-based, well-reasoned through a causal mechanism, consistent, precise and abstract enough to account for the phenomenon being studied. Moreover, the construction of an explanation in science classrooms is a multisemiotic experience, involving the use of multiple modes of representation, such as the use of language, mathematical symbols and diagrams. As Yeo and Gilbert (2014) point out, the success in constructing a scientific explanation also requires the skillful orchestration of multiple semiotic resources. This calls for an in-depth investigation into the construction of an explanation from a multisemiotic perspective – how meaning is discursively constructed through the orchestration of multiple semiotic resources. The next section will link the construction of explanations to the context under investigation, that is, secondary science classrooms in Hong Kong.

1.2.3 Why secondary science classrooms in Hong Kong

Hong Kong has been administered as a Special Administrative Region (SAR) of the People's Republic of China (PRC) since 1997, when its British colonial era ended. There are two authorities overseeing Hong Kong's education system: The Hong Kong Special Administrative Region Government (HKSAR) and the Education Bureau

(EDB). HKSAR warrants a nine-year free education for Hong Kong children (from primary to junior secondary level), while EDB supervises the quality of this school education. This nine-year school education is expected to cover eight Key Learning Areas (KLAs). They are (1) Chinese Language Education, (2) English Language Education, (3) Mathematics Education, (4) Science Education, (5) Technology Education, (6) Personal, Social and Humanities Education, (7) Arts Education, and (8) Physical Education. Science education forms an important constituent at not only the Primary level (P1-6), the junior secondary level (S1-3) but also the senior secondary level (S4-6). Starting from the junior secondary level (S1-3), students are expected to master the construction of an explanation among other key skills including observing, handling equipment, classifying, measuring, communicating, predicting and hypothesizing (Curriculum Development Council [CDC], 2017).

In 2015, EBD released a consultation document entitled "Promotion of STEM Education – Unleashing Potential in Innovation" to update the curricula of Science, Technology and Mathematics so that students can become "lifelong learners of science and technology" (CDC, 2015, p. 1). In the renewed curriculum framework of science education, the critical role of scientific literacy is highlighted. In a large-scale survey conducted by EDB from November 2015 to January 2016 for secondary and primary schools, the majority of science teachers (72.1% agreed and 19.3% strongly agreed) agreed about "the importance of scientific literacy" in the updated curriculum (CDC, 2015, p. 53). However, the notion of scientific literacy in the updated curricula is still limited to content knowledge of science, and neglects the role of language and other semiotic resources in developing students' knowledge of science. The major objectives of STEM education include

> …developing a solid knowledge base among students and enhancing their interests in Science, Technology and Mathematics, strengthening students' ability to integrate and apply knowledge and skills, nurturing creativity, collaboration and problem solving skills of students, and also strengthening the partnerships with community stakeholders, and developing talents/experts in STEM-related areas to foster the development of Hong Kong.
>
> (CDC, 2015, p. 1-2)

The linguistic and multisemiotic literacy demands remain hidden in the curriculum, which are encapsulated in general, knowledge-related terms such as "a solid knowledge base" and "students' ability to integrate and apply knowledge and skills". It is argued in this thesis that the development of knowledge and the advancement of literacy are inextricably linked. Therefore, it is necessary to provide science teachers with keys to uncover the "hidden curriculum" of language and other semiotic resources in science education (Bratkovich, 2018, p. 780).

In Hong Kong secondary classrooms, the KLAs are taught through the medium of either English (EMI) or Cantonese (CMI), and the medium-subject combinations vary greatly among schools. Science is among the subjects for which EMI is most popular because it is considered by the school administration to be able to bring benefits with fewer linguistic challenges than other subjects (Chan, 2016). However, teachers and students, especially those who are from former CMI schools, experience considerable challenges in teaching subjects in EMI (Lo & Macaro, 2012; Poon, 2013; Tam, 2013). The lack of attention to language and other semiotic resources in science education and the severe challenges faced by the teachers and students call for an investigation into the role of language and other semiotic resources in the construction of scientific knowledge.

1.3 The present study

1.3.1 Research aims and research questions

The present study set out to achieve two research aims. The first aim was to investigate how different modes of communication (i.e., spoken language, written language and images) in the classroom contribute to the construction of explanations adopting the systemic functional multimodal discourse analysis (SFMDA) approach. In the present study, the construction of explanations was examined from three aspects: the development of meaning, the representation of meaning and the multiplication of meaning. The development of meaning was examined in language in terms of Theme selection (the departure of a clause) and thematic progression (where Themes comes from). The representation of meaning was examined in images in terms of visual structures (narrative or conceptual structures) and their relations (how one visual structure connects to others). The multiply of meaning across modes was examined in terms of how spoken language and images interact to integrate meaning.

The second aim was to investigate how scientific knowledge (i.e., air pressure) was recontextualized in classrooms through the use of language (both spoken and written modes) and images. Recontextualization of knowledge refers to the modification in educational contexts of knowledge from its original scientific field of production (Bernstein, 1999). Like any knowledge in the school context, scientific knowledge related to the construction of explanations has been modified from the knowledge originating in its field of production so that students can acquire it. Each classroom can be considered as a site for recontextualization to occur, where scientific knowledge is selectively represented in semiotic resources, such as language and images. The present study focused on the recontextualization in two science classrooms of scientific knowledge in explaining air pressure-related phenomena through the use of language (both spoken and written modes) and images. The recontextualization of the relevant scientific knowledge was examined by comparing the linguistic and visual realizations of similar phenomena in two classrooms.

To address these two aims, three research questions were developed:

(1) How is language used to organize relevant scientific knowledge to construct explanations in the classroom?

(1a) What thematic patterns can be identified in the written explanations?

(1b) What thematic patterns can be used in the spoken discourse to construct these written explanations?

(2) How do images represent and link relevant scientific knowledge to construct explanations in the classroom?

(2a) What representational meanings can be identified in the images to construct explanations?

(2b) How are these representational meanings linked in the images to construct explanations?

(3) How do language and images interact in the construction of explanations in the classroom?

1.3.2 Significance of the study

The present study aims to make both theoretical and pedagogical contributions. Theoretically, this study is intended to contribute to the research fields of science education and linguistics. The theoretical contribution to the field of science education is expected to take the form of an integrated account of scientific literacy to highlight the relation between scientific knowledge and scientific language. In the field of science education, scientific literacy has been traditionally regarded as the command of scientific knowledge, such as understandings of science concepts and their relations, ability to think scientifically, and capabilities in addressing science-based social issues. In contradistinction to the traditional view of scientific literacy as the command of the content knowledge of science, Norris and Phillips (2003, 2009) identify another important constituent of scientific literacy apart from scientific knowledge, that is, scientific language. Norris and Phillips argue that science relies heavily on language, because science is "in part constituted by texts" and accumulates with the evolution of scientific language (Norris & Phillips, 2003, p. 233). Recognizing the indispensable role of scientific language, Norris and Phillips (2003, 2009) make a distinction between a derived sense of scientific literacy (scientific knowledge) and a fundamental sense of scientific literacy (scientific language). This distinction highlights the role of scientific language and allows for an investigation into the relation between the progress of scientific knowledge and the development of scientific language. Informed by Norris and Phillips's (2003, 2009) two senses of scientific literacy, the present study aims to further conceptualize the relation between knowledge and language, that is, the relation between scientific literacy in its fundamental and derived senses. Specifically, scientific literacy in its derived sense will be conceptualized within Bernstein's sociological perspective on knowledge, especially how knowledge goes through a process of recontextualization when being taught and learned in educational sites (see Section 2.3

for details on the recontextualization of knowledge). Scientific literacy in its fundamental sense will be conceptualized within a systemic functional (SF) view of language, which is a meaning-making system operating in context (see Section 2.4 for details on language and the semiotic construction of knowledge). This proposal is promising because both Bernstein's sociological theory and Systemic Functional linguistics (SFL) embrace the relation between knowledge and language. In addition, the fundamental sense of scientific literacy has been extended beyond language to other semiotic systems, such as images, that contribute to scientific meaning-making (see Section 2.5 for details on multimodality).

The theoretical contribution to the field of linguistics is projected to lie in the present study's potential to substantiate the "applicability" of Systemic Functional linguistics (SFL) in pedagogic discourses. SFL has been called "appliable linguistics" by Halliday (2008) because it aims to account for both the theoretical and applied aspects of language. Since the 1980s, studies employing SFL extensively examined literacy development across school curriculums to identify subject-specific language features, that is, those features that are inextricably linked to the representation of subject knowledge (Christie & Martin, 1997, 2007; Halliday & Martin, 1993; O'Halloran, 1998; 2000; Unsworth, 2000). These studies have illustrated how accessing subject knowledge is inextricably connected to a command of the lexicogrammatical features in written language, such as the construction of technicality in science with the resource of nominalization (Halliday & Martin, 1993). However, compared with the large body of research on the subject-specific features of written language, studies on spoken language (such as Lemke, 1990) are relatively few. With the understanding that scientific knowledge is represented, communicated, and developed through a dynamic interplay of several resources, such as language, gestures and images, a sole focus on written language is not enough to fully capture meaning-making in the classroom. This study is expected to offer new insights into the realizations of scientific knowledge in language (both spoken and written modes) and images in the process of explanation construction, and to develop new frameworks for analyzing features in language (both spoken and written modes) and images that can contribute to the development, representation and connection of scientific knowledge. The linguistic and multimodal features identified in this study, along with the emerging analytical frameworks, can be useful for further development of SFL in pedagogic discourses.

Pedagogically, the present study aims to examine the construction of scientific explanations in three sets of data: written explanations (see Section 4.2), verbal communications between teachers and students (see Section 4.3), and images (see Chapter 5). The present study is expected to identify schematic structures of scientific explanations and their linguistic realizations, which can be used to inform curriculum design, lesson planning, and the use of language and images as resources to make meaning. A multimodal analysis of classroom teaching in complex education contexts such as Hong Kong is valuable in helping teachers understand the ways of making meaning via language and other semiotic resources to enhance learning opportunities for their students. The findings from this study can shed light on learning-rich moments when multimodal resources are drawn on productively to multiply meaning. Such moments can be promoted and disseminated as good practices for science teachers. The findings from this study can also inform the design and development of teaching and learning materials and activities.

1.4 Outline of the thesis

The thesis consists of six chapters. This chapter presents the background, the rationale, the research aims and the guiding research questions of this study. Following a review of extant theoretical and empirical research in Chapter 2, the research design of this study, together with methods of data collection and analysis, is presented in Chapter 3. Chapter 4 presents the findings on the linguistic aspects of explanation construction from Theme analysis of written and spoken texts. Complementary to Chapter 4, Chapter 5 reports findings on the multimodal aspects of explanation construction from representational and logical analyses of images as well as analysis of language-image relations. Chapter 6 concludes this thesis with a summary of the major findings in relation to the research questions, a delineation of the contributions of this study, and a discussion of its limitations and suggestions for future research.

Chapter 2 Literature review

2.1 Overview

This thesis investigates the way different modes of communication (i.e., spoken language, written language and images) contribute to the construction of scientific explanations in the classroom. The present chapter reviews the theoretical and empirical studies relevant to this aim and delineates the nature of the present study.

The chapter begins with a review of the key concepts for this study, such as scientific literacy (Section 2.2) and knowledge (Section 2.3). This is followed by a review of theoretical work related to the semiotic construction of knowledge in education，that is, Systemic Functional Linguistics (Section 2.4) and Multimodality (Section 2.5). Empirical studies on the construction of scientific explanations are also reviewed (Section 2.6). The chapter ends with a summary of the theoretical and empirical literature underpinning the present study (Section 2.7).

2.2 Scientific literacy: Concepts, perspectives, and related research

The term "scientific/science literacy" was first introduced by Although it is a frequently mentioned concept in education and educational research, there has been little agreement among researchers as to its precise meaning (Airey, 2009). Given that it is not possible to discuss all the theoretical interpretations of this term, this section will focus on the interpretation of scientific literacy in two senses: its derived sense and its fundamental sense (Norris & Phillips, 2009).

Traditional views of scientific literacy mainly focus on the substantive or content knowledge of science, such as content of science, understandings of science and its applications, ability to think scientifically, and science-based social issues. These views are said to reflect the derived sense of scientific literacy (Norris & Phillips, 2009). The derived sense of scientific literacy reveals two conceptions of knowledge: 1) knowledge of science that can be used to interpret and explain the material world (i.e., the short-term view) and 2) knowledge about science in a social context that can be drawn on to develop life skills (i.e., the long-term view). While the short-term view advocates "science through education", placing the acquisition of content knowledge as the ultimate goal of science education, the long-term view adopts an "education through science" approach to lifetime science education with content knowledge serving as a means (Holbrook & Rannikäe, 2007). The difference reflects different views on values in science: The short-term view of scientific literacy assumes that science is value-free, objective, and comprised of universal concepts and laws, whereas the long-term view acknowledges values in science, that is, scientific literacy as composed of content knowledge and shaped by human activities in social contexts.

Notably, both views of scientific literacy fail to attend to the role of language in science. As Norris and Phillips (2003) argue, science depends crucially on text because "a person who cannot read and write is severely limited in the depth of scientific knowledge, learning, and education he or she can acquire" (p. 224). Such a view of the relationship between science and text reflects what Norris and Phillips (2003) term as the fundamental sense of scientific literacy. It is fundamental in the sense that "science would not be possible without text and … is in part constituted by texts and by our means of dealing with them" (Norris & Phillips, 2003, p. 233). Scientific knowledge is expressed through different levels of generalization and abstraction in language to allow for the accumulation of knowledge across time and space. The language of science, written texts in particular, also evolves to account for the accumulation of scientific knowledge and forms an integral component of scientific knowledge. As argued by Norris and Phillips (2003), reading a scientific text does not simply require an appreciation of the discipline-specific features of written language but also a continuous interpretation and reinterpretation of texts in context, where new meanings are actively constructed.

Norris and Phillips (2009) further argue that language is more than the instrument through which scientists accomplish tasks, but is inextricably linked to how scientists argue for their standpoint in scientific communities. At a micro level, language performs a wide range of functions in scientific inquiry, such as describing the subjects and data, recounting the research procedures and explaining the results. At a macro level, these functions are organized into an argumentative structure to favor a particular interpretation against the other alternatives (Norris & Phillips, 2009).

Norris and Phillips's (2003, 2009) distinction between the derived and the fundamental sense of scientific literacy is insightful, but has several limitations. First, the separation between the development of scientific literacy in its fundamental sense and that in its derived sense remains contested. Holbrook and Rannikäe (2007) questioned Norris and Phillips's (2003, 2009) notion of the fundamental sense, arguing that linguistic proficiency in reading and writing only forms part of scientific literacy in an "education through science" approach. In other words, the fundamental sense of scientific literacy cannot be developed in vacuum, but rather depends on the derived sense of scientific literacy. Conversely, the derived sense of scientific literacy also depends upon a range of linguistic resources to recontextualize scientific knowledge to serve different functions. Therefore, the present thesis assumes an interactive relationship between the fundamental and the derived sense of scientific literacy. Language of science makes meaning within its context of scientific knowledge and is shaped by the scientific knowledge, which is in turn shaped by language of science.

Second, the fundamental sense of scientific literacy remains ambiguous without a systemic account of language patterns. Norris and Phillips (2009) have identified three general types of errors in students' interpretations of reports: overestimating the degree of certainty expressed in the reports, confusing evidence with conclusions, and misinterpreting descriptions of phenomena with their explanations. They, however, have not provided answers to questions related to the nature of these patterns. For instance, to what extent is the degree of certainty controlled through linguistic resources? What distinguishes statements providing evidence from statements making conclusions? What are the characteristics of descriptions of phenomena and how do they differ from explanations of those phenomena?

To answer these questions, Bernstein's sociological perspective on knowledge and a Systemic Functional Linguistics (SFL) model of language can be useful in unmasking both knowledge and language patterns in developing scientific literacy. In discussing the nature of knowledge, Bernstein (1999, 2000, 2001) distinguishes knowledge structures in everyday communication and those in academic/professional communication. He also points out that knowledge in the school context goes through a process called recontextualization, whereby the original knowledge from its field of production is modified for students' acquisition. How scientific literacy in its derived sense can be further specified through knowledge structures and recontextualization of knowledge in school will be discussed in detail in Section 2.3.

In an SFL model, language is a semiotic system, which provides choices for one to make meaning. The ways of making meaning in language have been theorized in SFL on three dimensions, namely, the cline of instantiation (Section 2.4.2.1), the hierarchy of stratification (Section 2.4.2.2), and the spectrum of metafunctions (Section 2.4.2.3). These theoretical dimensions for the meaning-making of language provide a valuable resource for developing a comprehensive account of scientific literacy in its fundamental sense. How scientific literacy in its fundamental sense can be substantiated through an SFL model of language is discussed in detail in Section 2.4.

Third, although Norris and Phillips (2003, 2009) acknowledge that scientific texts are inherently multimodal and include the ability to interpret images and diagrams in such texts as part of scientific literacy in the fundamental sense, their primary focus remains on language, written texts in particular. However, this primary focus on language cannot account for complex and dynamic classroom interactions, which involve more than linguistic resources. In the classroom, scientific knowledge is represented, communicated, and developed through a dynamic interplay of semiotic modes (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001). This is because science communication requires "close and constant integration and cross-textualization" among semiotic resources (Lemke, 2002b, p. 27). In a detailed analysis of lesson video recordings, teaching materials and interviews with teacher/students to investigate their meaning-making in the classroom, Kress and his colleagues (2001) found that language, even talks supplemented by writings, was insufficient in understanding the classroom interactions, which did not constitute mere knowledge construction through the linguistic mode but a multisemiotic experience. Therefore, apart from the meaning-making of language (Section 2.4), the meaning-making of other semiotic modes than language (Kress & van Leeuwen, 2006) is essential to understanding how scientific knowledge is represented, developed and connected in the classroom. With this understanding, Norris and Phillips's scientific literacy in its fundamental sense can be further expanded by a multimodal perspective on the meaning-making of other semiotic modes than language. How scientific literacy in its fundamental sense can be supplemented with a multimodal perspective is discussed in detail in Section 2.5.

In sum, the notion of scientific literacy in the present thesis consists of both the fundamental and the derived sense of scientific literacy (Norris & Phillips, 2003, 2009). Scientific literacy in its derived sense focuses on the development of scientific knowledge in school education; the fundamental sense of scientific literacy concerns the role of language and other semiotic modes, such as images and gestures. In order to address the mutual development of scientific literacy in its derived and fundamental senses, Norris and Phillips's two senses of scientific literacy are supplemented by a sociological perspective on knowledge (Bernstein, 1999, 2000, 2001), an SFL model of language (Halliday, 1978; Halliday & Matthiessen, 2014), and an SFL-informed multimodal perspective on the meaning-making of other semiotic modes than language (Kress & van Leeuwen, 2006). In what follows, I shall explain how these perspectives can be integrated with and enrich Norris and Phillips's two senses of scientific literacy, as will be demonstrated in the present study.

2.3 Recontextualization of knowledge in education

The notion of knowledge, as used in this thesis, concerns the knowledge of science in school discourse. Bernstein's theory of pedagogic discourse has provided profound insights into both the nature of knowledge (Bernstein, 1999, 2000, 2001) and the recontextualization of knowledge in education (Bernstein, 1990, 2000).

In discussing the nature of knowledge, Bernstein (1999, 2000) distinguishes between horizontal discourses (e.g., everyday communication based on commonsense knowledge) and vertical discourses (e.g., school science with academic/disciplinary knowledge). Horizontal discourses are "local, segmental and context bound", whereas vertical discourses are "general, explicit and coherent" (Young, 2006, p. 118). Within vertical discourses, Bernstein also distinguishes between horizontal and hierarchical knowledge structures. Horizontal knowledge is segmentally organized and characteristic of disciplines such as the humanities and social sciences, whilst hierarchically organized knowledge is often found in natural sciences [1]. Therefore, the knowledge under investigation in this thesis can be further specified as embedded in hierarchical knowledge structures (i.e., explanations) found in vertical discourse (i.e., natural science).

Another important insight into knowledge in Bernstein's theory of pedagogic discourse is the recontextualization of knowledge in education (see Figure 2.1).

[1] The boundaries between the two types of discourses and knowledge are fractal rather than strict. As clarified by Abbott (2000) and Moore and Muller (2002), the dichotomies developed by Bernstein (1999, 2000) are fractal divisions, where the constitution of vertical knowledge structures can include elements of horizontality and vice versa.

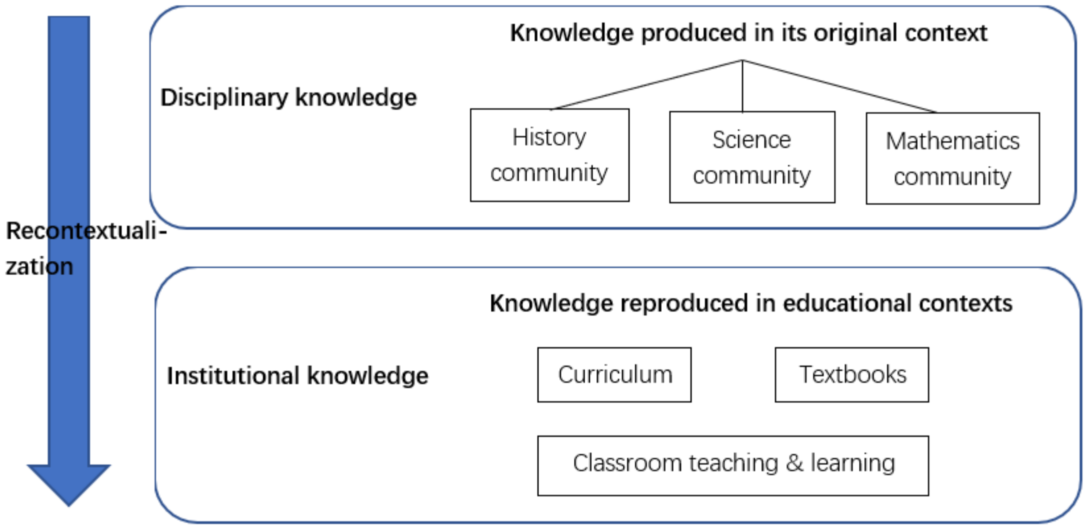


Figure 2.1 The theoretical framework of recontextualization (Bernstein, 2000)

Figure 2.1 illustrates what Bernstein (2000) referred to as the recontextualization of knowledge. Bernstein (2000) views recontextualization as the relocation of a discourse practice from its field of production into a new pedagogic discourse where the original discourse has been modified in order for social agents to acquire it. In such a process of recontextualization, the knowledge produced in its original context (e.g., science community) is selectively reproduced in different educational sites (e.g., school science curriculum, science textbooks, and science classroom teaching & learning). Therefore, the construction of school knowledge is not only discipline-specific, but also socio-culturally specific.

In what follows, how Bernstein's view of knowledge is related to SFL is discussed. To reveal the relation between knowledge and language, Bernstein (1999, 2000) argues that the different internal structuring of knowledge determines distinctive patterns of language. For vertical discourse, hierarchical knowledge structures are expressed through different levels of generalization and abstraction in language; In contrast, for horizontal discourse, segmentally organized knowledge is represented through a number of new specialized languages, without overarching principles to link them. Informed by Bernstein's sociological perspective, the relations between language, knowledge and context in pedagogic settings have been further examined by SFL scholars. An SFL perspective views language as an “exchange of meanings in interpersonal contexts” through which “people act out the social structure, affirming their own statuses and roles, and establishing the shared systems of value and of knowledge” (Halliday, 1978, p. 2). In this regard, an SFL analysis of classroom discourse has the potential for bridging classroom learning with knowledge and language use by participants in different sociocultural contexts.

According to Bernstein (2000), recontextualization involves two types of pedagogic discourses: instructional discourse and regulative discourse. Instructional discourse concerns the teaching of “specialized skills and their relationship to each other” (p. 31), whereas regulative discourse relates to “order, relations and identity” of social agents (p. 32) and dominates the pedagogic processes within which instructional discourse is usually embedded. Bernstein’s (2000) model of pedagogic discourse is reinterpreted by Christie (1999a, 1999b, 2001) within an SFL model in terms of instructional and regulative registers. The former relates to “the field of knowledge taught and learned”, whereas the later concerns “the pedagogic goals and organization of the classroom activity” (Christie &Soosai, 2001, p. 315). Together, these two registers are shaped by the recontextualization of knowledge, and in their turn, shape the distribution of knowledge in school (Rose & Martin, 2012). As illustrated by Rose and Martin (2012), knowledge can be recontextualized differently for high-achieving students (e.g., textbooks with dense technical information) and less advanced students (e.g., textbooks with brief texts and concrete examples). Therefore, it is important to attend to the possible transformation of knowledge in pedagogical discourses so that students at all levels can benefit from school education.

The recontextualization of knowledge in pedagogic discourses has been extensively researched drawing on Bernstein’ theory and SFL (Martin, 2011). This body of research includes studies of the transmission of knowledge in early years (e.g., Christie, 1999a, 2002; Halliday & Martin, 1993; Painter, 1999), in primary years (e.g., Christie, 2002; Gibbons, 2002; Iedema, 1996), at secondary school settings (e.g., Christie, 2002; Christie & Martin, 2007; Gibbons, 2003; Martin, 2007; Unsworth, 2000; Veel, 1997, 1999), and in higher education (e.g., Carvalho, Dong & Maton, 2009; Maton, 2013). These studies have been informed by a genre-based pedagogy, where the concept of genre, that is, a "staged goal-oriented social process" (Martin, 2009, p. 10), has evolved in three broad phases: the Writing Project and the Language and Social Power project in the 1980s, the Write it Right project in the 1990s, and the Reading to Learn project in the past decade (Rose & Martin, 2012). These studies have provided comprehensive accounts of the process of recontextualization of different forms of knowledge across school subjects and school years with an emphasis on knowledge about language. Underlying these studies was a model of language developed in SFL (e.g., Halliday & Matthiessen, 2014; Martin & Rose, 2007, 2008), which will be introduced in Section 2.4.

2.4 Language and the semiotic construction of knowledge

2.4.1 Language and knowledge in education

The role of language as one of the primary semiotic resources to construct knowledge in school education is widely recognized (e.g., Coffin & Derewianka, 2008; Halliday & Martin, 1993; Lemke, 1990; Schleppegrell, 2004). An adequate understanding of the language features associated with a specific discipline (e.g., scientific English) is considered essential for the successful teaching and learning of disciplinary knowledge (e.g., scientific knowledge) (Bratkovich, 2018). With this understanding, efforts have been made to integrate the learning of language and knowledge, such as school-based language immersion programs, Content-Based Language Teaching (CBLT) and Content and Language Integrated Learning (CLIL) in both native language (L1) and second language (L2) contexts (e.g., Lindholm-Leary, 2001; Lin & Lo, 2017; Mehisto, Marsh, & Frigols, 2008).

Among the linguistic theories informing those studies, SFL (Halliday, 1978; Halliday & Matthiessen, 2014; Martin, 1992) has provided valuable insights into the identification of distinctive language features in a discipline, such as the key genres across disciplines throughout school years and their corresponding lexicogrammatical features (Christie & Martin, 1997, 2007; Halliday and Martin, 1993; Martin & Rose, 2008, 2012; Unsworth, 1999). For instance, Halliday and Martin (1993) identified some unique features in scientific texts, such as technical taxonomies, abstraction and nominalization[2], which will be discussed in detail in Section 2.6. Those discipline-specific language features identified by SFL scholars have informed pedagogies that have been implemented in various contexts, such as Australia (e.g., Martin, 1999; He & Forey, 2018), the US (e.g., Schleppegrell, 2004), and Hong Kong (e.g., Forey & Polias, 2017). Those studies show that SFL is a powerful tool to analyze the ways of making meaning through language. The following section reviews the theoretical concepts from SFL that inform the analyses conducted in this study.

2.4.2 SFL: Theoretical concepts

SFL has been what Halliday (2008) calls "appliable linguistics", in that it aims to account for both the theoretical and the applied aspect of language. According to Halliday (1978, 1985, 2007), language is a semiotic system. A semiotic system is a system of meaning, where particular choices can be made out of the meaning potentials. SFL provides an array of different interrelated concepts for examining and understanding the semiotic system that are called "dimensions". These dimensions model language as a semiotic architecture that can be examined from different angles for different purposes. It is important to note that these dimensions are complementary to each other, as they are not in absolute isolation of their own. This study focuses on three complementary dimensions and their related concepts: the cline of instantiation, the hierarchy of stratification, and the spectrum of metafunction. These focal dimensions will be introduced in the following subsections.

[2]Nominalization is the grammatical choice of rendering verbs or adjectives into nouns or nominal groups (e.g., *utilization* and *applicability*).

2.4.2.1 The cline of instantiation

Instantiation is the dimension of language as a system and context. Instantiation in the language system explains the relation between the instance pole (i.e., particular observable instances of meaning-making in texts) and the potential pole (i.e., the overall possible meanings available in language system). In other words, the language system represents meaning potential, which provides all the possible choices for speakers/writers to make meaning, whereas a text is the particular choice of meaning made by the speakers/writers. The language system is related to texts through "instantiation" – a text is an instance of the potential and, consequently, instantiates the language system.

Above the linguistic system, context is "a higher-order semiotic system" (Matthiessen, Teruya, & Lam, 2010, p. 77). Similar to the language system, context extends along the cline of instantiation from the instance pole (i.e., context of situation) to the potential pole (i.e., context of culture). Context of situation represents particular instances of the overall system of context in a culture (context of culture). Context is organized by three register[3] variables: field, tenor and mode. Field covers social activities and human experiences in a given context; tenor enacts the role relationships between participants that are involved in these activities; mode concerns the role that is played by language in the context (Halliday, 1978). The relation between context and the linguistic system is realization. While context of culture is realized in the linguistic system, context of situation is realized in text. According to Halliday (1978), context of situation is "an instance of the meanings that make up the social system" (p. 142). Between the potential and the instance pole, there are a series of intermediate regions of subpotential-instance type on the cline of instantiation (see Figure 2.2).

[3] The use of the term register in this study follows Martin's (1992) tradition, which is a level within context. This is different from Halliday and Matthiessen's (2014) tradition, where register refers to a repertoire of text types and is a functional variety of language. To avoid confusion, register in Halliday and Matthiessen's (2014) sense is called "text type" in this study.

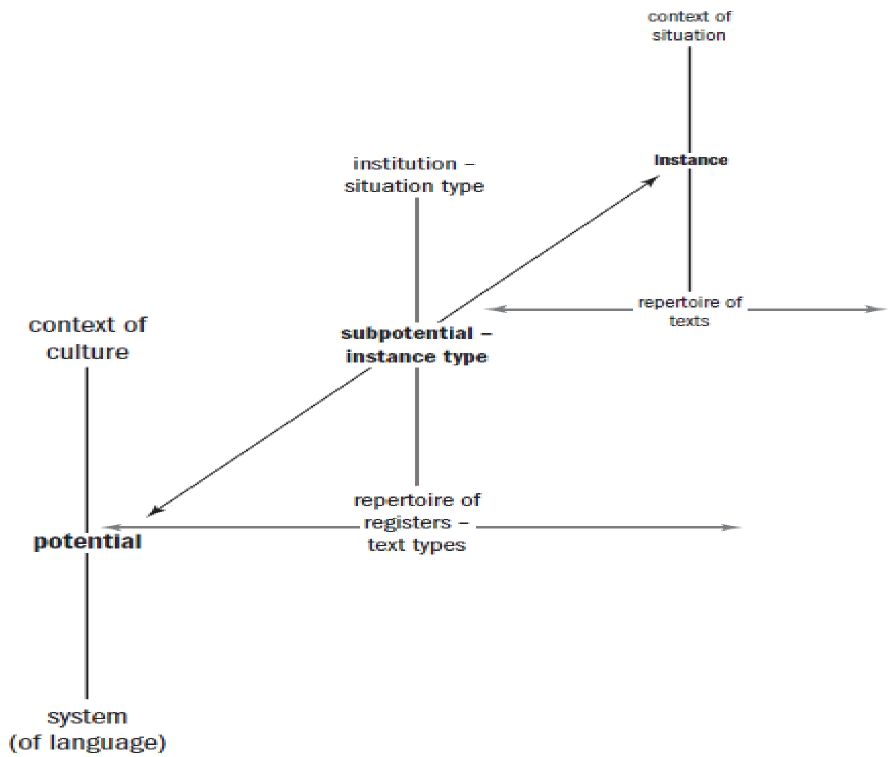


Figure 2.2 The cline of instantiation (Halliday & Matthiessen, 2014, p. 28)

The subpotential region in context is called institution/situation type, while the subpotential region in language is called text type. Institution is interpreted as a subsystem of the social system, such as workplace, school and home. Each institution embodies a range of recurrent situation types, with similar configurations of field, tenor and mode. For instance, in the institution of school, to explain a phenomenon can be observed across subjects, where the field is the construction of an explanation, the tenor is the interaction between teachers and students, and the mode can be spoken or/and written language. Institution/situation types are realized through a repertoire of text types. For instance, the institution of school covers a range of text types, such as procedure recounts, explanations, descriptions and argumentations. These institutions/situation types are instantiated in context of situation, such as a teacher explaining the Magdeburg Experiment to his students using speech. The realizations of such context of situation are a repertoire of texts, such as an explanation of the mechanism in the Magdeburg Experiment and a descriptive text of the instruments used in the experiment.

The theoretical framework of instantiation in the present study applies to both language system and image system, which is illustrated in Figure 2.3.

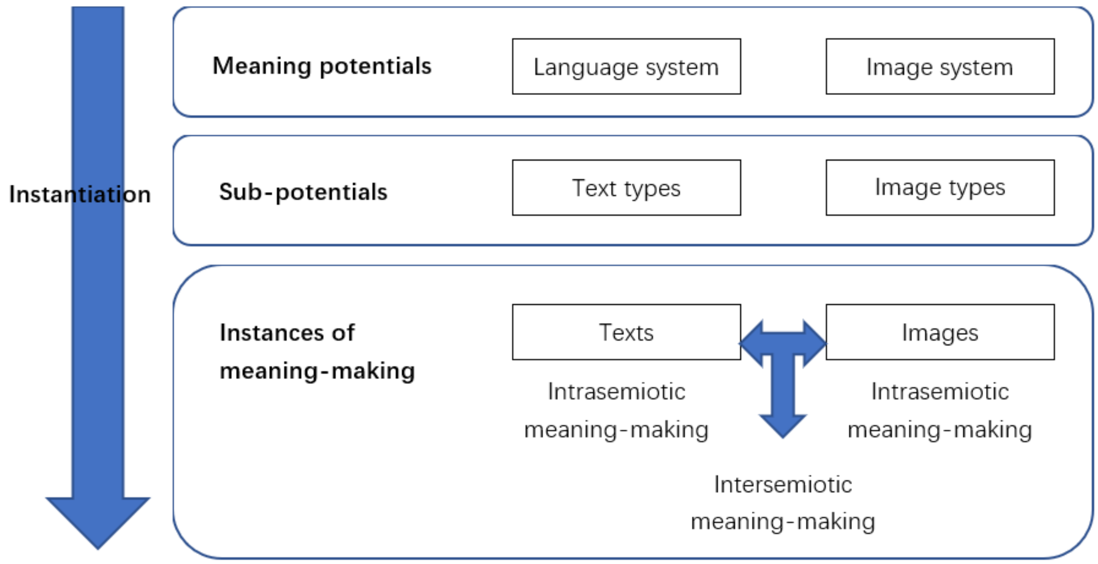


Figure 2.3 The cline of instantiation proposed in the present study

As Figure 2.3 shows, on the potential pole are meaning potentials in the language system and those in the image system; on the subpotential regions are text types and image types serving communicative purposes in institutions (e.g., to explain, to describe, and to recount); on the instance pole are choices of texts and images, which convey meanings in themselves (e.g., intrasemiotic meaning-making) and interact with the meanings in other semiotic systems (i.e., intersemiotic meaning-making). The present study is situated on the cline of instantiation between subpotentials and instances: the situation type is to explain a phenomenon in the institution of school through the text type of explanation (subpotential) and the context of situation is an instance of explaining by constructing an explanation (instances). The significance of the cline of instantiation is that it connects the linguistic analysis of the texts collected in this study (instances) with an investigation into the characteristics of an explanation and the ways of constructing an explanation in school in general (subpotential). It would also enable the analysis to move across text types (subpotential), such as explanations, descriptions and recounts, which is an interesting area but not examined in this study. It is important to note that the situation type of explaining can be realized in more than one semiotic system, such as images, gestures and space. While an extensive body of studies in SFL focuses on the realization of situation types in the system of language (e.g., Martin & Rose, 2008, 2012; Christie & Derewianka, 2008), studies on the realization of situation types in semiotic systems other than language are relatively few.

What I am particularly interested in is the construction of explanations in the written mode and the contributions from the semiotic systems of language (both spoken and written mode) and images. This perspective allows us to view the construction of a text as a product (e.g., the written text of an explanation) and as a process, where the ideational meanings from a semiotic system are organized internally (e.g., the formation of the written text) and interact with other semiotic systems (e.g., the interactions between language and images). To sustain such a perspective, it is useful to include two other dimensions in SFL: the hierarchy of stratification and the spectrum of metafunctions, which will be introduced in Section 2.4.2.2 and Section 2.4.2.3 respectively.

2.4.2.2 The hierarchy of stratification

Another complementary dimension in the architecture of language is stratification (Halliday & Matthiessen, 2014). This dimension represents the language system as a hierarchy of strata which are linked by realization (see Figure 2.4).

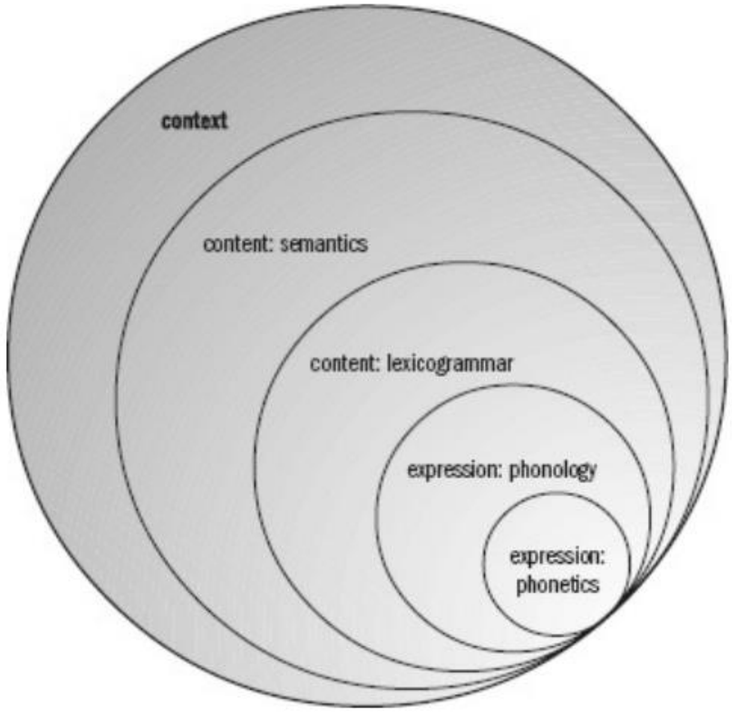


Figure 2.4 The hierarchy of stratification in the language system (Halliday &Matthiessen, 2014, p. 70)

The model in Figure 2.4 comprises context and the strata of language. The strata of language are "embedded" in context as language realizes context (cf. Halliday, 1978; Halliday & Hasan, 1985; Hasan, 1999; Martin, 1992). The strata of language are composed of semantics, lexicogrammar, phonology and phonetics. A higher stratum is collectively realized by all the lower strata. For instance, semantics is realized not only by lexicogrammar but also by phonology.

While there is a general agreement among SFL scholars that context is shaped by the three register variables of field, tenor and mode (see Section 3.2.1 for discussions on the register variables), a further stratification of context is suggested by Martin (1992). In this stratified model, context is further stratified into two connotative planes: genre and register. Genre refers to a system of "staged goal-oriented social processes" (Martin, 1986, p. 246), and operates at a higher order of context over register. Genre is realized through the lower level of context, namely register. Register is mediated through three register variables – field, tenor and mode. The stratified model of context and language is presented in Figure 2.5.

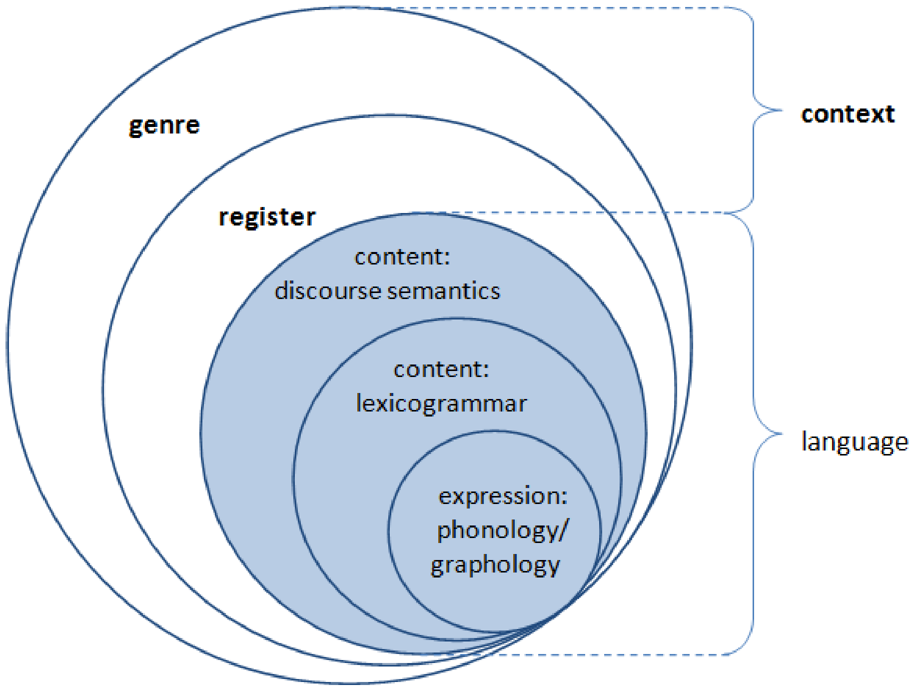


Figure 2.5 The stratification of language and context in Martin's (1992) model

Based on Hjelmslev's (1961) notions of "content" and "expression" planes, language can be internally stratified into content potential and expression potential. The content plane of the language system consists of semantics (meaning potential) and lexicogrammar (wording potential), while the expression plane consists of phonology and phonetics (sounding potential). Semantics is the higher stratum of the content plane and interacts with context to construe meaning. Lexicogrammar is the lower stratum of the content plane, located between semantics and phonology. It is the realization of meaning in wording through the resources of grammar and lexis. Phonology and phonetics form the expression plane of language. Phonology expresses meaning as sounding. For instance, lexicogrammatical features such as mood are expressed by prosodic features such as tone (Halliday & Greaves, 2008; Halliday & Matthiessen, 2014).

The relationship between strata is realization. While the relation between the strata within the content plane (i.e., semantics and lexicogrammar) is natural, the relation between the content plane and the expression plane is largely arbitrary depending on conventions (Martin, 1992). The inter-stratal relationship of realization is a kind of metaredundancy (Halliday, 1992; Matthiessen, 2007; Martin, 2010), a term which is coined by Lemke (1984). That is, lexicogrammar realizes context through the realization of semantics; phonology realizes semantics through the realization of lexicogrammar, and phonetics realizes lexicogrammar through the realization of phonology.

The significance of the hierarchy of stratification lies in the comprehensive view it offers into meaning-making in a semiotic system: from below, from above and from roundabout. From below, in the stratum of phonology, the vocal realization of grammatical features can be identified; from above in the stratum of semantics, the discourse functions of a text can be identified; and from roundabout in the stratum of lexicogrammar, an investigation into the relation between different grammatical features can be conducted. The present study adopts the views from above (i.e., in the stratum of semantics) and from roundabout (i.e., in the stratum of lexicogrammar). From above, in the stratum of semantics, discourse features, such as hyperThemes, are examined; from roundabout, lexicogrammatical features, such as the choices of Theme in a clause, are examined.

Apart from examining meaning-making within the system of language, the present study also investigates meaning-making in other semiotic systems (i.e., images). It is important to note that stratifications in semiotic systems can vary, and thus whether the stratification model of language can be applied to other semiotic systems requires careful consideration. The stratification in the system of images is discussed in Section 2.5. In addition to the dimensions of instantiation (Section 2.4.2.1) and stratification (Section 2.4.2.2), the third dimension in the SFL model is the spectrum of metafunctions (Section 2.4.2.3), which is crucial for understanding the construction of explanations in the present study.

2.4.2.3 The spectrum of metafunctions

The spectrum of metafunctions represents three types of meaning in the language system, that is, ideational, interpersonal and textual meanings. In an SFL model, when used to make meaning in a social context, language performs three metafunctions simultaneously: as ideational resources to construe human experience into categories or taxonomies; as interpersonal resources to enact social roles and relationships; as textual resources to organize both ideational and interpersonal resources into a coherent sequence of discourse (Halliday & Matthiessen, 2014).

The ideational metafunction construes experiences through two complementary modes of meaning: experiential and logical. Language in its experiential meaning reflects the construction of phenomena in the real world in the human mind; it is a “construct in the mind” (Halliday & Matthiessen, 1999, p. 7). Language in its logical meaning constructs logical relations between one model of experience and another. They are complementary in that they co-construct ideational meanings through the experiential system of TRANSITIVITY and the logical system of TAXIS in lexicogrammar (Halliday & Matthiessen, 2014). Interpersonal metafunction concerns the enactment of personal and social relationships through interaction with other people. Language has different resources for enacting interpersonal meanings, such as the semantic system of SPEECH FUNCTION and the grammatical system of MOOD (Halliday & Matthiessen, 2014). Textual metafunction refers to the organization of ideational and interpersonal meanings into a text which is coherent within itself and accords with the context. The resources for organizing a text include thematic progression, information flow pattern in the text as well as the grammatical systems of INFORMATION and THEME (Halliday & Matthiessen, 2014).

Since the meaning-making of a semiotic system such as language operates in context, the metafunctional spectrum orients towards the use of language in social context. In SFL, the spectrum of metafunctions, comprising ideational, interpersonal and textual metafunctions, each realizes the contextual parameters of field, tenor and mode respectively. The intersection of the hierarchy of stratification and the spectrum of metafunctions is illustrated in the stratification-metafunction matrix as shown in Figure 2.6.

	ideational		interpersonal	textual
context	field		tenor	mode
semantics	rhetorical relations	configuration	negotiation	progression
grammar	taxis & logico-semantic type	transitivity	mood & modal assessment	theme; information
phonology			tone	tonicity

Figure 2.6 Stratification-metafunction matrix (based on Matthiessen, Teruya, & Lam, 2010, p. 106)

The contextual values of field, tenor and mode correspond to meanings in language: they resonate with the stratum of semantics and penetrate into the stratum of lexicogrammar (Halliday & Matthiessen, 2014). The configuration of ideational meanings resonates with field values and is realized through grammar resources, such as transitivity, taxis and logical semantic types. The negotiation of interpersonal meanings resonates with interpersonal values and is enacted through mood and modal assessment. The progression of textual meanings resonates with mode values and is organized by such grammatical resources as theme and information. A metafunctional perspective on language provides interesting insights into the relationship between the social and communicative purposes of texts and their distinctive linguistic realizations (Halliday & Hasan, 1985). The spectrum of metafunctions enables a view of the production of a text as a multifunctional act in social context, performing "content function" (ideational metafunction), "participatory function" (interpersonal metafunction) and "enabling function" (textual metafunction) (Halliday, 1978, p.112). The contribution of a text to the situation that it operates in can orient towards field, tenor or a mixture of both field and tenor, depending on the goal of the situation (Halliday & Matthiessen, 2014).

The present study examines textual metafunction for two reasons. Firstly, the goal of the situation under investigation in this study is to explain a phenomenon in the institution of school; therefore, the texts operating in such situations tend to be field-oriented. With this understanding, the present study focuses on how the field of knowledge is developed through the use of language. The development of scientific knowledge resonates with the textual metafunction, specifically, the organization of ideational resources. Secondly, compared with the large number of studies conducted to examine the ideational metafunction (e.g., Christie, 2002; Halliday, 1993; Hao, 2018; He &Yang, 2018; Maxwell-Reid, 2015; Maxwell-Reid & Lau, 2016) and the interpersonal metafunction (e.g., Hood, 2010; Hood & Forey, 2005, 2008; Martin & White, 2005; Ngo & Unsworth, 2015; Painter, 2003), studies focusing on the textual metafunction are relatively few (with the exceptions of Banks, 2008, 2012; Forey, 2002, 2004; Kong, 2004; Taboada & Lavid, 2003; Thompson & Thompson, 2009).

Specifically, the development of knowledge through the language system is examined through Theme analysis and generic analysis of written and spoken texts related to explanations. The following section reviews studies on Theme and genre that are relevant to this project.

2.4.3 Focus of the present study: Theme and schematic structures

The textual metafunction has an enabling effect on the other metafunctions: it organizes ideational meanings and interpersonal meanings into a coherent text. Within the textual metafunction, the choice of Theme constitutes the major system. Theme functions as “the point of departure of the message” in a clause, and the remainder of the message is called Rheme (Halliday & Matthiessen, 2014, p. 89). In their comprehensive introduction to SFL, Halliday and Matthiessen (2014) provide two parameters of Theme at the clausal level: metafunctional types and Theme markedness. These two parameters will be discussed in Section 2.4.3.1 and Section 2.4.3.2 respectively.

2.4.3.1 Metafunctional types of Theme

Depending on their functions, Themes can be categorized into three metafunctional types: topical Themes, interpersonal Themes and textual Themes. The topical Theme of a clause is the first constitute of the experiential structure of the clause, which can be a participant, a circumstance or a process. An example of the topical Theme of a free clause is presented below:

Example 2.1 An example of identifying a topical Theme in a free clause

We	force out the air inside the rubber sucker by pressing it down.
Theme	Rheme

The Theme of this declarative clause is “we”, which appears first in the experiential structure. A process or a circumstance can be a Theme in a clause, such as “think” in the imperative clause “Think about it.”, and “this time” in the declarative clause “This time you are right.” A topical Theme is obligatory for the constitution of a Theme, though it is possible to include other optional elements in a Theme that perform textual and interpersonal functions. The elements proceeding topical Themes are called textual Themes and interpersonal Themes. A textual Theme structures the text and links the clauses, as exemplified by “so” in the clause “So we have a net force” to construct a causal relation between this clause and its proceeding one. An interpersonal Theme provides the writer’s/speaker’s viewpoint and suggests an angle to interpret the text. For instance, the interpersonal Theme “I think” in the clause “I think we will not go through them” suggests that “not going through them” is the viewpoint of the speaker. Categorizing Themes according to their metafunctional types enables the investigation of thematic patterns from three perspectives: topically (what experiential element is foregrounded in a clause), interpersonally (what viewpoint is provided by the producer of the text), and textually (how a clause is linked to another and how a text is structured). Relating to the goal of the present study, this metafictional perspective on Themes can elucidate the role performed by each type (i.e., topical, interpersonal and textual Themes) in the construction of scientific explanations.

2.4.3.2 Theme markedness

Another important parameter of Themes at the level of a clause is Theme markedness. An unmarked (topical) Theme refers to the typical realization of a Theme, such as the Subject (e.g., “we”) in a declarative clause (e.g., “We force out the air”). A marked (topical) Theme refers to the alternative realization of a Theme in contrast with the unmarked choice of a Theme, such as the Circumstance (e.g., “This time”) in a declarative clause (e.g., “This time we force out the air”). As pointed out by Halliday and Matthiessen (2014), the default choice of a Theme is its unmarked form (i.e., unmarked Theme) unless there is very good reason to foreground its alternative (i.e., a marked Theme). Unmarked choices of topical Themes can enhance the discourse flow, whereas marked topical Themes are motivated by the need to signal a shift or stage in the text or to invoke a particular angle to interpret the text (Forey, 2002). The motivation to choose a marked topical Theme can also derive from the need to maintain the development of a text through thematic progression, which will be discussed in Section 2.4.3.3.

Halliday and Matthiessen (2014) argue that Theme markedness concerns not only topical Themes but also interpersonal and textual Themes, which constitute “the full thematic potential of a clause” (p. 110). They suggest that when interpersonal or textual Themes appear in a clause, it is slightly less frequent for a topical Theme to be marked, because part of the “quantum of thematicity” has been taken up (p. 110). Based on the full thematic potential of a clause, they recategorize the realizations of non-topical Themes (i.e., interpersonal and textual Themes) under two main categories: inherently thematic and characteristically thematic elements. Inherently thematic elements consist of continuatives and conjunctions, which constitute the setting of a clause (continuatives) or a specific logical-semantic relationship in relation to another clause (conjunctions).

Characteristically thematic elements consist of conjunctive adjuncts[4], vocatives, modal adjuncts, finite verbal operators, and WH-items[5] in interrogative clauses, which construct a sematic relation with a proceeding element (conjunctive adjuncts) or express the speaker's angle (vocatives, modal adjuncts and finite verbal operators). Halliday and Matthiessen (2014) have proposed a scale to account for the Theme markedness of non-topical elements with increasing markedness: without any non-topical elements (the least marked), with inherently thematic items, and with characteristically thematic items (the most marked). An example is provided in Figure 2.7. The Theme and Rheme of a clause are separated with the symbol of "+".

Least marked → Most marked

	topical Theme unmarked	**topical Theme marked**
Without non-topical elements	You + can't store protein.	Protein + you can't store.
With inherent thematic items	But you + can't store protein.	But protein + you can't store.
With characteristic thematic items	However, you + can't store protein.	However, protein + you can't store

Most marked

Figure 2.7 An example of examining Theme markedness (adapted from Halliday and Matthiessen, 2014, p. 111)

The present study considers the Theme markedness of a clause in terms of topical and non-topical markedness (i.e., inherent and characteristical markedness). The examination of Theme markedness allows an investigation of the distribution of marked and unmarked choices, and the motivations behind those choices. The analytical framework for Theme markedness in this study is presented in Section 3.4.2.

[4] Conjunctive adjuncts are categorized as textual Themes according to metafunctional types, and recategorized as characteristically thematic elements according to the quantum of thematicy in a clause. Halliday and Matthiessen (2014) argue that although conjunctive adjuncts occupy roughly the same space as conjunctions, but they can appear either as Themes (e.g., "therefore the scheme was abandoned") or in other places of a clause (e.g., "the scheme was therefore abandoned"). This makes the choice of a conjunctive adjunct as the Theme of a clause more marked than a conjunction, and thus a conjunctive adjunct is considered as a characteristically thematic element.

[5] WH-items in interrogative clauses are both interpersonal and topical Themes (see Halliday and Matthiessen, 2014, p. 112 for detail).

2.4.3.3 Thematic progression

Thematic progression (TP) is one of the key thematic patterns at the level of discourse, which was first termed by Daneš (1974). TP concerns the choice and ordering of Themes in a text to develop a text, that is, how Themes are picked up from the previous discourse, and elaborated on or abandoned in the following discourse (Forey & Sampson, 2017). Daneš (1974) described three major TP patterns: simple linear, constant and derived hyperthematic progression. In a simple linear TP, Themes are picked up from the Rhemes of previous clauses. A constant TP involves Themes that are picked up from the previous Themes. In a derived hyperthematic progression, Themes are derived from higher-level discourse features, such as a title or a topic sentence of a paragraph. Daneš's work provided a new insight into the development of a text. However, derived hyperThemes are organized at a different level from the other two TP patterns, which makes the comparison between simple linear, constant and hyperThemes problematic. This section will focus on TP, and discuss matters related to hyperThemes in Section 2.4.3.4.

In a corpus study of biomedical slide talks, Dubois (1987) integrated Daneš's (1974) TP patterns into linear/themic (Themes from previous Themes) and constant/rhemic (Themes from previous Rhemes). She also added the types of contiguous and gapped progression to account for the continuity of progression. In a contiguous progression, the Theme is picked up from its immediate proceeding clause, whereas in a gapped progression, the Theme is picked up from a distant proceeding clause. In addition, she points out that the origin of a Theme can be traced back to multiple sources in a text. Dubois's (1987) study on spoken texts revealed distinctive TP patterns in spoken discourse, such as gapped progression. The introduction of contiguous and gapped progression provides tools for characterizing the continuity of TP progression, and the notion of a Theme deriving from multiple sources brings along a different perspective on TP patterns, that is, sources of a Theme.

Another study that is highly relevant to the present study is Taboada and Lavid (2003). In a corpus study of thematic patterns in scheduling dialogue, Taboada and Lavid (2003) examined Themes at both the levels of a clause and discourse to characterize generic stages of scheduling dialogue (see Section 2.4.3.5). At the clausal level, they assigned three parameters of Themes: metafunctional types (see Section 2.4.3.1), semantic categories of topical Themes, and topical Theme markedness (see Section 2.4.3.2). At the discourse level, they examined TP patterns. The TP patterns in their study incorporated Dubois's (1987) types – i.e., contiguous, gapped, and multiple progression (which can be separated or integrated) – and added a new type "Other" to account for the cases where Themes cannot be linked to the previous text (see Figure 2.8).

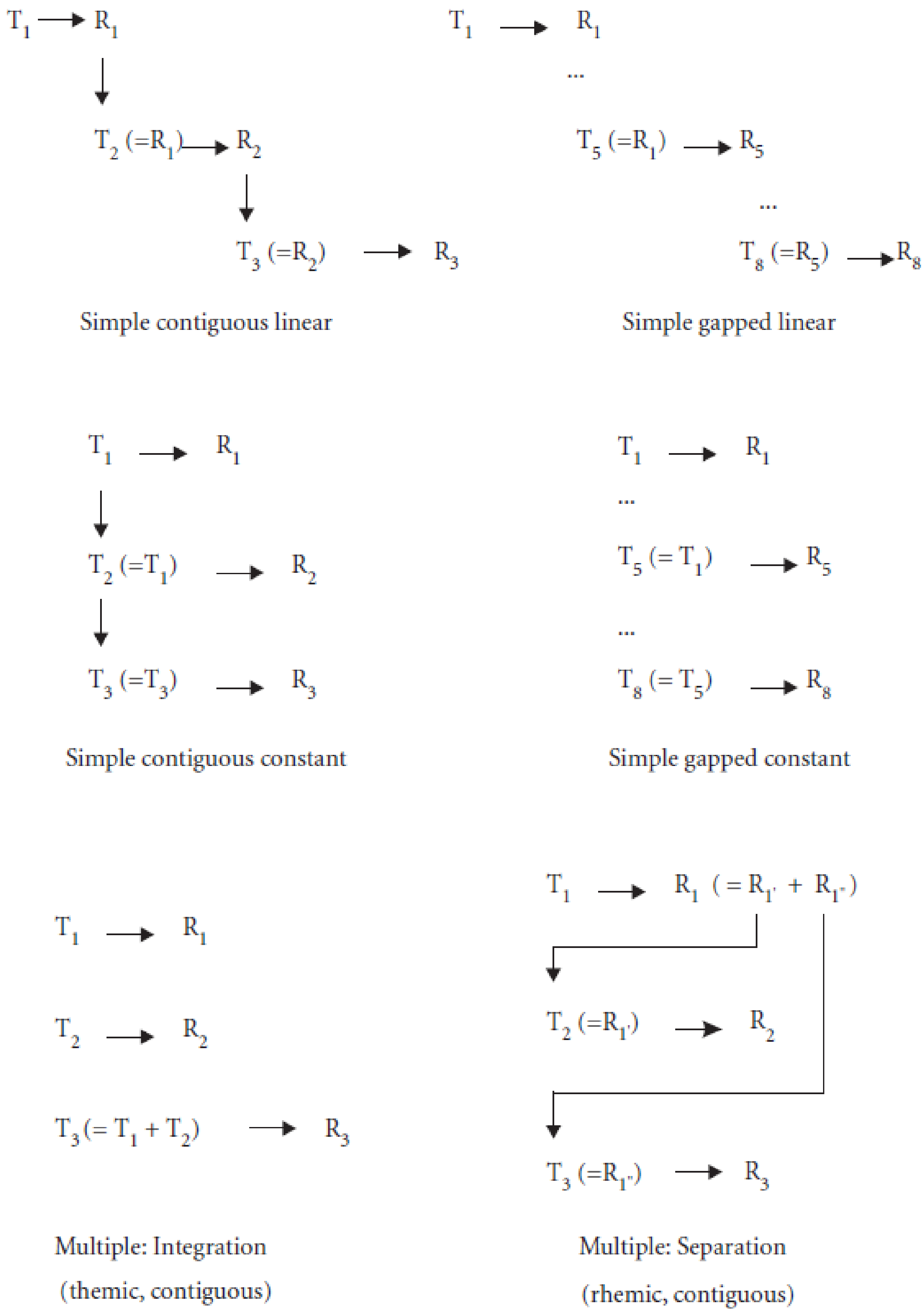


Figure 2.8 Thematic progression patterns in Taboda and Lavid (2003, p. 156)

Taboda and Lavid’s (2003) study has so far been the most comprehensive study of thematic patterns for three reasons. Firstly, their study considered thematic patterns beyond the level of a clause to incorporate discourse features, such as thematic progression. This enabled the examination of a Theme as the departure of a message in a clause and as the contributor to the overall development of a text. Secondly, the new TP patterns, such as contiguous and gapped progression, provided important tools for future research on spoken texts. Thirdly, their attempt to relating thematic features to generic stages of scheduling dialogue revealed distinctive thematic patterns performing certain functions, and highlighted the motivation behind the choice of Themes. However, their categorization of thematic patterns showed the parameters they attempted to examine selectively rather than exhaustively. They included the parameters of TP paths (i.e., linear or constant), sources (i.e., simple or multiple), and continuity (i.e., contiguous or gapped). However, some TP patterns were overlooked in their study, such as multiple linear gapped progression, where the Theme is derived from previous Rhemes that are not in the immediately preceding clause (see Section 3.4.2.1 for detail). In addition, the roles of hyperThemes and macroThemes were neglected in Taboda and Lavid’s (2003) study due to the nature of the spoken texts under investigation (see Section 2.4.3.4 for detail). Based on Taboda and Lavid’s (2003) framework, the present study proposes an analytical framework for analyzing thematic progressions that can be applied to both written and spoken texts (see Figure 3.16 for the parameters of the framework and Section 3.4.2 for a detailed presentation of analytical frameworks of Themes).

2.4.3.4 hyperThemes and macroThemes

Other thematic patterns at the level of discourse are hyperThemes and macroThemes. A hyperTheme is an introductory sentence in a paragraph, which predicts the type of topical Themes that are likely to occur in the following clauses (Martin, 1992). A hyperTheme is similar to the traditional notion of topic sentence in a paragraph, which can be predicted by a macroTheme (Martin, 1992). Typically, hyperThemes are realized by a sentence and macroThemes by a paragraph. As pointed out by Thompson (2014), hyperThemes and macroThemes tend to associate with planned monologic texts, such as formal written texts and planned spoken monologue. Focusing on written texts for academic purposes, Hood (2009) highlighted the key role played by hyperThemes in organizing a text and regarded hyperThemes as one crucial component of successful academic writing.

2.4.3.5 Genres and schematic structures

The basic unit at the stratum of semantics is a text. Internally, the text is organized as patterns of ideational, interpersonal and textual meaning. Externally, the context where the text operates in projects the structure of the context of situation onto the text. Genre is defined as “the social purpose of a text” which coordinates the register variables of field, tenor and mode into recurrent structural organizations (Martin & Rose, 2008, p. 22). Martin and his colleagues have developed a framework to account for genre analysis in educational discourse (Martin & Rose, 2012). Admittedly, there are other frameworks in analyzing genres, such as Hasan’s Generic Structure Potential (GSP) (Halliday & Hasan, 1985) and Swales’ (1990) move analysis, but Martin and Rose’s (2012) genre model is adopted in this study for two reasons. Firstly, this model has been developed for textual analysis in educational contexts. Secondly, this model enables a fine-grained analysis of texts in a secondary school context (Maxwell-Reid & Lau, 2016).

Studies based on Martin and Rose’s (2008) genre model have identified key genres in a range of school subjects, such as history, science and English language. The key genres in science education at the junior secondary level are procedural recounts, descriptive and classifying reports, and explanations, among which explanations stand out as the most challenging genre for students (Love, 2009; Martin & Rose, 2008). The schematic structure of an explanation text is Phenomenon Identification ^ Explanation Sequence, which consists of two stages: to identify the phenomenon under investigation (i.e., Phenomenon Identification) and to explain the phenomenon through a series of events that are causally linked (i.e., Explanation Sequence) (Martin & Rose, 2008). Depending on the type of phenomenon under investigation, explanation texts can be further categorized into five types: causal, factorial, consequential, conditional and theoretical explanations (Martin & Rose, 2012; Veel, 1997). Table 2.1 shows different types of explanation and their generic stages, with the symbol "^" suggesting the relation of "followed by", and "1-n" suggesting the number of elements involved can range from one to numerous.

Table 2.1 Types of explanation and their generic stages (based on Rose & Martin, 2012, p. 130; Veel, 1997, p. 172)

Type	**stage**
Causal explanation	Phenomenon ^ Explanation sequence (1-n)
Factorial explanation	Phenomenon ^ Factor (1-n)
Consequential explanation	Phenomenon ^ Consequence (1-n)
Conditional explanation	Issue ^ Explanation (1-n)
Theoretical explanation	Phenomenon/Statement of theory ^ Elaboration (1-n)

As Table 2.1 shows, the stages of each type of explanation vary according to the type of phenomenon under investigation and the focus of the explanation. Causal explanations serve the function of explaining how and why a phenomenon occurs through a sequence of events that are linked in sequential and causal relations. Factorial explanations account for a phenomenon in terms of the collective effect of several factors. In contrast to factorial explanations, consequential explanations focus on a phenomenon which several consequences can be attributed to. Conditional explanations provide alternative explanations of a phenomenon. Theoretical explanations introduce a theoretical principle to account for a phenomenon that is counter-intuition. The categorization of explanations with varied generic stages can make explicit the relations between linguistic features related to context and facilitate the discussion of the contextual motivation of a text.

2.4.3.6 Empirical studies on thematic patterns

Studies of thematic patterns in written texts have focused on professional communication (e.g., Forey, 2002; Kong, 2004, Tompson & Tompson, 2009) and educational discourse (e.g., Berry, 1995; Christie & Derewianka, 2008; Coffin, 2004).

These studies have highlighted one or several thematic patterns mentioned in the previous sections in relation to the motivations behind such choices of Themes, because of either registerial or contextual considerations. For instance, in their work on history textbooks, Coffin and Derewianka (2008) point out the crucial role of circumstantial adjuncts as Themes to motivate the development of a history narrative along the scale of time. In a corpus study of scientific journal articles, Banks (2008) observed that the TP path in scientific written texts involves a hybridization of constant and linear patterns, with a linear TP path to narrate the experiment and a constant TP path to explain the phenomenon. He also suggests a set of 14 semantic categories for topical Themes in scientific journal articles, which can reveal the semantic nature of the text and locate areas of discrepancy. In another study of thematic structures in eighteenth century astronomical texts, Banks (2012) found similar thematic structures in written texts intended for varied audiences - such as dominating topical Themes related to the ongoing study - in all these texts, suggesting a less distance between professional and non-professional writing in the eighteenth century than it is today.

As Thompson (2014) points out, compared with the large body of research on Themes in planned written texts, less work has been conducted to investigate Themes in spoken texts, involving spontaneous conversation between more than one speaker. One of the noticeable exceptions is Taboda and Lavid's (2003) study on scheduling dialogues. In their corpus study of thematic patterns in dialogues scheduling an appointment, Taboda and Lavid (2003) found that interpersonal and textual Themes occurred frequently in spoken texts. The most frequent semantic type of topical Theme is Participant, followed by Circumstance and Process. In terms of Theme markedness, most topical Themes were unmarked, and the marked Themes occurred mostly in the middle of a turn to propose a new date. With respect to TP patterns, constant patterns were used more often than linear patterns; gapped progressions were more frequent than contiguous progressions. Based on the distinctive thematic patterns to characterize different stages in the spoken texts of appointment-scheduling dialogues, they identified three generic stages: an Opening stage, a Task-Performance stage, and a Closing stage. Their study opened up the way of examining thematic patterns in spontaneous spoken texts, which adds to an understanding of the schematic structure of a genre.

Given that this study focuses on thematic patterns in both written and spoken texts, the analytical framework for Theme analysis in the present study should be comprehensive enough to cover a wide range of possible thematic patterns. Those thematic patterns to be examined in the analytical framework are: metafunctional types of Theme, Theme markedness, thematic progression, hyperThemes and macroThemes. The identification of those thematic patterns enables the generation of a schematic structure to specify a type of written/spoken texts. The identification of schematic structures based on emerging thematic patterns adds to the understanding of scientific explanations as a discursive literacy practice in addition to a repertoire of knowledge and skills. The analytical framework for Theme analysis is presented in Section 3.4.2.

The following section, Section 2.5, reviews the literature on multimodality and the semiotic construction of knowledge through other resources than language.

2.5 Multimodality and the semiotic construction of knowledge

2.5.1 Social semiotics and multimodality

Multimodality, for linguists and semioticians, refers to the integration of multiple meaning-making resources (i.e., semiotic resources) in the communication of meaning. From a social semiotic lens, multimodality has been described as a phenomenon (e.g., O'Halloran, 2011a, 2011b), a research field (e.g., Kress & van Leeuwen, 1996/2006; O'Halloran, 2005; Kress, 2014), and an analytical approach (e.g., Jewitt, 2008; O'Halloran, 2007a, 2007b, 2008a). First, the interpretation of multimodality as a phenomenon is straightforward, as we all live in "a multimodal world" (Baldry, 2000, x). This is mainly due to the prevalence of the Internet and other digital media, which have "led to a significant expansion of the repertoires of human cultural exchange"

(O'Halloran & Smith, 2012a, p. 1). O'Halloran and Smith (2012b) argue that multimodality can be studied as abstract and physical phenomena:

> Within the human sciences, multimodality thus implicates both abstract and physical phenomena in its study: the semiotic (e.g. abstract systems and structures of semiotic resources and inter-semiotic processes through which semiotic choices combine to create meaning; as well as the actual multimodal artefacts and events); and the physical media through which semiosis takes place.
>
> (O'Halloran & Smith, 2012b, p. 3)

Second, multimodality can also be viewed as a research site for developing theories of and approaches to multimodality itself. Based on the concept of language as social semiotic resources (Halliday, 1978), the notion of social semiotics has been extended to investigate other modes of communication (e.g., Kress & van Leeuwen, 1996/2006; O'Toole, 1994/2010). Multimodal theory building informed by SFL falls into two approaches: the contextual approach and the grammatical approach (O'Halloran, 2011). These two approaches are also referred to as social semiotic multimodality and systemic functional multimodality (Jewitt, 2009). While both approaches have originated from Halliday's (1978, 1985) social semiotic approach to language and extended insights from language to other semiotic resources, their fidelity to SFL's theorization of semiotic resources differs in terms of the degree of emphasis on context and meta-principles of semiotic systems.

In the contextual approach to multimodality, multimodal artefacts are treated as "material instantiation of social conditions and the representation of knowledge" (Jewitt, 2014, p. 35). Research in this approach adopts general meta-principles of SFL and emphasizes the role of context and the ideology of signmakers (e.g., Kress, 2003; Jewitt, 2007; van Leeuwen, 2005). In other words, multimodal artefacts are examined as choices made by signmakers of potential meanings available in a semiotic system to achieve a communicative goal in a given context. In their seminal work *Reading images: A grammar of visual design*, Kress and van Leeuwen (1996) extends the metafunctional perspective on language to images and proposes the simultaneous unfolding of representational, interactive and compositional meanings in images, which correspond to ideational, interpersonal and textual meanings respectively in language (see Section 2.5.2).

The grammatical approach (O'Halloran, 2009), also referred to as systemic functional multimodal discourse analysis (SF-MDA) or multimodal discourse analysis (MDA) (Jewitt, 2014), is complementary to the contextual approach and examines one specific piece of discourse at a micro level to establish a detailed mapping of metafunctional systems and systematic choices (e.g., Baldry & Thibault, 2006; O'Toole, 2004/2010; O'Halloran, 1996, 2000, 2004). The aim of studies from this approach is to establish systems to account for semiotic potentials available in general, which can be applied to examine other multimodal artefacts. The present study adopts a grammatical approach to multimodality because the primary motivation is to understand how linguistic and visual resources contribute to the construction of scientific explanations, and the secondary motivation is to adapt and develop analytical tools for examining the meaning potentials of images that can be extended and adapted for other multimodal artefacts.

Third, multimodal theories can be applied to investigate the meaning-making of multimodal artefacts that constitute instances of discourse (O'Halloran & Smith, 2012a). These multimodal studies focus on two objects in multimodal theories: the systems and structures of semiotic resources (i.e., semiotic affordances), and the meaning-making processes through semiotic resources (i.e., intrasemiosis and intersemiosis) (Jewitt, 2014).

While studies on semiotic affordances intend to elucidate the possibilities and constraints of the meaning-making potentials of different semiotic systems (Kress, Jewitt, Ogborn, Tsatsarelis, 2001), studies on intersemiosis (i.e., meaning-making through multiple semiotic resources) and intrasemiosis (i.e., meaning-making through one semiotic resource) are intended to reveal how meaning-making occurs (O'Halloran, 2005). For instance, in his work on texts and images used in science, Lemke (2002b) points out different semiotic affordances of language and images. While language specializes in categorizing things, processes and their relations, visual representations have an advantage of describing quantitative variations and relationships, such as shape, temperature, velocity, angle, color, voltage, concentration and mass.

From an intrasemiotic perspective, studies informed by SFL have explored the meaning-making mechanisms of individual semiotic resources, such as films (e.g., Tseng, 2013), animation (e.g., O'Toole, 2011), picture books (e.g., Painter, Martin, & Unsworth, 2013), printed documents (e.g., Bateman, 2008), and gestures (e.g., Hood, 2011). From an intersemiotic perspective, studies have investigated the multiplication of meanings when multiple modes of communication are co-adopted in a multimodal phenomenon. For instance, Kress and his colleagues (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001) have explored how the repertoire of semiotic resources (e.g., actional, visual, gestural, and linguistic resources) were organized in the classroom to make meaning. Studies have also attempted to develop frameworks to account for intermodal relations, such as image-text relations in multimodal texts (e.g., Liu & O'Halloran, 2009; Martinec & Salway, 2005, 2013; Royce, 2002) and the intermodal relations involving multiple modes of communication (e.g., Zhao, Djonov, & van Leeuwen, 2014). The multimodal studies provide a comprehensive account of the meaning-making of semiotic resources in general, which sheds lights on how multimodality can be explored in educational discourse.

Studies of multimodal educational discourse include investigations into the design of multimodal learning materials (e.g., Unsworth, 2002, 2008), learning technologies and new media (Jewitt, 2008; Kress, 2003), and multimodality in different disciplines, such as History (e.g., Derewianka & Coffin, 2008), English (e.g., Lim, 2011; Macken-Horaik, Sandiford, Love, & Unsworth, 2015), Mathematics (e.g., O'Halloran, 2000, 2005, 2008a, 2008b) and Science (e.g., Guo, 2004; Lemke, 1998, 2002b; Tang, Delgado, & Moje, 2014). These studies have identified distinctive multimodal features in educational discourse and highlighted the need to investigate the affordances of semiotic resources and the meaning-making of these resources individually or/and collectively (The New London Group, 1996).

In the discipline of science, meanings are made from an orchestration of linguistic, visual, actional, gestural and linguistic resources. As Lemke (2002b) points out, science makes meaning through an integration of language to conceptualize and classify, and mathematical and visual representations to describe the quantitative covariation of variables. Findings from recent studies on multimodality in science classrooms (e.g., Airey & Linder, 2009; Jaipal, 2010; Tang, Delgado, & Moje, 2014) have urged for an awareness of the multiplication of meanings between semiotic resources that support successful learning. For instance, Ainsworth (2006) found that different representations may constrain or complement the meaning-making of each other.

To account for the complexity in scientific multimodal communication, the present study analyzes the meaning-making of images in science classrooms from both intrasemiotic and intersemiotic perspectives. From an intrasemiotic perspective, the present study examines both representational and logical meanings in images with the aim of elucidating how visual resources contribute to the construction of scientific knowledge. From an intersemiotic perspective, the present study examines the multiplication of meanings between two semiotic systems: language and images. This perspective enables an investigation of the simultaneous orchestration of semiotic resources to understand the overall meaning-making in the classrooms. The following section reviews theories and studies from an intrasemiotic perspective that are relevant to the present study.

2.5.2 An intrasemiotic perspective: visual grammar and visual linking

2.5.2.1 Visual grammar

Visual grammar (Kress & van Leeuween, 1996; 2006) extends Halliday's (1978) notion of social semiotics from language to images and adapts the spectrum of metafunctions in the language system to visual systems. The relationship between Kress and van Leeuwen's (1996) visual metafunctions and Halliday's (1978) linguistic metafunctions are shown in Table 2.2.

Table 2.2 Mapping linguistic and visual metafunctions

	Field	Tenor	Mode
Linguistic metafunctions (Halliday, 1985)	Ideational (Experiential)	Interpersonal	Textual
Visual metafunctions (Kress & van Leeuwen, 1996)	Representational	Interactional	Compositional

The transfering of linguistic metafunctions to other systems allows for the development of multimodal studies to investigate the meaning-making in systems other than language, such as images (Kress & van Leeuwen, 1996; 2006), sound (van Leeuween, 1999), color (van Leeuween, 2002) and gesture (Martinec, 2000; 2004). Kress and van Leeuwen's (1996, 2006) visual grammar is so far the only systematic system of images that allows for identifying visual meanings through their realizations in pictorial elements. This model is adopted in the present study to ensure a systematic analysis of the properties of images that are relevant to the construction of explanations (i.e., representational metafunction). In what follows, Kress and van Leeuwen's (1996; 2006) visual grammar is reviewed with a focus on representational metafunction.

To analyze visual meanings in images, Kress and van Leeuwen (2006) identify two types of structure for representing experiential meanings: narrative and conceptual structures. Narrative structures present "unfolding actions and events, processes or change, transitory spatial arrangements", while conceptual structures represent "participants in terms of their more generalized and more or less stable and timeless essence, in terms of class, or structure or meaning" (Kress & van Leeuwen, 2006, p. 79). Vectors are fundamental in distinguishing narrative structures (with vectors) from conceptual ones (without vectors). A vector represents actions or movements, which can be realized as a line, an arrow or a gaze. Narrative structures consist of five types of process: action, reactional, mental, verbal and conversion. The first four types are agentive processes as they all involve a distinct agent (i.e., Actor in action processes; Reactor in reactional processes; Senser in mental processes; Sayer in verbal processes). The action processes can be transactional action (with both Actor and Goal of the action), non-transactional action (with only Actor), or event (with both Actor and Goal deleted) depending on whether the Actor and the Goal of the action are presented or not.

The conversion process is non-agentive as it represents the transitions of natural events. This type of process is typically presented as a cycle, such as food chain diagrams. Participants in a conversion process are called Relays to distinguish their role in signifying agency from Actors and Goals.

Conceptual structures comprise three types of process: classificational, analytical and symbolic processes. A classificational process relates the participants through taxonomic relations, with some participants (Subordinates) occupying a subordinate position in relation to another participant (Superordinate). A classificational process can be either overt (with Subordinates and Superordinate) or covert (with only Subordinates) depending on the presence or absence of a Superordinate.

An analytical process relates the participants through a part-whole relation. The participants in an analytical process are the Carrier (i.e., the whole) and the Possessive Attributes (i.e., the parts constituting the whole). Analytical processes can be subdivided into naturalistic analytical processes (with all the Possessive Attributes presented) and schematic analytical processes (with only some of the Possessive Attributes presented) depending on whether the Possessive Attributes presented exhaust the space of the Carrier or not.

A symbolic process defines the meaning or identity of a participant (i.e., the Symbolic Carrier). Apart from the Symbolic Carrier, another participant may be presented to establish the meaning in this process (i.e., a Symbolic Attribute). It is also possible for a Symbolic Carrier to derive the meaning within itself, without relying on a Symbolic Attribute. The ways of deriving the meaning, either with or without the presence of a Symbolic Attribute distinguish a symbolic attributive process (with both the Symbolic Carrier and the Symbolic Attribute) from a symbolic suggestive process (with only the Symbolic Carrier). The visual process types are summarized in

.

Table 2.3 Types of visual structures in images (based on Kress & van Leeuwen, 2006)

Process			Participant
Narrative structure	Action	Transactional action	Actor; Goal
		Non-transactional action	Actor
		Event	∅
	Reactional (gaze)		Reactor; Phenomenon
	Mental		Senser; Phenomenon
	Verbal		Sayer; Addressee
	Conversion		Relays
Conceptual structure	Classificational	Overt	Superordinate; Subordinates
		Covert	Subordinates
	Analytical	Exhaustive	Carrier; Possessive Attributes (all)
		Inclusive	Carrier; Possessive Attributes (partial)
	Symbolic	Attributive	Symbolic Carrier; Symbolic Attribute
		Suggestive	Symbolic Carrier

These types of visual structures will be adapted in my analytical framework for analyzing representational meanings in images, with the addition of some new types emerging from the data (see Section 3.4.3 for the analytical framework adopted in the present study). Kress and van Leeuwen's (1996, 2006) visual grammar enables the investigation into the construction of representational meanings in images, which corresponds to experiential meanings in language. However, this framework does not consider the construction of logical meanings in images, which corresponds to logical meanings in language. To compensate for the lack of logical meanings in Kress and van Leeuwen's (1996, 2006) visual grammar, van Leeuwen's (2005) framework of visual linking in moving images is adopted in the present study. The following Section 2.5.2.2 reviews van Leeuwen's (2005) framework of visual linking that informs the analysis of logical meanings in images in the present study.

2.5.2.2 Visual linking in images

In his examination of information linking in written texts and images, van Leeuwen (2005) identifies four main types of information linking in moving images (film). The types of visual linking are: elaboration, temporal, spatial, and logical. The visual linking of elaboration relates the details of a subject to an overview of this subject. Elaboration can be Overview (transition from details to overview) or Detail (transition from overview to details). Temporal links associate an event to another event in terms of their occurring time. The events can occur simultaneously (Simultaneous event) or subsequently, with one event (Previous event) occurring before the other (Next event). Spatial links associate subjects through location cues. Such location cues can be realized through the proximity in location (Proximity) or the co-presence of details (Co-presence). Finally, logical connect the subjects through the viewer's logical reasoning about a comparison between these subjects in terms of either their similarities (Similarity) or differences (Contrast). The four types of visual linking proposed by van Leeuwen (2005) are shown in Table 2.4.

Table 2.4 Four types of visual linking (based on van Leeuwen, 2005, p. 229)

Type of visual linking	Subtype	Realization	Typical environment
Elaboration	Overview	cut or other transition from close shot (CS) to long shot (LS) of same subject	description
	Detail	Cut or other transition from LS to CS of same subject	
Temporal	Simultaneous event	Cut or other transition to simultaneous event	narrative
	Next event	Cut or other transition to next action or event	
	Previous event	Cut or other transition to previous action or event	
Spatial	Proximity	Relative location indicated by matching angle	description
	Co-presence	Series of two or more details	
Logical	Contrast	Contrasting subject (no narrative connection)	persuasion
	Similarity	Similar subject (no narrative connection)	

While van Leeuwen's (2005) framework yields a useful tool for analyzing the logical meanings in images, it is observed that this framework mainly focuses on ways to link information in moving images (film). The main data set from the present study comprises images in teacher's PowerPoint slides, which differ from moving images in the types of logical meaning afforded and the ways to realize the logical meanings. Therefore, adaptations are made to better account for the logical meanings in the images that are presented in PowerPoint slides (see Section 3.4.4 for the framework of this study).

This section reviewed studies that inform the present study from an intrasemiotic perspective, the next Section 2.5.3 shifts the focus on an intersemiotic perspective.

2.5.3 An intersemiotic perspective: relations between language and images

Given that meaning-making can involve more than one semiotic resource, multimodal studies have also investigated the distribution of labor among different semiotic systems that interact with each other to construct meanings, which can also be called the multiplication of meaning (Lemke, 1998) or intersemiosis (O'Halloran, 1999; 2005). This line of research has focused on the intersemiotic relations between different semiotic systems, such as image-text relations (e.g., Liu & O'Halloran, 2009; Martinec & Salway, 2005, 2013; Royce, 2002) and intermodal relations involving multiple modes of communication (e.g., Zhao, Djonov, & van Leeuwen, 2014).

In a pioneering work by Barthes (1977), three types of relationships were identified between text and image: anchorage, illustration, and relay. In the relationship of anchorage, texts specify the visual meanings in images by suggesting what visual meanings to focus on and how to interpret them (image more general than text). Typical examples of anchorage are caption texts and pictures in newspaper, where caption texts inform the reader of what to focus on in the pictures. Reversely, in the relationship of illustration, images support the linguistic meanings in texts by providing details of a message in texts (text more general than image). The third type of image-text relationship is relay, where both texts and images are the providers of information, whose roles are equal and balanced. Based on Barthes's (1977) work, scholars in SFL have developed frameworks for analyzing intersemiotic relations from different perspectives, such as a discourse-oriented approach in Liu and O'Halloran (2009) and a grammatical approach adopted in Martinec & Salway (2005). Martinec and Salway's (2005) framework is adopted in the present study as it aims to analyze the image-text relations in both old and new medias, which can better account for the type of images under investigation in the present study, that is, images on PowerPoint slides. Martinec and Salway's (2005) will be reviewed in detail in the following paragraphs.

Building on Barth's (1977) seminal work, Martinec and Salway (2005) proposed a framework to account for image-text relations in terms of image-text status, and logical semantic relations between text and image. The system of image-text status relations is presented in Figure 2.9.

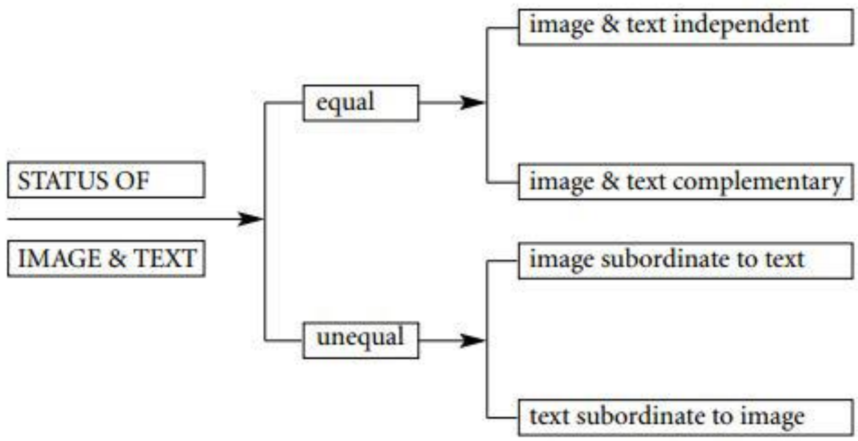


Figure 2.9 System of image-text status relations (Martinec & Salway, 2005, p. 349)

The status of image and text can be categorized as equal or unequal, depending on the dependency of one on the other to construct meanings. The equal status relationship covers Barthes's (1977) notion of relay, which is further divided into two subtypes: independent and complementary. The subtype of complementary relationship refers to the cases where both image and text contribute to the construction of a meaning unit, with equal roles played by them. In this sense, Barthes's (1977) notion of relay is considered as an equal complementary status in Martinec and Salway's (2005) system. It is also possible for image and text to exist on their own, contributing to a parallel of meanings. In this case, the status between text and image is described as an equal independent relationship. It is also possible to have an unequal status between text and image, when the interpretation of one mode (either image or text) is dependent on the other (either text or image). An unequal status can be further categorized as [text subordinate to image] and [image subordinate to text], depending on where the interpretation starts from.

To ensure the reliability of their framework, Martinec and Salway (2005) also provided explicit methods of identifying the image-text status relations based on their assumptions that language and image can be described in a compatible way (Bateman, 2014). The first step is to provide transitivity analyses for both text (grammatical transitivity) and image (visual transitivity), which result in grammatical processes (Halliday & Matthiessen, 2014) and visual processes (Kress & van Leeuwen, 1996/2006). The second step is to identify the connection between the grammatical and visual processes. An equal status applies to cases where an "entire image" is related to an "entire text" (Martinec & Salway, 2005, p. 343). Specifically, an equal independent status can be identified when all the visual processes correspond to the grammatical processes, or there is no connection between visual and grammatical processes. If the configuration of a process is realized by the combination of visual and linguistic elements, the status is an equal complementary relationship. An example of an equal complementary status is a drawing of fork and knife to realize the process of "eat" and a text of "fish and small prey" to realize the goal of this process. For an unequal status, part of a text or image is related to the image or the text. Depending on the dependency in interpreting the meaning from text to image or from image to text, an unequal status can be further divided into two subtypes: text subordinate to image (interpreting from image to text) and image subordinate to text (interpreting from text to image).

The second dimension in Martinec and Salway's (2005) framework is the categorization of logico-semantic relations between text and image. Informed by the clause-combining relationships in SFL, Martinec and Salway (2005) distinguished two main types of relationships between text and image: projection and expansion. Projection is associated with events of thinking, saying, perceiving and so on, whereas expansion adds information on the existing one in terms of three subtypes: elaboration, extension, and enhancement. To consider these expansion relations within grammatical transitivity analysis, elaboration adds further information on an existing process about the process and its participants; enhancement adds information about the circumstances of the process; and extension adds information of another process (see Bateman, 2014). Martinec and Salway (2005) extended the logico-semantic relations of clause combinations to examine image-text combinations, with adaptations on the system of expansion. The system of expansion in Martinec and Salway (2005) is presented in Figure 2.10.

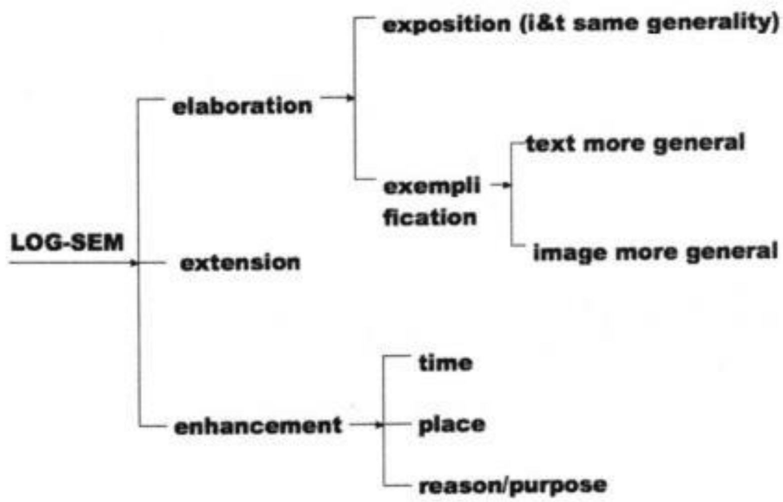


Figure 2.10 System of logico-semantics for image-text relations (Martinec, 2013, p. 155)

The logico-semantic relation of elaboration in image-text combinations has two subcategories: exposition and exemplification, depending on the level of generality of the added information. Exposition refers to the cases where information is restated at the same level of generality, while in exemplification, the added information shows a different level of generality, either text more general or image more general. Extension adds further information that is semantically intrinsically unrelated. Enhancement provides quantifying information, such as time, place and reason. Martinec and Salway's (2005) framework provides explicit classifications of image-text relations from the dimensions of status and logico-semantic relations in "a hierarchical set of contrast" (Bateman, 2014, p. 196), which supports a fine-grained analysis of the relations between texts and images in particular and enables an exploration of the overall potential in intersemiotic relations in general. However, although Martinec and Salway's (2005) framework aims to account for image-text relations in both old and new medias, the focus is on the relations between written texts and images. Given the focus of the present study on the relations between spoken texts and images, adaptations are needed to Martinec and Salway's (2005) framework.

Another study informing the investigation of intersemiotic relations in the present study is Zhao, Djonov, and van Leeuwen's (2014) study of PowerPoint. They proposed to study PowerPoint as a semiotic practice in three respects: the design of software, the multimodal composition of slideshows, and the presentation of PowerPoint slides to audiences. The aspect of slideshow presentation is of importance to the present study in analyzing the relations between images presented on PowerPoint slides and spoken texts in teacher-student interactions. Zhao, Djonov, and van Leeuwen (2014) proposed that the analysis of complex multimodal events such as PowerPoint presentations should focus on more than identifying different types of intersemiotic relations to include an understanding of how meanings of different modes can be coordinated by semiotic resources, such as gestures, to form an integration of semantic meanings. Their proposal of including semiotic resources for coordinating is adopted in the present study, as it helps reveal what visual meanings and verbal meanings are activated to form a semantic integration, where image-text relations are established to multiply the meanings. The analyzing framework for image-text relations adopted in this study is presented in Section 3.4.5, with adaptations to Martinec and Salway's (2005) framework of image-text relations and Zhao, Djonov, and van Leeuwen's (2014) framework of semantic integration.

The literature on theories of language (Section 2.4) and multimodality (Section 2.5) reviewed above provides insights into how language and other semiotic resources make meanings. The next section, Section 2.6, reviews specifically empirical studies on the construction of scientific explanations.

2.6 Constructing scientific explanations as a multisemiotic literacy practice

2.6.1 Explanation construction in science

Explanation formulation is regarded as one crucial practice in science discourse and constitutes an integral component of current school curriculums in most countries, such as the United States (National Research Council, 2012), Australia (Australian Curriculum, Assessment and Reporting Authority, 2014) and Singapore (Curriculum Planning and Development Division, 2012). For instance, in Australia's Foundation to Year 10 Curriculum (F-10 Curriculum), knowledge of and abilities to construct explanations are highlighted from Year 3 onwards, as reflected in the requirements in the learning objectives of explaining everyday observations (Year 3), explaining observations and findings in science experiments (Year 4), developing explanations for events and phenomena (Year 5, Year 6), and evaluating alternative explanations (Years 7-10). It is important to note that these requirements are interrelated and accumulative in that previous knowledge and abilities prepare for new knowledge and abilities. Teaching science involves not only the acquisition of scientific knowledge and the development of inquiry skills but also the understanding of science as a human endeavor (ACARA, 2014). In this regard, constructing a scientific explanation is expected to achieve at least two objectives: 1) using science concepts and different forms of representation to make sense of a particular phenomenon; and 2) using language and other semiotic resources to express these understandings.

Studies on explanation construction in science classrooms have revealed a vast difference between explanations constructed by students and scientifically accepted explanations. Compared with the precise, abstract and evidence-based explanations in established science (Kapon et al., 2010), students' explanations tend to be intuition-driven (Touger, Duresne, Gerace, Hardiman, & Mestreet, 1995), less precise and less abstract (Heckler, 2010). This is at least partly due to the fact that an explanation in its scientific sense is different from an explanation in its everyday sense. While describing an occurrence in the form of "what happened" is counted as an explanation in its everyday sense, a scientific explanation answers questions beyond "what is there" and addresses how or why a phenomenon is observed. However, such differences between scientific and everyday explanations are often overlooked by students and even teachers, who tend to equate explanations with explications (Zangori & Forbes, 2013). It is important to note that students have both limited opportunities to produce explanation texts (Martin & Rose, 2012) and limited exposure to scientific texts as models (Jong, Chiu, & Chung, 2015; Schwarz et al., 2009), contributing to their tendency to describe rather than explain a phenomenon.

One crucial point to be addressed is the nature of explanations. The nature of explanations has been discussed in voluminous literature in disciplines ranging from philosophy of science (e.g., Salmon, 2006; Gilbert, Boulter, & Rutherford, 2000) to functional linguistics (e.g., Halliday & Martin, 1993) and to science education (e.g., Yeo & Gilbert, 2014). Debates in the field of philosophy of science mainly focus on "what" is a scientific explanation. This question can be broken down in two sub-questions: 1) what are the characteristics that distinguish an explanation from other types of text (e.g., description)? 2) How does a scientific explanation differ from an unscientific one?

To answer the first question, philosophers of science generally agree that at the heart of an explanation is causation, that is, the causal mechanism bonding a set of claims. In this sense, a mere description of a set of claims with supporting evidence, however accurate it may be, will not be regarded as an explanation. Despite a wide recognition of the centrality of causation, how it is realized in an explanation remains disputed, which constitutes the raison d'être of different competing models of explanations (for a review of the models of scientific explanation, see Salmon, 2006).

Also related to both the first and the second sub-question, it is debatable to define all explanations in terms of causation because explanations may vary in purposes, depth, generalizability and complexity. Thus, to simply equate causal claims and explanations oversimplifies the variation of explanations. The present study considers a scientific explanation in three respects: function, quality and realization. Each reflects a different way of categorizing explanations. The next section will discuss how scientific explanations can be categorized depending on their functions.

2.6.2 Categorization of scientific explanations based on their functions

Although an immense literature has been devoted to scientific explanations, relatively little attention has been paid to the functions of explanations, especially in relation to the purpose of inquiry. One notable exception is Gilbert, Boulter, and Ruther's (2000) typology of scientific explanations based on their functions (see

Table 2.5). The typology classifies different scientific explanations into six general types: contextualizing, intentional, descriptive, interpretive, causal and predictive explanations. This typology examines scientific explanations in terms of the trajectory of scientific inquiry: discovery, justification, hypotheses developing and testing. A new phenomenon is identified and conceptualized in linguistic forms through contextualizing explanations, its significance evaluated through intentional explanations, its properties examined through descriptive explanations, possible models for thinking about it proposed through interpretive explanations, its "cause-and-effect" mechanisms explicated through causal explanations, and the validity of predictions about the phenomenon established through predictive explanations. This typology takes account of the varied forms of explanations to answer why-questions (intentional and causal explanations), what-questions (contextualizing and descriptive explanations) and how-questions (predictive explanations). It provides a basis for exploring semiotic resources that can be drawn on to construct a scientific explanation in relation to its function.

Table 2.5 A typology of scientific explanation (Gilbert, Boulter, & Ruther, 2000)

Type of explanation	Purpose	Question answered
Contextualizing	Gives a phenomenon a name, an identity, and enables it to be treated linguistically as a noun	What exactly is being investigated?
Intentional	Provides a reason why a phenomenon is being enquired into and its importance	Why should a particular phenomenon be investigated?
Descriptive	States the nature of and typical values for its physical properties	What are the properties of a phenomenon?
Interpretive	States and describes the model that can be used to think about the properties of the phenomenon	What models can be used to think about the phenomenon?
Causal	States how the postulated model is thought to produce the observed behavior by the operation of 'cause-and-effect' mechanisms	Why does the phenomenon behave as it does?
Predictive	Convinces others of the explanation's degree of validity (justification) or ability to produce predictions	How will the phenomenon behave under other, specified, circumstances?

Among the six types of explanations presented above, it is mainly causal explanations that are valued in science curricula (e.g., ACARA, 2014). Studies have shown that students tend to have problems in constructing causal explanations and often provide only descriptions of evidence without articulating the causal mechanism (e.g., Braaten & Windschitl, 2011; Klein & Rose, 2010; Zangori, Forbes, & Biggers, 2013). The neglect of causal mechanisms in explanations is also observed in teachers' practices. In their study on the construction of evidence-based explanations by four pre-service teachers, Zangori and Forbes (2013) found that although the teachers stressed the importance of writing scientific explanations, they considered explanations as "descriptions of their investigations, data, and evidence" (p. 320). These teachers were found struggling to adequately support their students in assigning causality to evidence when constructing an explanation. Given the importance of causal explanations in science and because of the observed problems with this type of explanation in the classroom, the present study focuses on causal explanations, and the notion of explanation hereafter refers to the causal explanation in Gilbert Boulter, and Ruther's (2000) typology of scientific explanations presented earlier. Understanding the function performed by an explanation is considered the first step to exploring the other two aspects of an explanation: the quality of an explanation (Section 2.4.3) and the realization of an explanation with semiotic resources (Section 2.4.4). The following section reviews previous research on ways of examining the quality of an explanation.

2.6.3 Examining the quality of an explanation

Studies in science education mainly focus on the quality of an explanation, that is, to what degree its construction serves its purpose. The construction of explanations can be examined at the levels of precision, abstractness, and complexity (Yeo & Gilbert, 2014). The precision of an explanation concerns the extent and accuracy of the depiction of a given phenomenon and its ability to account for additional or new occurrences of the phenomenon. An explanation is more precise if it can account for additional examples of the phenomenon, describe the behaviors or entities involved more accurately, and increase the definiteness of the causal mechanism. A high level of explanatory precision usually requires the articulation of abstract entities or topics.

In a study of middle-school students' construction of scientific explanations, Hakkarainen (2004) found that while these students showed no difficulty in forming intuition-driven explanations based on perceivable phenomena, they were unable to form theoretical explanations, especially with respect to abstract topics such as gravity and cosmology. Similarly, Heckler's (2010) study of undergraduate students' construction of force diagrams showed that they tended to use less precise and more situation-based means to rationalize the phenomenon instead of using the more precise and abstract Newtonian laws. Basca and Grotzer (2003) point out that students typically explain air pressure-related phenomena without considering abstract entities such as air pressure in a linear causal model, where one observable event directly leads to an outcome, rather than a relational model, where the relationship between two variables causes the outcome. For instance, when explaining drinking from a straw, students tend to attribute the cause to their actions of sucking (a linear model without abstract entities) rather than a pressure differential between the lower pressure inside the straw and the higher pressure outside the straw (a relational model including abstract entities).

Closely related to the level of precision is the level of abstractness in visual representations of an entity and a phenomenon. Abstractness results from processes of simplification employed to accentuate one aspect of an entity (e.g., the magnitude of a magnetic field) by omitting some other aspects of the entity (e.g., the shape of the magnet) and/or adding some features that may not exist or be observable (e.g., lines of forces). While the simplification by omission distances the entity from reality, the simplification by addition conceptualizes the entity in reality. This complex process of abstraction is suggested by Hartshorne (1974) as "concrete abstractness" (p. 457), where the form of a representation may or may not resemble the actual referent properties, and the meaning inscribed by the representation may be experienced or observed directly in the phenomenon or need to be inferred indirectly.

Peirce (1955) categorizes visual representations of an entity into three groups according to how closely they resemble the referent: the iconic, the indexical, and the symbolic. While an iconic representation closely resembles the referent (e.g., a picture of the equipment), an indexical representation does not resemble but is in existential relation with the referent (e.g., arrows representing directions of force), and a symbolic representation does not have an inherent connection but an arbitrary and conventional relation with the referent (e.g., equations).

Depending on the abstractness of representations of a phenomenon, Johnstone (1993) proposes three levels of visualization: macro, sub-micro, and symbolic. A macro visualization represents a phenomenon as experienced with the senses, that is, directly observable, experienced, and empirical (e.g., temperature and pH). A sub-micro visualization is based on inferred entities (e.g., atoms and molecules) which are not directly observable through naked eyes. A symbolic visualization is a representation where entities are removed and whose focus is on abstract relationships (e.g., formulas and equations). The connection between Pierce's (1955) categorization of visual representations of entities and Johnstone's (1993) categorization of visual representations of phenomena is presented in Table 2.6.

Table 2.6 Mapping Pierce's (1955) model to Johnstone's (1993) model

Visual representations of entities in Pierce's model	Iconic representations	Indexical representations	Symbolic representations
Visual representations of phenomena in Johnstone's model	Macro level phenomena	Sub-micro level phenomena	Symbolic level phenomena

In both models, visual representations are categorized according to the level of abstractness, from concrete representations (i.e., iconic representations, macro level phenomena) to representations with an intermediate level of abstractness (i.e., indexical representations, sub-micro level phenomena) and to abstract representations (i.e., symbolic representations, symbolic level phenomena). Studies on the level of abstractness have shown that learning in the classroom involves the development of increasingly abstract representations (e.g., Botzer & Reiner, 2005; Reiner, 2009; Yeo & Gilbert, 2014). In a study of elementary students' use of representations based on their resemblance to the observed phenomena, Botzer and Reiner (2005) found that the use of indexical representations played a significant role in developing students' increasingly abstract representations. They also argued that the progression with increasing abstraction from macro-level to sub-micro-level and then to symbolic-level visualization might improve students' visual strategies. The progression with increasing abstraction in visual representations was also observed in Reiner's (2009) study of students' spontaneously generated pictorial referential system and Yeo and Gilbert's (2014) study of students' use of pictorial visualizations.

The third level of explanation is the level of complexity, which has to do with the composition, completeness, and coherence of an explanation. For instance, an explanation that responds to a causal question by narrating causal claims only is less complex than one comprising causal claims, reasons and evidence to support them. In their study on sixth-grade students' construction of explanations, Wu and Hsieh (2006) proposed four components of a well-articulated explanation (categorized as a causal explanation in Gilbert, Boulter, & Ruther's (2000) typology of explanations): a description of the phenomenon identified, a causal relationship, a logical argument linking the description and the relationship (reasoning), and empirical data used as evidence. Their findings showed that while students had difficulty in including all these four components of a scientific explanation before their participation in teacher-guided learning activities, they made significant progress with each of these four components after their participation in the learning activities. However, over 70% of the causal relationships in the students' explanations were simple, bi-variable relationships and lacked references to scientific concepts in their reasoning. These results suggested a low level of complexity in the explanations. The difficulty in constructing a scientific explanation with a high level of complexity was also observed in Glassner, Winstock, and Neuman (2005) and McNeil, Lizotte, Krajcik, and Marx (2006), both of which involved middle school students. Glassner, Weinstock, and Neuman (2005) found that the explanations constructed by their students had simple structures and often lacked supporting evidence and adequate reasoning from the identified phenomenon to causal relationships. In their study of seventh-grade students, McNeil and his colleagues (2006) found that students often did not provide reasons to their claims in an explanation.

Previous research examining the quality of an explanation has highlighted the characteristics of a good explanation in terms of precision, abstractness and complexity, and pointed to ways of investigating the characteristics of an explanation in relation to its function (Section 2.6.2). On the one hand, findings from the studies on the levels of explanations, for example, Gilbert Boulter, and Ruther's (2000) typology of explanations, have provided answers to questions such as "how does an explanation differ from a description" and "how does a causal explanation differ from a predicative one?" On the other hand, these findings have drawn attention to the multiple aspects of a well-articulated scientific explanation that students need to attend to in their construction of explanations, and highlighted the challenges that students encounter when they are asked to provide such a scientific explanation. However, in this line of research, the roles of semiotic resources in the construction of explanations remain rather implicit and are in need of a systematic investigation. Section 2.6.4 below addresses this issue by reviewing extant linguistic and multimodal studies on the realization of explanations with semiotic resources, such as language and images.

2.6.4 Representing an explanation with semiotic resources

2.6.4.1 Representing an explanation in language

The view that science is represented with the specialized system of language as well as other representative systems is reflected in how an explanation is characterized in terms of an array of linguistic and multimodal features. The language-based research by SFL scholars (Halliday & Matthiessen, 2014) clarifies the inter-dependence between language and learning of content knowledge. As Coffin (2006) points out, a functional linguistic view of language and learning aims to provide students with both access to and control of written texts in mainstream education, such as a persuasive essay, a laboratory report, and a critical review of an artwork.

In his seminal work with a particular focus on spoken texts, Lemke (1990) argues that scientific knowledge needs to be talked into existence and that learning science inevitably involves learning the way of talking science. Seminal work by Halliday and Martin (1993), with a particular focus on written texts, has identified several features of scientific language, such as technicality, abstraction and nominalization (i.e., the translation of verb forms or adjective forms into their noun forms). Following the pioneering work, subsequent studies investigated the realization of written explanations and identified generic, discoursal, and lexicogrammatical features. Based on Martin and Rose's (2008) genre model, key genres have been identified in school subjects, among which explanations stand out as the most challenging genre for students (Love, 2009; Martin & Rose, 2008). By examining written science texts in the context of laboratory science, industry science and school science, Veel (1997) identified the dominant genres in secondary school science underpinned by four social purposes: to enable, to explain, to document, and to persuade. The genre of explanation is further divided into six types: sequential explanation (to explain how an observable process occurs), causal explanation (to explain why an abstract or not observable process occurs), factorial explanation (to explain events with several co-occurring causes), theoretical explanation (to explain a theoretical principle), consequential explanation (to explain events with several co-occurring effects), and exploration (to account for events with alternative explanations) (see Table 2.1 for a summary of types of explanations and their generic stages in Section 2.4.3.5).

Investigations have also been conducted to examine discoursal features of the explanatory genre, such as thematic progression (Banks, 2008), hyperThemes and macroThemes (Rose & Martin, 2012). The examination of lexicogrammatical features of the explanatory genre includes thematic patterns, grammatical metaphors (Hao, 2015; Martin, 1993; Maxwell-Reid, 2015), present tense, declarative mood, generic nominal groups, causal and temporal connectors (Coffin, Donohue & North, 2013). In a corpus study of scientific journal articles, Banks (2008) found that written explanations progress through a hybridity of constant and linear TP paths, where linear TP paths are associated with phenomenon identification in experiments and constant TP paths with the construction of explanations for the phenomenon under investigation. Rose and Martin (2012) point out the important roles of macroThemes and hyperThemes in predicting the field that follows, and hyperThemes and hyperNews in identifying key information in written texts, including written explanations.

Along this line of research, there is a consensus that the construction of a cause-and-effect relationship is crucial to a scientific explanation (Halliday, 1998). Causal relations can be realized explicitly (e.g., with "because" or "so") and implicitly (Halliday, 1998). Rose and Martin (2012) called attention to the implicit realization of causal relations in an explanation through what they called implication sequences. In an implication sequence, a cause and its effect are posited in a sequence of activities with both temporal and consequential relations. Causal relations in an implication sequence are presented implicitly, and readers have to infer the cause and the effect from the temporal sequence. In addition, Martin (1993) found that an implication sequence can be packaged into one technical term (i.e., grammatical metaphor), resulting in a metaphoric way of realizing scientific causality. Building on these seminal works, Hao (2018) argues that the construction of scientific causality can be examined at the levels of lexicogrammar, discourse semantics and field. Hao (2018) points out the importance of making distinctive choices explicit in the construction of causality, especially those discoursal semantic meanings with similar grammatical realizations. In a similar vein, Veel (1997) emphasizes that because causal explanations generally deal with abstract entities and processes that are not directly observable or experienced, it is important to make both sequential and causal links between events explicit to students in order to formulate “a logical and credible explanation” (p. 179).

However, these linguistic structures of causal explanations are seldom taught explicitly and, thus, pose considerable challenges to students and even teachers when they need to produce a well-articulated explanation (Perkins & Grotzer, 2005). Furthermore, the knowledge of science is represented, communicated and developed through the “close and constant integration and cross-textualization” among different semiotic resources (Lemke, 2002b, p. 27). In this regard, students need to understand how different semiotic systems make meanings and be able to relate, contextualize and integrate the information represented with different semiotic resources to successfully construct a scientific explanation (Ainsworth, 2006; Airey& Linder, 2009). Given that science communication is multimodal, the representation forms of a scientific explanation in the present thesis are not restricted to the system of language but include other semiotic systems that are involved in the process of construction. In what follows, I will review studies on the construction of explanations from a multimodal perspective.

2.6.4.2 Representing an explanation from a multimodal perspective

Lemke, in his study of science journal articles (Lemke, 1998) and multimedia resources in science education (Lemke, 2002), concludes that science communication is “close and constant integration and cross-textualisation among semiotic modalities” (Lemke, 1998, p. 27). Building on pioneering studies on multimodality (e.g., Kress & van Leeuwen, 1996/2006; O’Toole, 1994/2000), recent SFL-informed studies have extended the focus from language to include other semiotic resources, such as multimodal texts (in textbooks, e.g., Guo, 2004; in journal articles, e.g., Lemke, 1998; in newspaper and science magazine articles, e.g., Taboada & Habel, 2006; in multimedia, e.g., Lemke, 2002; Unsworth, 2004), the use of images (e.g., Lemke, 1998), symbolisms (e.g., O’Halloran, 2000; Liu & O’Halloran, 2009), and gestures (e.g., Martinec, 2001, 2004; Pozzer-Ardenghi & Roth, 2005, 2009) in the classroom.

Studies on the construction of explanations with multimodal resources have shown two trends. The first trend is the investigation of semiotic affordances of different modes, that is, how each mode of communication allows for and constrains specific meanings to be made in science. In their seminal work on visual grammar, Kress and van Leeuwen (1996, 2006) have identified a wide range of visual strategies that can be drawn on to represent scientific concepts and their relationships (see Section 2.5.2.1 for a review of their work). For instance, they point out the strength of topographical visuals and charts in scaling quantitative values, where quantitative values can be presented by the quantity or frequency of identical visual symbols (e.g., ten million dollars shown as ten identical symbols of “$”), and the quantitative values can be compared according to the relative sizes of visual symbols (e.g., a larger circle symbolizing a larger quantity and a smaller circle symbolizing a smaller quantity). They also articulate the different organizing principles of language and images: while language is organized to “sequence in time” actions, events and state of affairs, the fundamental organizing principle of images is “a conceptual order”, realized by the spatial arrangement of visual elements (Kress & van Leeuwen, 2006, p. 41). The different semiotic affordances of language and image are supported by Doran’s (2016) investigation of images, language, and mathematical symbolism in scientific texts. Doran (2016) found that images do not appear to clearly distinguish between temporal and causal relations, which are both presented as multiple activities that are related temporally. Doran (2016) argued that the advantage of images is their abilities to present multiple visual structures that characterize different aspects of a scientific phenomenon. This co-presence of multiple visual structures also results in the multifunctionality of visual elements, where one visual element may carry multiple semantic meanings.

Research on semiotic affordances has also examined the semiotic properties of visual elements, that is, how representational elements, such as signs and symbols, can be interpreted in a specific context to generate meaning (Lemke, 1998). In their seminal work on visual grammar, Kress and van Leeuwen (1996, 2006) point out that in contemporary Western society, visual symbols of squares and rectangles are associated with artificial and mechanical construction, whereas visual symbols of circles and curved forms are associated with natural and organic growth. Unlike these two types of visual symbols, triangles convey a strong sense of directionality and process. Kress and van Leeuwen (2006) also point out that variants of an arrow may affect the construction of visual meanings. For example, an amplified arrow carries a strong sense of intensity compared with an attenuated arrow.

The second trend in multimodal studies of explanation construction is a focus on the meaning-making of semiotic resources in the science classroom. Within this trend, the meaning-making of semiotic resources has been explored both intrasemiotically and intersemiotically. From an intrasemiotic perspective, Polias (2006) identified the importance of using visuals, such as flow charts, to support students' construction of causal explanations because such explanations are organized based on both cause-and-effect and temporal relations. Taking an intersemiotic perspective, Taboada and Habel's (2013) study of multimodal documents from newspapers, science magazines and academic journals found that image-text relations tend to differ in figures, tables, and pictures, where figures elaborate on the text, tables provide evidence for the text, and pictures offer background and motivations for reading.

Studies in science education have focused on multiple representations and re-representations (Hubber, Tytler, & Haslam, 2010), where one scientific concept is represented in several representative forms. It is important to point out that the study of multiple representations may involve both intrasemiotic and intersemiotic meaning-making, as one scientific concept can be represented in several images (intrasemiotic meaning-making) and in a range of semiotic resources, such as images, gestures, and language (intersemiotic meaning-making). The use of multiple representations, on the one hand, provides students with opportunities to acquire scientific knowledge in different ways and with all their senses (e.g., visual, verbal, gestural and actional). On the other hand, the meaning-making of multiple representations requires a high level of multisemiotic literacy: students need to understand ways of making meaning in each semiotic system and ways of multiplying meanings across semiotic systems. The benefits and challenges of the use of multiple representations in science classrooms have been observed in previous studies, such as Danielsson (2016), Forey and Polias (2017), He & Forey (2018), and Tang, Delgado, and Moje (2014).

Danielsson (2016), in a study of multiple representations of atoms, found that different modes were good at representing different aspects of atoms: gestures at highlighting the dynamic aspects (e.g., electrons swirling around the nucleus), images at accentuating the spatial aspects (e.g., the relative size and position of particles), and speech at integrating both dynamic and static aspects. Regarding the multiplication of meanings across modes, Danielsson (2016) identified both similar and dissimilar patterns in what she called “multimodal ensembles”, where a scientific concept was presented with a combination of modes, such as multimodal drawings, speech and the accompanying gestures or images. She also found that dissimilar patterns, where the co-adopted modes conveyed opposing meanings, constituted a potential obstacle to developing a scientific understanding of a phenomenon.

In a project designed to develop the concepts of size and scale, Tang, Delgado, and Moje (2014) found that different visual representations of sandpapers led to varying understandings of a scientific concept (i.e., self-cleaning nanotech surfaces). While top-view representations of sandpapers led to explanations based on the number of bumps (an argument of quantity), side-view representations of sandpapers induced explanations based on the varying depth of sandpapers (an argument of depth). The researchers also observed that gestural, verbal and visual resources played different yet complementary roles in the construction of explanations. For instance, an explanation based on the argument of depth was constructed through verbal language of actions (e.g., “get into”, “get it”, “get down”), a side-view representation of sandpapers, and gestures creating links between verbal and visual meanings. This study highlighted the links between an intrasemiotic and an intersemiotic perspective in relation to the construction of explanations with multiple semiotic resources.

Recent work by Forey and Polias (2017) has pointed to the importance of mobilizing different resources in the classroom to provide students with maximal access to content knowledge and of scaffolding students with constant shifts between commonsense knowledge and academic knowledge. They have argued that learning science in the classroom is an accumulative process of meaning-making through a range of multimodal resources, where scientific understandings are gradually built upon students' current understanding of science (i.e., the Zone of Proximal Development in Vogotsky's term). They have proposed that it is through such continuous and cyclical transfer along the learner's ZPD that knowledge is "unpacked" from abstract scientific discourse to concrete everyday discourse and, based on the understanding, "repacked" into more technical forms.

He and Forey (2018), in their study of students' construction of explanations for digestion, found that while gestures and animations were organized through the logics of time and space, language played a vital role in mediating the technicality of scientific knowledge. They also identified two ways of multiplying meanings across modes: creating multimodal links and reiterating organizing structures. Base on the findings, He and Forey (2018) called for explicit instruction on how multimodal resources can be capitalized on to create and multiply meanings crossmodally.

These studies, among others, have illustrated that the construction of scientific explanations involves the mobilization of knowledge, language and other semiotic systems. Importantly, these studies have shown that how science is represented with the specialized system of language and other semiotic systems is not apparent to a novice learner. Given that science makes meaning through multimodal resources, there is an increasing recognition that multisemiotic literacy constitutes a crucial component of scientific literacy (Gilbert, 2005; Gilbert, Reiner, & Nakhleh, 2008; Lemke, 2004). A systemic analysis of the language and multimodal resources used in the classroom can elucidate how knowledge can be constructed effectively through different channels of communication and yield new insights into ways of developing scientific literacy in both its fundamental and derived senses (Norris & Phillips, 2003).

In sum, the studies reviewed above in the fields of philosophy of science, linguistics and science education have focused on different aspects of scientific explanations. While philosophers of science have been interested in the properties of an explanation in general and a scientific explanation in particular, science educators have developed models to evaluate the quality of a scientific explanation in terms of its precision, abstractness and complexity, and linguists have closely investigated the representational forms of explanation – linguistic and multimodal forms. The present thesis adopts a multidimensional perspective on explanation construction in relation to the functions of explanations (i.e., the purposes of explanations), levels of scientificity (i.e., levels of precision, abstractness and complexity), and representational forms (e.g., linguistic and multimodal forms). This multidimensional perspective is adopted for three reasons. Firstly, it enables an in-depth analysis to be conducted on a particular type of explanation to reveal distinctive patterns within this type. Secondly, this multidimensional perspective can provide a comparative account of well-constructed scientific explanations and student-constructed ones based on their levels of scientificity. Thirdly, the perspective makes it possible to track the development of scientific literacy in its fundamental sense (i.e., development of content knowledge) and its derived sense (i.e., development of multisemiotic literacy) in the science classroom.

2.7 Summary of Chapter 2

This chapter has introduced key concepts for this study, such as scientific literacy (Section 2.2) and knowledge (Section 2.3). The present study proposes to conceptualize scientific literacy in its derived and fundamental senses (Norris & Phillips, 2003, 2009), borrowing Bernstein’s sociological perspective on knowledge and an SFL model of language. The extant theoretical work related to the semiotic construction of knowledge has been reviewed from a linguistic perspective (Section 2.4) and a multimodal perspective (Section 2.5). The chapter has also reviewed relevant empirical studies on explanation construction from the fields of philosophy of science, science education and linguistics. Based on these studies, the present study proposes to examine the construction of explanations in terms of function, quality and representational forms (Section 2.6). Thus, the study aims to investigate how modes of communication contribute to the construction of scientific knowledge, in this case, the construction of scientific explanations. To this end, it adopts analytical tools from SFL at the strata of semantics and lexicogrammar, including Theme analysis of language (both spoken and written modes) at both the levels of semantics and lexicogrammar, representational and logical analyses of images at the level of semantics, and image-text relations at the level of semantics. The detailed research design of the present study will be presented in the following chapter.

Chapter 3 Methodology

3.1 Overview

Chapter 2 discusses the theoretical and empirical background that underpins this study. This chapter explains and justifies the methods adopted for this study, bridging the theoretical and empirical backgrounds detailed in Chapter 2 and the findings and discussions presented in Chapter 4 and Chapter 5.

The goal of this study is to investigate the multimodal nature of pedagogic discourse in science. This study aims to understand:

(1) How different modes of communication (i.e., spoken language, written language and images) in the classroom contribute to the construction of explanations;

(2) How scientific knowledge is recontextualized in the classroom through the use of language (both spoken and written) and images.

These aims motivate the following research questions (RQs):

(1) How is language used to organize relevant scientific knowledge to construct explanations in the classroom?

(1a) What thematic patterns can be identified in written explanations?

(1b) What thematic patterns can be used in spoken discourse to construct these written explanations?

(2) How do images represent and link relevant scientific knowledge to construct explanations in the classroom?

(2a) What representational meanings can be identified in the images to construct explanations?

(2b) How are these representational meanings linked in the images to construct explanations?

(3) How do language and images interact in the construction of explanations in the classroom?

This chapter starts by situating the methodology of this study within a research paradigm and research approaches (Section 3.2). This is followed by presenting the details of the data collection procedures and the data (Section 3.3) and the procedures of data analyses (Section 3.4). The chapter concludes by drawing together the methodological issues (Section 3.5).

3.2 Situating the methodology

3.2.1 Research paradigm

Although sometimes not explicitly stated, any research is guided by a basic set of beliefs, or a paradigm (Guba, 1990; Mertens, 2010). Other terms used to refer to such beliefs are worldviews (Creswell & Creswell, 2018), epistemologies and ontologies (Crotty, 1998), and broadly conceived research methodologies (Neuman, 2009). To a large extent, the paradigms held by individual researchers decide the research design. Among those beliefs that researchers bring to inquiry, four paradigms or worldviews are widely discussed in the literature: post positivist, constructivist, transformative, and pragmatic (Creswell & Creswell, 2018).

The post-positivist paradigm is also called positivist/post-positivist research, scientific research, scientific method, and empirical science. This paradigm represents the traditional form of research, aiming to identify and evaluate causal relationships. The intent is to comprise, verify and refine the laws or theories that govern the world by narrowing ideas into measurable variables. Researchers working within the post-positivist paradigm usually adopt quantitative research methods, such as experiments. In contrast, the second paradigm, constructivism, renders importance to the complex views constructed by individuals. This paradigm is also called social constructivism, interpretivism or hermeneutics. Constructivists believe that individuals understand the world by interacting with others and by conforming to historical and social norms in their lives. The third paradigm, the transformative paradigm, is similar to the constructivist paradigm in recognizing the indispensable role of historical and social contexts in shaping our understandings of the world. However, researchers subscribing to the transformative paradigm advocate a political change agenda to confront social oppression on marginalized people, a goal that differs from that of the constructivist paradigm. Most studies informed by the constructivist and transformative paradigms adopt qualitative methods. The fourth paradigm, pragmatism, differs from the other three paradigms in that it does not subscribe to a specific system of beliefs. For pragmatists, the system of beliefs emerges from the interpretation of the phenomenon, and both quantitative and qualitative methods can be employed to address the issues arising from actions and situations.

The paradigm adopted for this study is more aligned with social constructivism, where "the constructed meanings of actors are the foundation of knowledge" (Lincoln, Lynham, & Guba, 2011, p. 106). Knowledge is constructed from individual experience, the interaction with others, and the social cultural environment. The aim of this study is to understand and interpret classroom experiences, specifically teacher-student interactions, where "individual belief and action intersect with culture" (Denzin & Lincoln, 2011, p. 2). This intersection occurs in both data collection and data analysis in the present study.

First, the data needed for the present study were collected in natural settings rather than a controlled environment typically set up in an experiment. The classroom data collected reflected both the teachers' and their students' beliefs, which shaped their actions in contexts. The data also captured their interpretations of knowledge, which subjectively and partially represent the social contexts in which the knowledge is produced and the social contexts of participants in the interaction.

Second, it is also important to note that data analyses also involve beliefs and perspectives brought by the researcher in the interactions between the inquirer and the inquired into. Thus, social interaction in this study not only consists of the interaction between the participants but also the interaction between the participants and the researcher. The analysis of the classroom interactions was designed on the basis of my research objectives, my theoretical and paradigmatic stance, and my social cultural background. Therefore, the analysis was unavoidably interpretative and would differ from the analyses conducted by other researchers on similar data collected from similar classrooms. The focus of this study is on the process of meaning-making in particular social cultural contexts. The objective is to understand the complexity of meaning-making in natural classrooms rather than testing hypotheses about variables in a controlled experimental environment. To better capture the complexity, a qualitative research design was adopted for this study that combined the strategies of case study (Stake, 1995; Yin, 2009, 2012), participant observation (Spradley, 1980), and multimodal discourse analysis (Kress & van Leeuwen, 2006). Given the heavy influences of a researcher's background and beliefs on the selection, collection, analysis and interpretation of research data, it is important to outline my background and experience. I am a female researcher in my early thirties, and I was educated in mainland China till the tertiary level and obtained my MA in English Language Teaching in Hong Kong. I received science education at the secondary level through the medium of Chinese (Putonghua). Learning science through the medium of English was a new experience for me as I could recall most of the content knowledge that was stored visually and linguistically, but the language related to scientific knowledge was in Chinese instead of English.

3.2.2 Trustworthiness and generalization

In natural science, the positivist notions of validity and reliability are well established in terms of internal validity, external validity, reliability, replicability and objectivity (Creswell, 2004). However, using the positivist notion of validity to judge the quality of a qualitative study is inappropriate. The goal of such qualitative research as case studies is not the formulation of an abstract empirical generalization; rather the objective is to meet the criteria of trustworthiness in the analyses. As Corbin & Strauss (2007) points out, quantitative analysis is “not a process that can be rigidly codified”, which requires “an intuitive sense of what is going on in the data; trust in the self and the research process” (p. 16).

In an early attempt to address the issue of trustworthiness in qualitative studies, Lincoln and Guba (1985) suggested substituting the notions of reliability and validity in natural science with the notions of dependability, credibility, transferability and confirmability. Dependability refers to the extent that the study can be repeated by other researchers to generate consistent findings. Lincoln and Guba suggested that the issue of dependability can be addressed with detailed descriptions of the data and the procedures of data analyses so that future researchers can repeat the process. Credibility refers to the level of confidence that researchers have in accurately reporting the phenomenon under investigation. In other words, it deals with the question of “How congruent are the findings with reality?” (Merriam, 1998). Ways to ensure the credibility of a qualitative study include the adoption of well-established research methods (Yin, 1994), prolonged engagement between researchers and participants (Lincoln & Guba, 1985), multiple case studies (Stake, 1995), and triangulation via different methods and varied data sources (Guba, 1981; van Maanen, 1983). Transferability refers to the extent to which the researcher has supplied sufficient contextual information that enables potential appliers to determine whether the findings have applicability in their contexts. Transferability can be enhanced by means of purposive sampling, sophisticated descriptions of the research context and the phenomenon under investigation (Lincoln & Guba, 1985), and the demarcation of boundaries of the study (Cole & Gardner, 1979). Confirmability refers to the degree to which the trustworthiness of the data and findings can be corroborated. Possible ways to ensure the confirmability of a study include triangulation of research methods and data sources (Guba, 1981; van Maanen, 1983), admission of researcher’s beliefs and assumptions (Patton, 1990), member checks (Guba & Lincoln, 1985), and detailed descriptions of the phenomenon under investigation (Silverman, 2006).

As pointed out by Guba and Lincoln (2005), qualitative research is not only about understanding a phenomenon but also about reconstructing the phenomenon. Denzin and Lincoln (2011) contend that the quality of a qualitative study can be measured through trustworthiness, where the researcher is seen as the primary research instrument for collecting and analysing data. In qualitative studies, the researcher needs to know the social cultural context in which the data are produced and recognize the meaning brought by his or her own beliefs and backgrounds. The trustworthiness of the approach adopted in this study is ensured by thick descriptions of the context in which the data were produced, constant reflections on my background as a researcher and my role as the key instrument for collecting and analyzing data to guide against possible interpretive biases, and the theory-based analyses to bring together multiple perspectives on the interpretations. In addition to the detailed descriptions of the context and the phenomena under investigation, in-depth methodological descriptions are provided to allow for comparisons between the present study and other studies. The detailed description of methodology also enables the findings of the present study to be scrutinized by other researchers before transferring these findings to other situations and contexts with necessary adaptations if needed. Despite these efforts, the evaluation of the trustworthiness of my study is an independent and subjective judgement of each reader. However, it is hoped that the trustworthiness of the present study can be ensured through the adoption of well-established research methods that are guided by a theory, detailed descriptions of the context, the phenomena under investigation, the background and beliefs of the researcher, and the methodology.

Another important issue with interpretative qualitative research, such as case studies, is its ability to generalize. Williams (2000) identifies three main types of generalization:

> 1. Total generalizations, where situation S1 is identical to S in every detail. Thus, S1 is not a copy of S but an instance of a general deterministic law that governs S also.
> 2. Statistical generalizations, where the probability of situation S occurring more widely can be estimated from instances of S.
> 3. *Moderatum* generalizations, where aspects of S can be seen to be instances of a broader recognizable set of features.
>
> The first of these are almost certainly impossible in the social sciences and in the natural sciences mostly restricted to a few fundamental laws of nature. The second [...] form the basis of

> aggregate description in the social sciences. Both [...] are neither possible nor desirable outcomes of interpretive data, but [...] the third seems to be an attainable goal.
>
> (Williams, 2000, p. 100, italics in original)

It is the third type of generalization, *moderatum* generalization, that is aimed at in the present study. The interpretations are regarded as instances of a potential set of meanings. The objective of this study is to understand how the potential of the meaning-making systems can be activated in a specific situation, and how the activated meanings interact with each other for a specific social purpose – to construct explanations. To achieve this goal, three sets of data, namely written texts, spoken texts and images, were selected to explore how they contributed to the construction of explanations. Details about these data are presented in Section 3.3. While the results from these data are surely confined by the context and scope of this study, it is possible for readers to generalize subjectively from the instances according to their own personal experiences and social contexts.

3.2.3 Case study

This thesis is an example of case study research. However, as Merriam (1998) points out, while many have heard of case-study research, there is little consensus on what constitutes a case study or how this type of research is conducted. Therefore, it is important to unpack the meaning of this term.

Bassey (1999) summarizes the characteristics of case studies in educational settings as follows.

> An educational case study is an empirical enquiry that is conducted:
>
> - within a localized boundary of space and time (i.e., a singularity);
> - into interesting aspects of an educational activity, or programme, or institution, or system;
> - mainly in its natural context and within an ethic of respect for persons;
> - in order to inform the judgments and decisions of practitioners or policy makers, or of theoreticians who are working to these ends;
> - in such a way that sufficient data are collected for the researcher to be able to:
>   1. explore significant features of the case;
>   2. create plausible interpretations of what is found;
>   3. test for the trustworthiness of these interpretations;
>   4. construct a worthwhile argument or story;
>   5. relate the argument or story to any relevant research in the literature;

6. convey convincingly to an audience this argument or story; and
7. provide an audit trail by which other researchers may validate or challenge the findings or construct alternative arguments.

Bassey (1999, p. 58)

Stake (2005) offers a useful division of case study research into two types: intrinsic and instrumental. While the primary focus of intrinsic case studies is on understanding the case itself, instrumental case studies use the as a means to provide insights into an issue or a phenomenon. A case study, as Creswell (2013) points out, may be a data collection technique rather than an analytic approach. Researchers use a variety of data collection procedures to collect detailed information on one or multiple cases over a sustained period of time (Stake, 1995; Yin, 2009, 2012).

These unique characteristics enable a case study to explore a phenomenon in great depth. According to Yin (2006), case study research is a useful approach to address "either a descriptive question (*what* happened?) or an explanatory question (*how or why* did something happen?)" (p. 112). Another strength of a case study, as pointed out by Yin (2006), is its ability to "illuminate a particular situation" using "direct observations" rather than "derived data" such as questionnaires and statistics (p. 112). To sum up, a case study is well equipped to capture dynamics and complexity in a snapshot rather than providing a macroscopic overview of a phenomenon. As classroom interactions between teachers and students are complex in nature, using a case study design has great potential to highlight the complexity of the communications. However, it is necessary to admit that capturing the complexity of a case usually means sacrificing the generalizability of the results. Although the complexity of interactions highlighted in this study provides raw materials for designing and adapting frameworks for linguistic and multimodal analyses (see Section 3.4 for details), to what extent these frameworks are generalizable to other contexts calls for further validation.

To answer the research questions formulated for this study requires both a descriptive account and an explanatory account. Descriptively, this thesis elucidates what meanings are constructed by means of a certain semiotic resource (language or images) in forming a scientific explanation; explanatorily, this thesis investigates how these meanings are negotiated through the integration of semiotic resources (language and images). To these ends, data were collected from two classrooms in Hong Kong. The next section describes the process of data collection and the criteria used to select the focal classrooms.

3.3 Data

3.3.1 Selection of cases

The data were collected from the professional development project, Establishing and Supporting a Learning Circle for Secondary Schools Using English as the Medium of Instruction for the Key Learning Area of Science Education (Science Learning Circle). The aim of the professional development project was to support secondary science teachers in Hong Kong from October 2013 to December 2014, involving six secondary schools (band 1, band 2 and band 3[6]), 16 science teachers and seven English teachers. This project was a collaboration between a research team based in The Hong Kong Polytechnic University and the Education Bureau of Hong Kong. The objectives of this project included supporting science teaching and learning in English, creating a platform for sharing teaching materials within a school and among schools, and cultivating a trans-disciplinary approach by encouraging the cooperation between Science teachers and English teachers. The project included a three-day workshop and one-day course planning at The Hong Kong Polytechnic University, classroom observations in the participating teachers' own schools, and a reflection and sharing session in a theater on the EDB premises that was open to all secondary teachers in Hong Kong. In the workshop, science teachers received considerable input on language, literacy and learning in science, such as genres and registers commonly used in science education (Martin & Rose, 2008; Rose & Martin, 2012), language and other meaning-making systems (Kress & van Leeuwen, 2006), and scaffolding in the classroom (Gibbons, 2002, 2003; Hammond & Gibbons, 2005). They then co-planned their

[6] Students in Hong Kong are categorized into three bands according to their academic capability: band 1 (with highest academic capability), band 2 (with average academic capability) and band 3 (with low academic capability) (Chan, 2016).

lessons with English teachers based on a genre-based pedagogy known as the Teaching Learning Cycle (TLC) (see Forey & Polias, 2017, for a detailed discussion on TLC). The co-planned lessons were taught and observed in the teachers' schools and commented on by the project team members. Five months later, these teachers were invited for a sharing session where they reflected on their teaching practices and shared their experiences with other teachers from Hong Kong secondary schools.

Video recordings of two lessons observed for the TLC project formed the primary data for this study. These two lessons were selected based on two criteria: instructional content and participants' consent to participate in this study. More specifically, the content involved explanation constructions with the use of multimodal resources; both the teachers and their students agreed to participate in this study and be video-taped to provide the needed data. The following section provides more details on the two selected lessons and the participants.

3.3.2 Setting and participants

The two lessons that were observed and videotaped were from two lessons in a boy's school situated in the New Territories region of Hong Kong. During the school year when the data were collected, there were 55 teachers and 922 students in this school. This secondary school is a government-funded school, where the MOI was Cantonese for all subjects before the fine-tuning MOI policy. After the implementation of the fine-tuning MOI policy, full EMI was adopted for two content subjects: Integrated Science (IS) and Mathematics at the junior secondary level (S1-3). Most students from this school were categorized as band 2, suggesting that the students had an average academic ability.

The lessons were observed in a laboratory room, with the teacher's desk placed in the front of the room and students' operating tables arranged in four rows. Behind the teacher's desk placed a blackboard in the middle and two projecting screens hanging on the left and right sides. A camera was set on a tripod at the back of the classroom, mainly focusing on the teacher (see Figure 3.1 for the classroom layout).

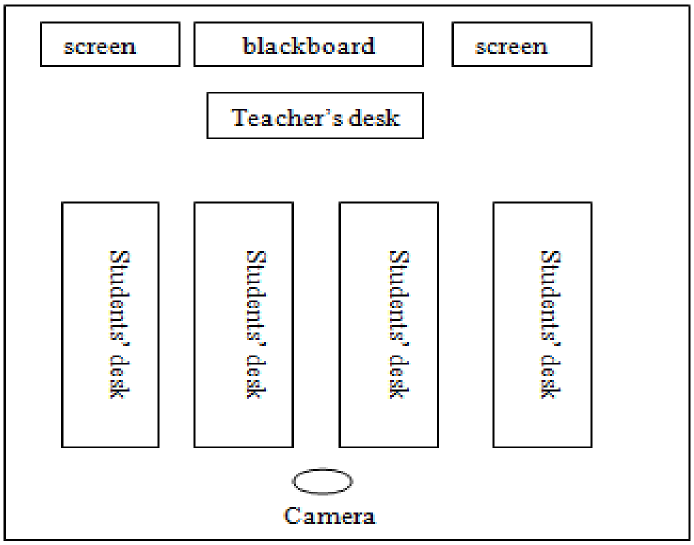


Figure 3.1 The classroom layout in Lesson A and Lesson B

Informed consent for video-taping the lessons and using the data for research purposes were obtained from all participants prior to the study, including the science teachers and their students (see Appendix I for consent forms). Personal information of the participants, such as their names, was anonymised. The two science teachers Mr. Michael (pseudonym) and Mrs. Emily (pseudonym) were locally trained science teachers, with both a Bachelor degree in Science (B.Sc) and an in-service Diploma in Education (Dip.Ed.). Mr. Michael has been teaching for 20 years, mainly in Chemistry and partly in Integrated Science. He thought the role of a teacher was that of a learning facilitator and that a good teacher "must know the students well and love them". He found online video clips demonstrating experiments useful in his teaching although he was slightly worried about his English proficiency in facilitating a lesson in EMI. Mrs. Emily has been teaching for three years, mainly in Biology and Integrated Science. Similar to Mr. Michael, she also considered a teacher as a facilitator and believed that a good teacher should be "prepared and organized". Mrs. Emily thought resources such as animations, videos and models could facilitate students' learning of science if they were "selected carefully and the content is suitable". According to Mrs. Emily, a science teacher should maintain a balance between the development of language and content knowledge.

The students in Michael's and Emily's classes were all boys in their first year of junior secondary schooling (13 years old on average). There were 34 students in Michael's class (Lesson A) and 39 students in Emily's class (Lesson B). The aim of both lessons was to conduct experiments demonstrating the applications of air pressure and to construct explanations for the observed phenomena, each lesson lasting for about 80 minutes. The teaching materials were prepared collectively by Michael and Emily. I was a research associate for the TLC project during the period of data collection.

3.3.3 Data collection

The data were collected from October 2013 to December 2014, on the sites of TLC workshops, lesson planning, lesson observations, and sharing sessions. A variety of data were collected from different sources to provide a detailed account of the issues under investigation.

1) Video recordings

The use of video enables the capture of dynamic interactions and the use of other semiotic resources than language. The video recordings of the two lessons conducted by the two teachers (159 minutes in total) were collected during the lesson observations. In each lesson observation, a video camera was placed at the back of the classroom to record the classroom interactions between the teacher and the students. The camera was placed on a tripod, focusing on the teachers for most of the time, and zoomed in on the other resources deployed by the teacher, such as PowerPoint slides, hand gestures and writings/drawings on the blackboard. The video recording of each lesson lasted about 80 minutes. The total recordings of the two lessons were 159 minutes in length. The structure of Lesson A and of Lesson B are shown in Table 3.1 and Table 3.2, respectively. The structure of each lesson is shown through teaching stages, which marks the stages of interactions between the teacher and students to achieve a particular communicative goal.

Table 3.1 The teaching stages of Lesson A

Teaching stage			Duration
Lesson initiation	1.	Greetings	1 minute
	2.	Air pressure gun demonstration	5 minutes
	3.	Revision & Learning objectives	6 minutes
Lesson progress	4.	The Magdeburg experiment	23 minutes
	5.	The Balloon experiment	10 minutes
	6.	The Rubber sucker experiment	12 minutes
	7.	The vacuum bag experiment	23 minutes
Lesson closure	8.	Closing	1 minute
Total			81 minutes

Table 3.2 The teaching stages of Lesson B

Teaching stage			Duration
Lesson initiation	1.	Greetings	2 minutes
	2.	Revision & Learning objectives	5 minutes
	3.	Air pressure gun demonstration	4 minutes
Lesson progress	4.	The Magdeburg experiment	12 minutes
	5.	The balloon experiment	19 minutes
	6.	The beverage can experiment	14 minutes
	7.	The vacuum bag experiment	19 minutes
Lesson closure	8.	Closing	2 minutes
Total			77 minutes

Lesson A started with an opening stage which consisted of short greetings between the teacher and his students (1 min), an introduction of the topic (i.e., air pressure applications) through an air pressure gun experiment demonstration (5 mins), and a review of previously taught content and a presentation of the new learning objectives (6 mins). The related concepts such as air particles, air pressure and net force were reviewed briefly to prepare for the learning objectives of this lesson, that is, to understand the operation of the causal mechanism in the phenomenon and to construct explanations for each experiment. The opening stage was followed by the demonstration and explanation of four experiments related to air pressure applications: the Magdeburg experiment (23 mins), the balloon experiment (10 mins), the rubber sucker experiment (12 mins), and the vacuum bag experiment (23 mins). Lesson A ended with a brief session to summarize the content taught in this lesson and assign homework for students.

Similar to Lesson A, Lesson B started with an opening stage of greetings (2 mins), a review of previously taught content and a statement of learning objectives (5 mins), and an introduction to the topic of the lesson: explaining air pressure-related phenomena with a demonstration of the air pressure gun experiment (4 mins). The opening stage was then followed by demonstrations of four air pressure-related phenomena, each requiring the construction of an explanation. These four air pressure-related phenomena were demonstrated by the Magdeburg experiment (12 mins), the balloon experiment (19 mins), the beverage can experiment (14 mins), and the vacuum bag experiment (19 mins) respectively. The closure stage of Lesson B was a brief summary of the lesson and an assignment of homework (2 mins).

2) Teachers' products and students' products

Teachers' products were the written texts of explanations and the pre-prepared visuals on the PowerPoint slide shows (including written texts, still and moving images), hand writing or drawing on the blackboard and comments on students' worksheets shown on the projecting screens. The students' products were the texts revised, re-organized or constructed in group/individual tasks, which were later shown on the projecting screens. These products by the teachers and their students were captured through the zoomed-in video camera. A total of 46 images and 11 written explanations were collected from two classrooms (see Appendix Ⅱ for the written explanations and Appendix Ⅲ for the images). A total of 13 images were used in Lesson A. Lesson A produced six written texts of explanations, among which one was written by the teacher, one by the students, and the other four were formed in group tasks and thus counted as collaborations by the teacher and students. In Lesson B, a total of 33 images were used. Also produced in Lesson B were five written texts of explanations, consisting of one modeling text by the teacher, two student texts, and two collaborated texts by the teacher and students. These written texts of explanations were 68 words in length on average, ranging from 36 words to 84 words. The details of these written texts are shown in Table 3.3 and Table 3.4 below.

Table 3.3 Written texts of explanations in Lesson A

Text	No. of words	Teaching & Learning activity	Phenomenon to be explained
Text A1	72	Teacher modeling an explanation text	Magdeburg Experiment
Text A2	36	Student activity: selecting the processes	Balloon experiment
Text A3	50	Student activity: sequencing the events	Rubber sucker experiment
Text A4	52	Student activity: writing down the effects	Vacuum bags experiment
Text A5	57	Teacher modeling adding connectives	Rubber sucker experiment
Text A6	58	Student activity, writing an explanation text	Vacuum bags experiment
Total	325		

Table 3.4 Written texts of explanations in Lesson B

<table>
<tr><th>Text</th><th>No. of words</th><th>Teaching & Learning activity</th><th>Phenomenon to be explained</th></tr>
<tr><td>Text B1</td><td>84</td><td>Teacher modeling an explanation text</td><td rowspan="2">Magdeburg Experiment</td></tr>
<tr><td>Text B2</td><td>73</td><td>Teacher modeling an explanation text</td></tr>
<tr><td>Text B3</td><td>78</td><td>Student activity: sequencing the events</td><td>Balloon experiment</td></tr>
<tr><td>Text B4</td><td>84</td><td>Student activity: selecting the processes</td><td rowspan="2">Beverage can experiment</td></tr>
<tr><td>Text B5</td><td>81</td><td>Student activity: adding connectives</td></tr>
<tr><td>Total</td><td>400</td><td></td><td></td></tr>
</table>

3) Field notes

Field notes were taken during the lesson observations and the informal interviews during the lesson break. They were used to describe the classroom setting, the structure of the lessons, events and activities, the participants' reactions, with my comments or reflections on the side. Figure 3.2 shows an excerpt of the field notes about the classroom as an example.

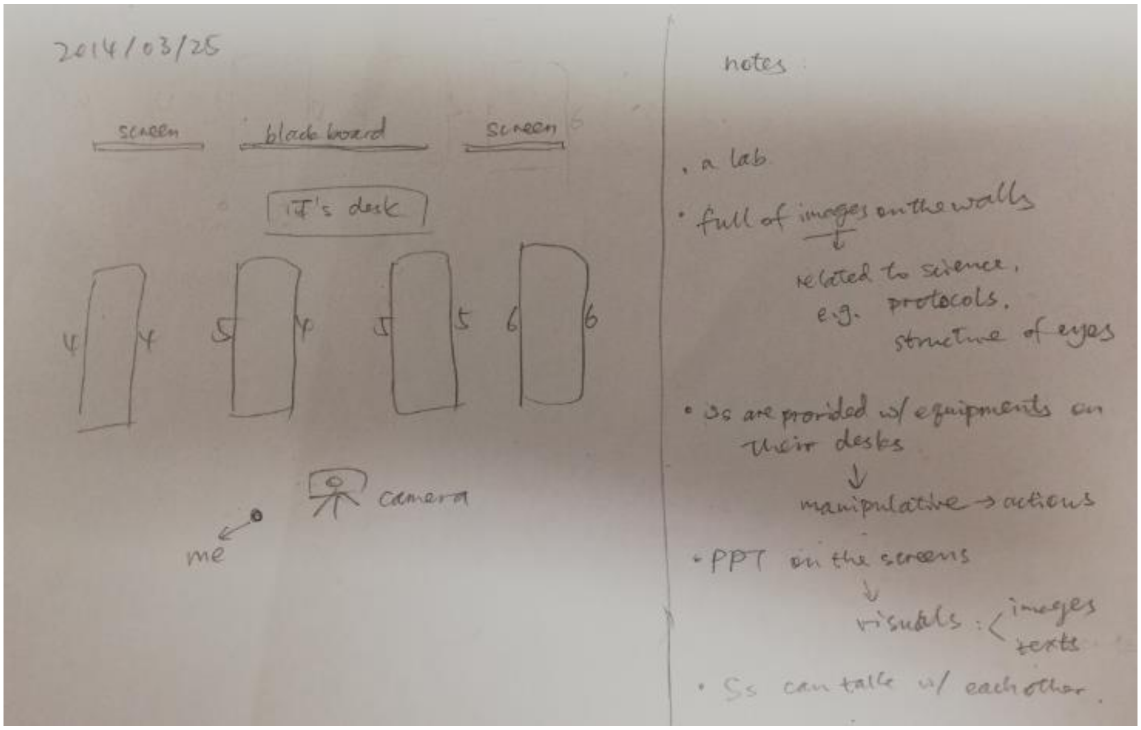


Figure 3.2 Examples of field notes

The filed notes consisted of two columns with the left column documenting factual data (e.g., date, time, physical setting, and actions of the participants) and the right column recording my reflections (e.g., comments, questions, and other related thoughts). As Figures 3.2 illustrates, the left column of the field notes documents the factual data such as the spatial arrangement of the classroom, the distribution of students, and the position of the camera. In the right column further information about the context of the classroom is added: it is a lab with images on the walls. Also presented in the right column are thoughts of the researcher in how the provision of equipment and PowerPoint slides allows for actional and visual meanings to be made.

3.3.4 Sampling and transcribing data

The selection of the video data for transcription was based on the following two considerations:

(1) The video data captured moments of knowledge construction, that is, when the scientific knowledge was represented, negotiated, interpreted and reproduced by

the teacher and/or students. This means that the video data related to classroom management and the revision of previously taught knowledge were not analyzed for this study. Specifically, only lesson segments involving explanation constructions were selected for analysis because the primary goal of this study was to investigate the construction of scientific explanations in the classroom.

(2) The video data captured moments when multiple semiotic resources were adopted in the process of explanation construction. This means that the video data of the teaching stages where only one semiotic resource, such as language, was adopted were not included for analysis. Special attention was paid to the lesson segments that exhibited richness of meaning-making in a single mode and complexity in meaning-making across modes. This would shed lights on how meanings were made intramodally and intermodally.

The data thus selected for transcription and analysis were expected to reveal the relation between the teaching and learning of content knowledge and the use of multimodal resources in the construction of scientific explanations. Specifically, the focus was on explaining air pressure-related phenomena through the use of language (both written and spoken modes) and images. Language and images were selected for analysis due to their primary roles in the construction of explanations in both classrooms. How language and images in the video data were transcribed will be elaborated in the following paragraph.

The video data was transcribed in a matrix that contained three columns. The first column showed the speaker, using T for teacher, S1 for a student, and Ss for the whole class. The second column was designed for the utterances and non-verbal actions (i.e., spoken texts by the teacher and students, gestures, and movements). The different modes were transcribed in one column instead of separate columns to highlight the "complexity of interlinked communicative modes" (Norris, 2004a, p. 104). The third column illustrated a snapshot from the video when the utterance and non-verbal actions occurred. The video snapshots focused on the teacher and the visuals shown on the projecting screens or the blackboard. A sample of the video transcription is shown in

Figure 3.3 below.

Speaker	Utterance & Non-verbal Actions	Video snapshots
T	Now in emm many science experiments like this (T pointed to the PPT) we have a cause, we. we suck out the air inside the MH (moved close to the PPT)	
	and the result (T pointed to the Result part of PPT written texts) is that they are difficult to pull apart	
	Now we have to explain (T withdrawed his hand and moved away from the PPT toward the students) what is happening inside by a series of steps,	
	and we call them (T moved back toward the PPT and pointed to the schematic diagram of causal explanation) cause and effect	

Figure 3.3 A sample of video transcription

All the written explanations produced by teachers and students (a total of 13 written texts) were selected for linguistic analysis to capture the development of scientific literacy in a lesson focusing on thematic patterns (see Section 3.4.2 for analytical frameworks of Themes). The written texts of explanations were coded using two digits, one showing the context of the text and the other showing the consecutive number of this text. The coding scheme for written texts is shown in Figure 3.4. For instance, the code A1 suggests that the written text was the first one produced in Lesson A.

Figure 3.4 The coding scheme for written text identification

The spoken texts of the Magdeburg experiment in Lesson A and Lesson B were selected for detailed linguistic analysis for two reasons. First, this teaching stage involves more teacher-student interactions via spoken language, and therefore provides rich data for analysis. Second, although a similar teaching stage of modelling the explanations was observed in both lessons, the use of spoken language tended to vary between Lesson A and Lesson B. The selected data would allow me to compare the linguistic patterns in Lesson A and those in Lesson B, providing insights into how scientific knowledge can be recontextualized in two classrooms. The spoken texts of explanations were coded using two digits linked by a dash, one digit showing the context of the text and the other showing the consecutive number of this text. The coding scheme for spoken texts is shown in Figure 3.5. For instance, the code A-1 suggests that the spoken text was the first one produced in Lesson A.

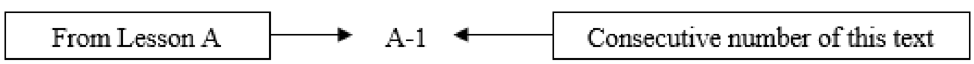


Figure 3.5 The coding scheme for spoken text identification

These spoken texts of the Magdeburg experiment concerned either experiment demonstrations (Text A-1 and Text B-1) or explanation constructions (Text A-2 and Text B-2). The teaching phases of experiment demonstrations (Text A-1) and explanation constructions (Text A-2) in Lesson A are shown in Table 3.5 and Table 3.6 respectively. As for Lesson B, the teaching phases of experiment demonstrations (Text B-1) are illustrated in Table 3.7 and the teaching phases of constructing an explanation (Text B-2) in Table 3.8.

Table 3.5 The teaching phases of demonstrating the Magdeburg experiment in Lesson A (Text A-1)

Phase	Teaching/Learning Activity	Description
1	Introducing Magdeburg Hemispheres	Michael introduced the instrument Magdeburg Hemispheres to students
2	Experiment demonstration	Michael asked two groups of students to demonstrate the Magdeburg Experiment

Table 3.6 The teaching phases of explaining the Magdeburg experiment in Lesson A (Text A-2)

Phase	Teaching/Learning Activity	Description
1	Schematic structure of causal explanations	Michael explained the schematic structure of causal explanations.
2	Guiding Question 1 (Cause-Effect 1)	Michael asked the first guiding question about the number of particles in relation to the first explanation sequence (Cause-Effect 1).
3	Guiding Question 2 (Effect 1-Effect 2)	Michael asked the second guiding question about the gas pressure inside Magdeburg Hemispheres in relation to the second explanation sequence (Effect 1-Effect 2).
4	Guiding Question 3 (Effect 2-Effect 3)	Michael asked the third guiding question about the difference between air pressure outside and inside the Magdeburg Hemispheres in relation to the third explanation sequence (Effect 2-Effect 3).
5	Guiding Question 4 (Effect 3-Result)	Michael asked the fourth guiding question about net force in relation to the final explanation sequence (Effect 3-Result).
6	The explanation for the Magdeburg Experiment	Michael used the schematic structure of causal explanations to explain the Magdeburg experiment and showed three force diagrams.

Table 3.7 The teaching phases of demonstrating the Magdeburg experiment in Lesson B (Text B-1)

Phase	Teaching/Learning Activity	Description
1	Introducing the first Magdeburg experiment	Emily introduced the first Magdeburg experiment conducted in 1654 to students using pictorial narratives.
2	Experiment demonstration	Emily asked one group of students to demonstrate the Magdeburg experiment.

Table 3.8 The teaching phases of explaining the Magdeburg experiment in Lesson B (Text B-2)

Phase	Teaching/Learning Activity	Description
1	Schematic structure of causal explanations	Emily explained the schematic structure of causal explanations.
2	Guiding Question 1 (Cause-Effect 1)	Emily asked the first guiding question about the number of particles in relation to the first explanation sequence (Cause-Effect 1).
3	Guiding Question 2 (Effect 1-Effect 2)	Emily asked the second guiding question about the gas pressure inside Magdeburg Hemispheres in relation to the second explanation sequence (Effect 1-Effect 2).
4	Guiding Question 3 (Effect 2-Effect 3)	Emily asked the third guiding question about the difference between air pressure outside and inside the Magdeburg Hemispheres in relation to the third explanation sequence (Effect 2-Effect 3).
5	Guiding Question 4 (Effect 3-Result)	Emily asked the fourth guiding question about net force in relation to the final explanation sequence (Effect 3-Result).
6	The explanation for the Magdeburg Experiment	Emily used the schematic structure of causal explanations to explain the Magdeburg experiment.
7	Causal relations	Emily elaborated how to construct causal relations by adding causal connectives.

To assist identifying the spoken texts in the analysis and the discussions, they were coded using four digits, indicating the context of the text and the number of the clause. The coding scheme for the spoken texts is exemplified in Figure 3.6.

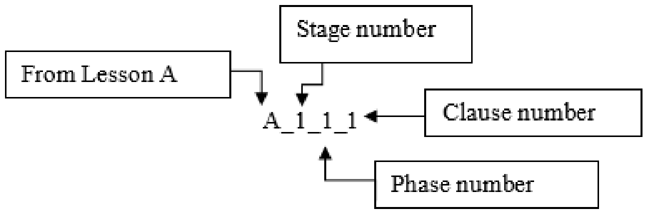


Figure 3.6 The coding scheme for spoken text identification

The first letter (A or B) indicates the context of the text, namely Lesson A (abbreviated into A) or Lesson B (abbreviated into B). The second and the third digit show the position of the text in the teaching stage (the second digit) and the teaching phase (the third digit). The last digit shows the clause number, which helps identify the Theme of each clause (see Section 4.4.2 for the Theme analysis). For instance, the code A_1_1_1 indicates that the clause in question was the first clause in the first teaching phase of the first teaching stage from Lesson A.

All the images used by the teachers (a total of 46 images) were selected for multimodal analyses to reveal the meaning-making of images on PowerPoint slides (see Section 3.4.3., Section 3.4.4 for the analytical frameworks of representational meanings and logical meanings respectively) and the multiplication of meanings between images and spoken language (see Section 3.4.5 for the analytical framework of image-text relations). The images were coded using three digits, shown in Figure 3.7.

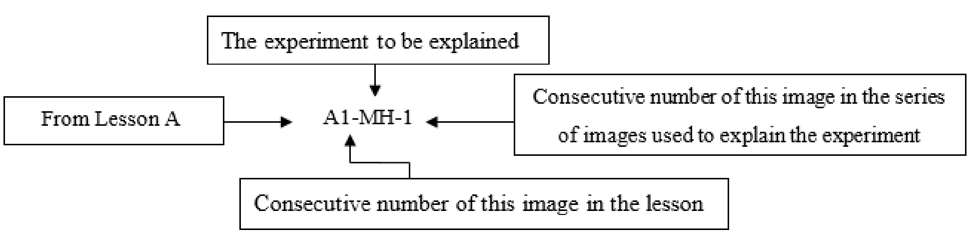


Figure 3.7 The coding scheme for image identification

The first letter indicates the context of this image, that is, the lesson in which it appeared. The second digit shows in which experiment the image was used. The experiments are indicated by abbreviations: MH for the Magdeburg experiment, BL for the balloon experiment, RS for the rubber sucker experiment, VB for the vacuum bag experiment, and BC for the beverage can experiment. The final digit indicates the consecutive number of this image in the series of images that were used to explain the experiment. For instance, the code A1-MH-1 indicates that the image in question was the first image used to explain the Magdeburg experiment in Lesson A, and it was also the first image used in the whole lesson. The code B22-MH-16 means that this image was the 16th image used to explain the Magdeburg Experiment in Lesson B, and it was the 22nd image used in Lesson B.

3.4 Procedures and analytical frameworks

3.4.1 Units and procedures of analysis

The video data comprised three semiotic modes under investigation: written texts, spoken texts (classroom talks between teachers and students) and images. The co-occurrence of multiple modes called for multilevel analytical units. The analytical units adopted for this thesis comprised a hierarchy: discourse, teaching stages, teaching phases, and multimodal acts/clauses. Kress and van Leeuwen (2001) define a discourse as "socially constructed knowledge of (some aspect of) reality" (p. 4). Discourse in this thesis refers to the socially constructed knowledge of science through the teachers' and students' use of multimodal resources in a lesson. Discourse can be realized through unfolding stages of interactions between social actors to achieve a specific communicative purpose, such as forming an explanation for a phenomenon demonstrated in a classroom experiment. The formation of an explanation may span several teaching stages: identifying the phenomenon, constructing explanations, and making clarifications. A teaching stage contains one or several teaching phases and links a series of actions around the same topic, such as forming an explanation sequence through a question-answer exchange, assessing the explanations constructed or clarifying the unclear points. These actions are the smallest units of analysis, which can be realized mono-modally (e.g., the action of uttering the clause "Will the number increase?") or multi-modally (e.g., the actions of uttering the clause "Will the number increase?" and making an upwards pointing gesture simultaneously).

The analytic units adopted in this study and their relationships are presented in Figure 3.8.

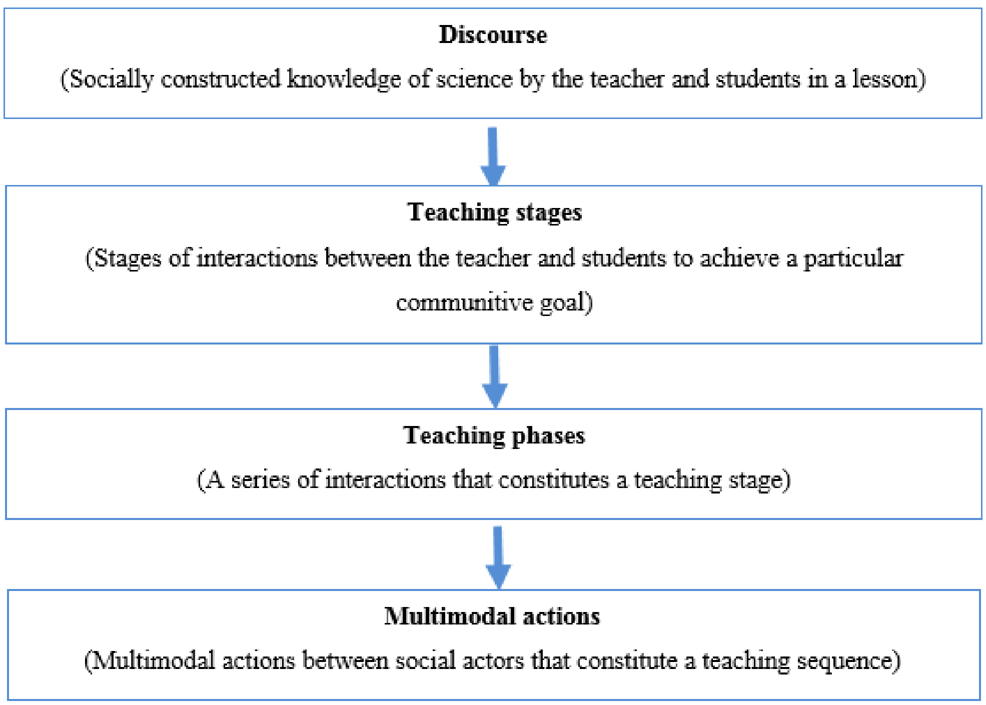


Figure 3.8 The hierarchy of analytic units

In each lesson, meanings are constructed through the moment-by-moment multimodal actions, which accumulate and interact with the meanings that are constructed in a larger unit, such as teaching phases and teaching stages. This study aims to provide linguistic and multimodal characterizations of the construction of explanations in two science classrooms within the unfolding of a lesson. In order to address the research questions, language texts and images collected from two science classrooms were analyzed in three phases. In Phase One, the language texts (both written and spoken) collected from the two science classrooms were analyzed in terms of thematic patterns to address RQ1. In Phase Two, the images from the two classrooms were analyzed in terms of representational meanings (see Section 3.4.3 for the analytical framework), and logical meanings (see Section 3.4.4 for the analytical framework) to address RQ2. In Phase Three, the multiplication of meanings between language and images were analyzed in terms of image-text relations (see Section 3.4.5 for the analytical framework) to address RQ3. Results of the analyses were compared to highlight the relations between modes of communication (i.e., spoken language, written language and images) and the construction of explanations (Aim 1). Results of the analyses of language and images in Lesson A were compared with those in Lesson B to unveil the recontextualization of knowledge (i.e., scientific explanations and air pressure) through the use of multimodal resources of language and images (Aim 2). The procedures of data analyses are schematized in Figure 3.9.

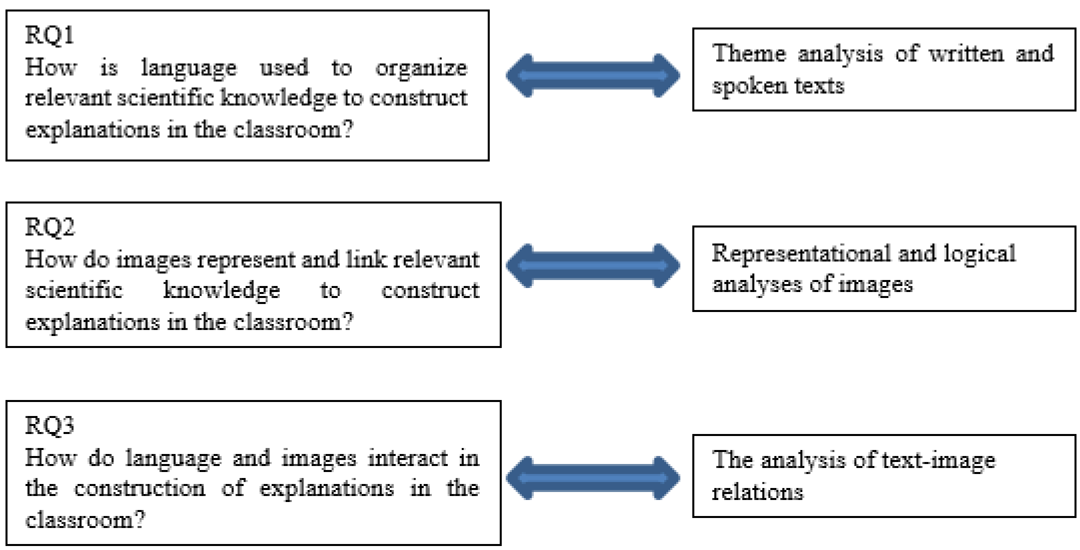


Figure 3.9 Data analyses in relation to the research questions

In what follows, the procedures of data analyses are described in detail.

First, the teaching stages and teaching phases involving the construction of explanations (the written texts) were identified in each lesson. The organization of content knowledge (ideational meanings) in the written explanations was identified via a thematic analysis (thematic selection and thematic progression patterns). The analytical framework for the Theme analysis is presented in Section 3.4.2.

Second, the multimodal actions in these teaching stages and phases were analyzed focusing on the use of classroom talks (the spoken texts) and images. The distribution of thematic selection and progression patterns in the spoken texts were analyzed to identify the organization of content knowledge (ideational meanings) in the spoken texts. The use of images was analyzed from two perspectives: the content knowledge (ideational meanings) available for students through the image display, and the content knowledge (ideational meanings) activated by the teacher, such as a pointing gesture to the image. This enabled an investigation into the ideational meaning affordance of images related to the social action of explaining and an examination of the types of ideational meanings that were privileged by the teacher's deliberate choices. The analytical frameworks for visual analysis are presented in Section 3.4.3 and Section 3.4.4. The analytical framework for image-text relations is presented in Section 3.4.5.

The macro design of the study is schematized in Figure 3.10 to manifest the relations between the units and procedures of data analyses and research questions.

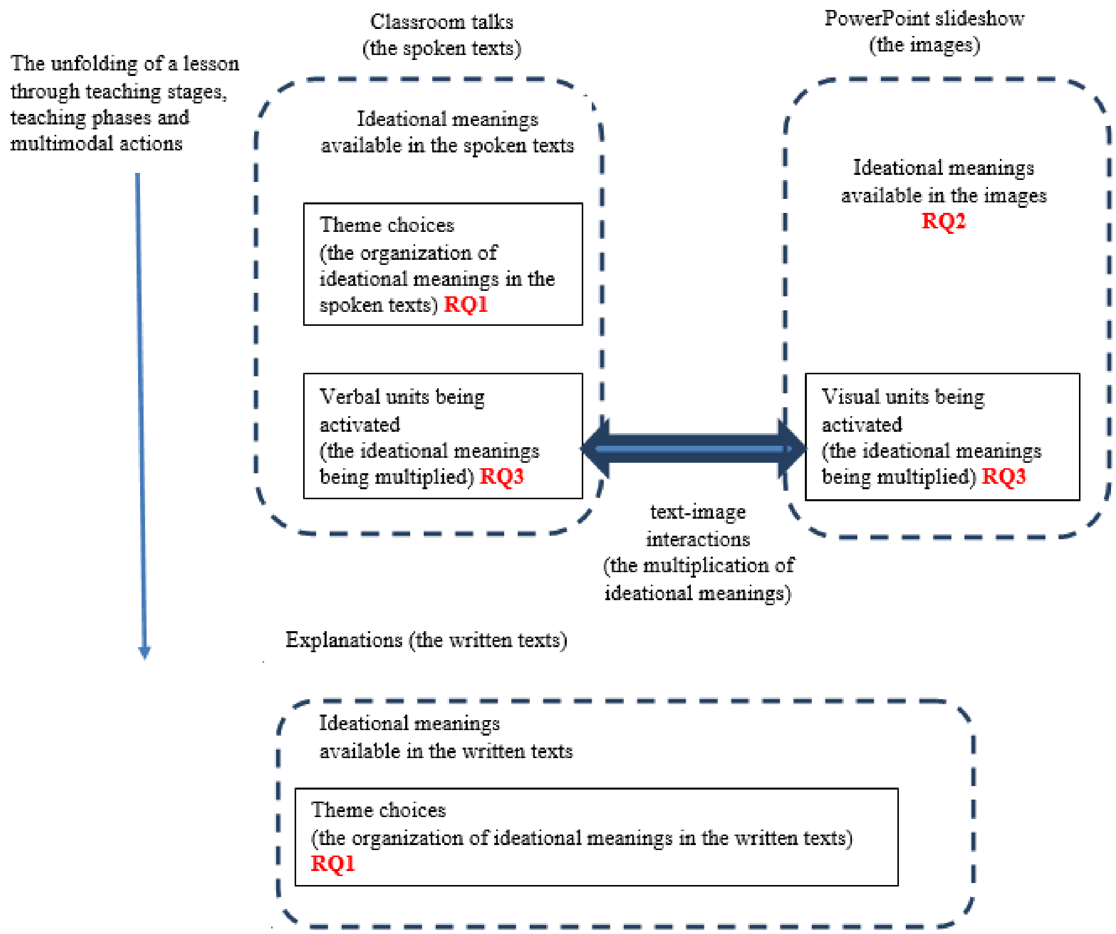


Figure 3.10 The macro design of the present study

3.4.2 The analytical framework for Theme analysis of written and spoken texts

This section presents the framework for analyzing Themes in language. It starts by defining the unit of analysis, which is followed by showing ways of identifying Themes at the clausal and discourse levels. This section ends with presenting the analytical frameworks for analyzing the Theme markedness at the clausal level and ways of analyzing Themes at the discourse level through tracking hyper-/macro-Themes and thematic progression.

The theme analysis was conducted at two levels: at the clausal level and at the discourse level. The analytic unit of Themes at the clausal level is a ranking clause for its primary contribution in developing the Theme-Rheme of a text. A ranking clause can be either a free clause (i.e., an independent clause) or a non-embedded bound clause (i.e., a dependent clause in the clause complex that is not an attributive clause). Examples of the theme analysis of a free clause and a non-embedded bound clause are shown below:

Example 3.1 Theme analysis of a free clause

We	force out the air inside the rubber sucker by pressing it down.
free clause	
Theme	Rheme

Example 3.2 Theme analysis of a non-embedded bound clause and its main clause

When we	force out the air inside the rubber sucker by pressing it down,	the number of air particles inside the rubber sucker	decreases.
dependent clause (non-embedded bound clause) β		main clause α	
Theme	Rheme	Theme	Rheme

Based on their distinct functions, Themes at the clausal level can be categorized into three types: textual Themes, interpersonal Themes, and topical Themes. According to Halliday and Matthiessen (2014), a Theme "extends from the beginning of the clause and up to (and including) the first element that has a function in transitivity" (p. 89) and a Rheme includes "the remainder of the message" (p. 89). The first transitivity element that separates a Theme and a Rheme can be participant, circumstance or process, which is called a topical Theme. The topical Theme in a declarative clause can be realized through a Subject (e.g., *I* in *I did an experiment today*), a Circumstantial Adjunct (e.g., *Today* in *Today I did an experiment*), and a Complement (*an experiment* in *An experiment I did today*). A topical Theme is obligatory and may be preceded by textual or/and interpersonal elements, which are optional. Those textual and interpersonal elements preceding the experiential element in the Theme are referred to as textual Themes (structuring the text and linking the clauses) and interpersonal Themes (involving writer/speaker's angle or value on the matter). A textual Theme can be realized through a Continuative (e.g., *yes, okay, well*), a Conjunctive Adjunct (e.g., *actually, thus*), a Conjunction (e.g., *because, and, if*), a Relative (e.g., *who, where, whichever*), or any combination of them. As suggested by Forey and Sampson (2017), textual Themes provide links between clauses and thus contribute to the overall coherence of a text. Another feature often found before a topical Theme is an interpersonal Theme, which is used to construct the writer's viewpoint. An interpersonal Theme can be realized through a Modal Adjunct (e.g., *luckily, please*), a modal finite (e.g., *can, would*), a Vocative (e.g., *Ms. Lam* in *Ms. Lam, could you show the slide?*), and a wh-interrogative (e.g., *who* in *Who wants to try?*[7]). Examples of textual, interpersonal, and topical Themes are shown below.

Example 3.3 An illustration of topical, textual, and interpersonal Themes

So	will	the pressure	go up?
Conjunction	Modal finite	Subject	Finite
textual Theme	interpersonal Theme	topical Theme	
Theme			Rheme

Another feature that is related to the identification of topical, textual and interpersonal Themes is Theme markedness. Based on Halliday and Matthiessen's (2014) notions of inherent thematicity and characteristical thematicity, the present study investigates theme markedness on two dimensions: topical markedness (topical Themes); inherent and characteristical markedness (interpersonal and textual Themes). On the dimension of topical markedness, the markedness of topical Themes is dependent on mood types. For instance, the unmarked topical Theme in a declarative is the Subject while the unmarked topical Theme in a yes/no interrogative is the Finite verbal operator + the Subject. The scale of topical Theme markedness ranges from the least marked choices (i.e., unmarked topical Themes) to the most marked choices. On the dimension of inherent and characteristical markedness, the least marked choice is a clause without any non-topical elements. A clause with characteristically marked elements is considered more marked than a clause with inherently marked elements. The framework for analyzing the scale of Theme markedness in declaratives (see Figure 3.11), yes/no interrogatives (see Figure 3.12), wh-interrogatives (see Figure 3.13), and imperatives (see Figure 3.14) are shown below.

[7] The wh-elements in wh-interrogatives function as both an interpersonal Theme and a topical Theme.

Inherent & characteristical markedness

least marked → most marked

Topical markedness (least marked ↓ most marked)

	inherently & characteristically unmarked	inherently marked	characteristically marked
topical Theme	without textual Theme	textual Theme: Continuative/Conjunction	textual Theme: conjunctive Adjunct
Subject	I did an experiment today.	**Well** I did an experiment today. **But** I did an experiment today.	**Actually,** I did an experiment today.
circumstantial Adjunct	**Today** I did an experiment.	**Well, today** I did an experiment.	**Actually, today** I did an experiment.
Complement	**An experiment** I did today.	**Well an experiment** I did today.	**Actually, an experiment** I did today.

Figure 3.11 The scale of Theme markedness in declarative clauses

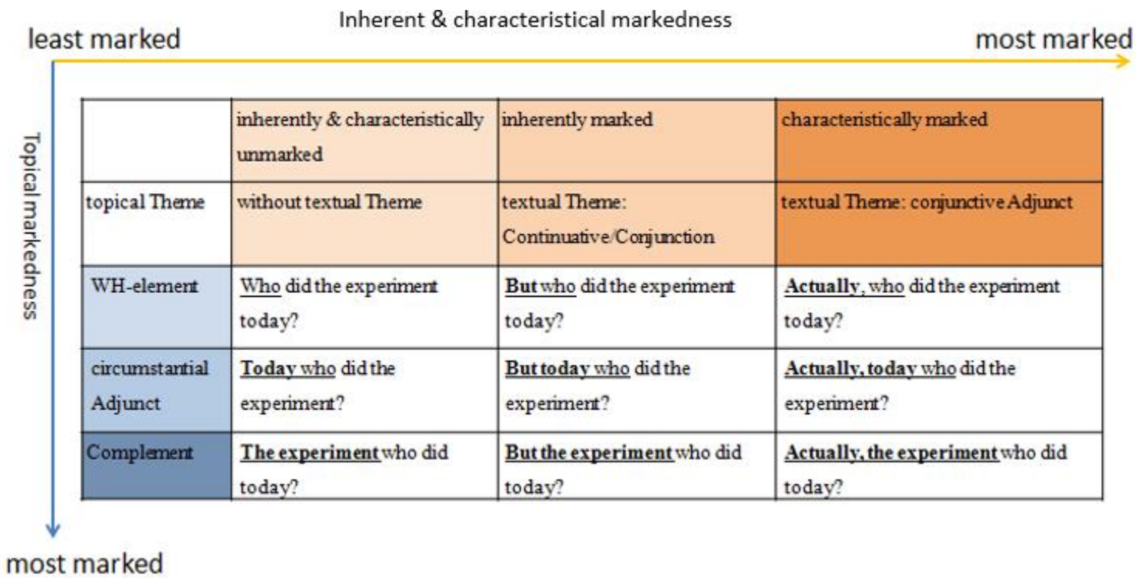
Inherent & characteristical markedness

least marked → most marked

Topical markedness (least marked ↓ most marked)

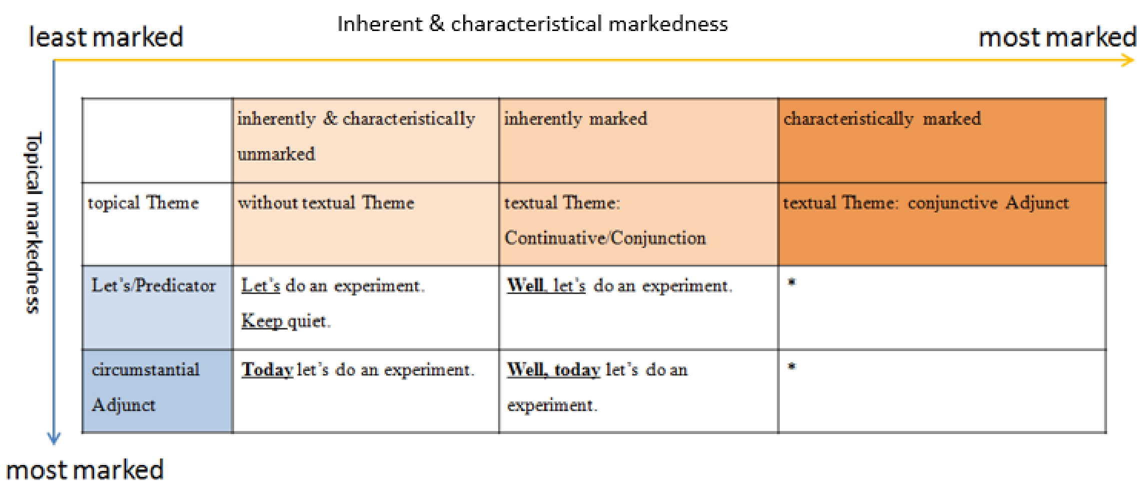
	inherently & characteristically unmarked	inherently marked	characteristically marked
topical Theme	without textual Theme	textual Theme: Continuative/Conjunction	textual Theme: conjunctive Adjunct
Finite verbal operator + Subject	Could you do the experiment?	**But** could you do the experiment?	**Actually,** could you do the experiment?
circumstantial Adjunct	**Today** could you do the experiment?	**But today** could you do the experiment?	**Actually, today** could you do the experiment?
Complement	**The experiment** could you do today?	**But the experiment** could you do today?	**Actually, the experiment** could you do today?

Figure 3.12 The scale of Theme markedness in yes/no interrogative clauses



	inherently & characteristically unmarked	inherently marked	characteristically marked
topical Theme	without textual Theme	textual Theme: Continuative/Conjunction	textual Theme: conjunctive Adjunct
WH-element	Who did the experiment today?	**But** who did the experiment today?	**Actually**, who did the experiment today?
circumstantial Adjunct	**Today** who did the experiment?	**But today** who did the experiment?	**Actually, today** who did the experiment?
Complement	**The experiment** who did today?	**But the experiment** who did today?	**Actually, the experiment** who did today?

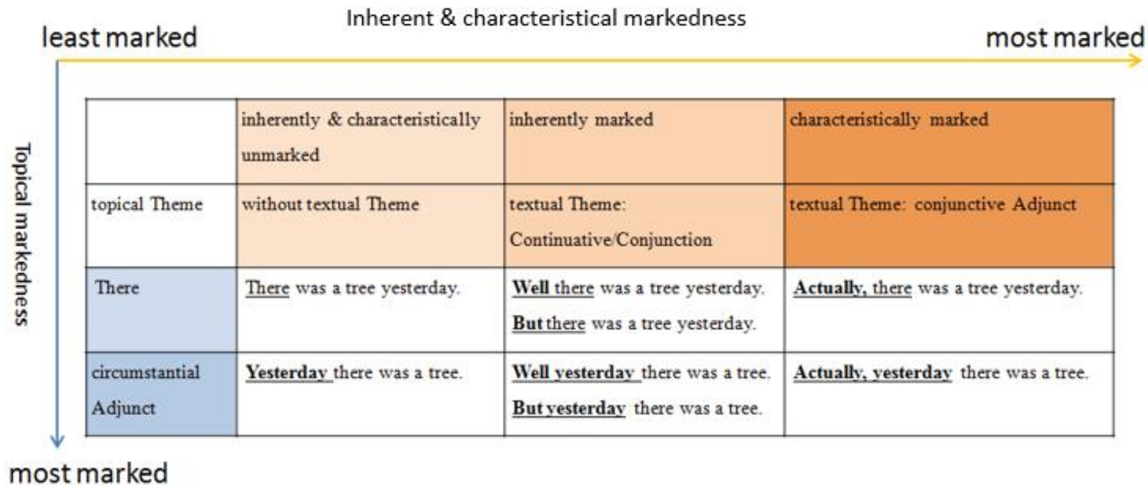
Figure 3.13 The scale of Theme markedness in WH- interrogative clauses



	inherently & characteristically unmarked	inherently marked	characteristically marked
topical Theme	without textual Theme	textual Theme: Continuative/Conjunction	textual Theme: conjunctive Adjunct
Let's/Predicator	Let's do an experiment. Keep quiet.	**Well**, let's do an experiment.	*
circumstantial Adjunct	**Today** let's do an experiment.	**Well, today** let's do an experiment.	*

Figure 3.14 The scale of Theme markedness in imperative clauses

Within the declaratives, the Themes of existential *there* clauses (those starting with *there*, showing the existence of an object or an event) are different from the default topical Theme Subject. The unmarked topical Theme for this type of clause is *there*, whereas the marked topical Theme can be a Circumstantial Adjunct (see Figure 3.15 for examples).



	inherently & characteristically unmarked	inherently marked	characteristically marked
topical Theme	without textual Theme	textual Theme: Continuative/Conjunction	textual Theme: conjunctive Adjunct
There	There was a tree yesterday.	**Well** there was a tree yesterday. **But** there was a tree yesterday.	**Actually,** there was a tree yesterday.
circumstantial Adjunct	**Yesterday** there was a tree.	**Well yesterday** there was a tree. **But yesterday** there was a tree.	**Actually, yesterday** there was a tree.

Figure 3.15 The scale of Theme markedness in existential there declarative clauses

At the discourse level, Themes can be analyzed in relation to a paragraph (hyperTheme) and a text (macroTheme). The analytic unit of hyperThemes and macroThemes in written texts at the discourse level is no longer a clause, but a sentence, a group of sentences or even a paragraph. In the spoken texts, whose discourse structures were not as overt as the written ones, the identification of macroThemes and hyperThemes were related to the activity stages and sequences in the teaching/learning activities. While a hyperTheme oriented the listeners to the activities in a teaching/learning sequence, a macroTheme oriented them to the activities in a teaching/learning stage, which comprised a series of teaching/learning sequences. Examples of macroThemes and hyperThemes in the spoken texts are illustrated below, where the teacher guides the classroom activities through several guiding questions.

Example 3.4 HyperThemes and macroThemes in spoken texts

Transcript	Theme at the discourse level
T: We are asking you some guiding questions	macroTheme
Number one, now think about it.	hyperTheme
…. Okay, now we look at question two…	hyperTheme
…now we look at question three…	hyperTheme

Another feature related to Themes at the discourse level is thematic progression. The patterns of thematic progression in the written texts and in the spoken texts were identified by tracking the source of Themes. The thematic progression patterns identified in this study were classified according to three parameters: 1) thematic progression paths, 2) sources of Themes, and 3) the continuity of progression (see Figure 3.16).

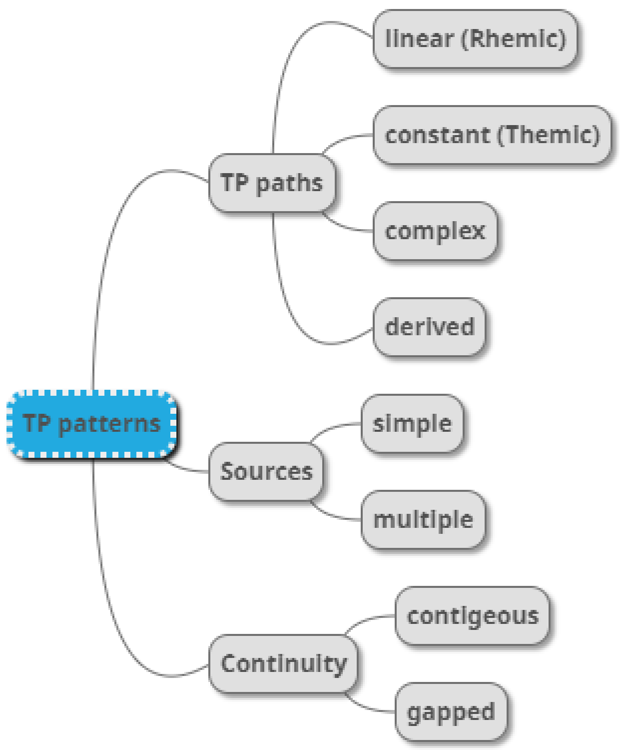


Figure 3.16 The parameters for classifying thematic progression patterns

The first parameter, thematic progression paths, classifies the TP patterns according to the origins of the Themes, from the previous Rheme(s) (i.e., linear/Rhemic progression), from the previous Theme(s) (i.e., constant/Themic progression) or not retrievable from previous Themes and Rhemes and therefore exhibiting no progression (i.e., derived). In "complex" TP patterns, the origin of a Theme can be traced to multiple sources, such as both the Theme and Rheme of the proceeding clause. In such a case, the TP path includes both linear and constant progression patterns and thus is considered complex. Derived TP patterns, where no thematic progression is observed, fall into two categories:

new and syntactic. Themes not related to the preceding linguistic material are considered as new Themes, for example, referential items evoked contextually (e.g., *we* referring to the teacher and students) and extralinguistic items pointing to the text itself (e.g., *this text* referring to the written text) or other texts (e.g., *these slides* pointing to the texts shown on the slideshow). In the written texts, if a Theme was not related to any preceding clauses, it was considered as a new Theme, whereas in the spoken texts, a Theme was considered to be new if it was not related to the preceding clauses within one teaching sequence. This is because the spoken texts in a teaching sequence were composed of a long stretch of dialogue, providing a rich linguistic environment for the analysis of thematic progression. Another subtype of derived TP pattern comprises syntactic Themes, that is, dummy subjects carrying no semantic content (e.g., *There* in the existential clause *There are fewer air particles*).

The second parameter of TP classification concerns the sources of Themes, which can be simple or multiple. Where a simple source is involved, the Theme corresponds to a previous Theme/Rheme. In cases of multiple sources, the Themes are related to previous elements through integration (i.e., the integration of multiple previous Themes/Rhemes into one Theme) or separation (i.e., the separation of one previous Theme/Rheme into multiple Themes).

The third parameter is the continuity of TP patterns, which can be either contiguous (i.e., the progression of a Theme from the immediately preceding clause) or gapped (i.e., the progression of a Theme from earlier clauses, other than its immediately preceding one). The three parameters discussed here provide a comprehensive toolkit for analyzing TP patterns and for identifying TP patterns that were overlooked by previous studies (e.g., MaCabe, 1999; Taboada & Lavid, 2003; Wei, 2015). An example of an overlooked TP pattern is multiple linear gapped progression, where the Theme is derived from previous Rhemes that are not in the immediately preceding clause (see Figure 3.17).

$T_1 \rightarrow R_1$
…
$T_5 \rightarrow R_5$
…
$T_8 \ (= R_1+R_5) \rightarrow R_8$

Figure 3.17 Multiple linear gapped progression

The analysis of the thematic choices in the written and spoken texts proceeded as follows: Theme selection within the structure of a clause was analyzed in terms of 1) the metafunctional type (i.e., textual, interpersonal and topical Themes), 2) the semantic type of topical Themes, and 3) the scale of Theme markedness (i.e., inherent/characteristical markedness and topical markedness). The thematic choices at the discourse level were analyzed through the identification of 1) hyperThemes and macroThemes and 2) the TP patterns of topical Themes according to three parameters: TP paths, Theme sources, and the degree of continuity (see Figure 3.16). The results of the Theme analysis of the written and spoken texts are presented in Section 4.2 and Section 4.3, respectively.

3.4.3 The analytical framework for representational meanings in images

This section presents the framework for analyzing the images. The analysis is conducted at two levels: the construction of an individual process and all the processes in the images used in a teaching stage (see Section 3.4.1 for a definition of a teaching stage). While the analysis at the level of a process enables an overview of what types of experience are constructed in the images, the analysis at the level of a teaching stage provides a lens into the types of representational meanings in images that are favored in specific teaching stages.

The analysis of images comprises two parts: analyzing the representational meanings of images and analyzing the logical meanings in an individual image and across images. While Section 3.4.4 presents the frameworks for analyzing logical meanings in images, this section (Section 3.4.3) focuses on the ways of conducting representational analysis.

This section starts by demonstrating how visual structures will be identified to conduct representational analysis before discussing the unit of analysis for representational analysis. The coding scheme for identifying visual structures is shown in Figure 3.18.

Figure 3.18 The coding scheme for identifying visual structures for representational analysis

This coding scheme was adapted from Kress and van Leeuwen's (2006) visual grammar on representative meanings in images (see Section 2.5.2.1 for a review of visual grammar). The main adaptations are elaborated in the following paragraph.

The first adaptation was distinguishing activity sequences from other narrative figures. As an activity sequence consists of several narrative figures, it should be considered as a different category from a narrative figure. The second adaptation was the addition of a new category to action figures, namely, elliptical event figures, which emerged from the data under investigation (see Section 5.2.1.1 for examples of elliptical event figures). The third adaptation was changing Kress and van Leeuwen's (2006) terminologies of exhaustive analytical processes and inclusive analytical processes to naturalistic analytical figures and schematic analytical figures respectively. These changes were made to avoid possible misunderstandings of analytical visual structures.

The unit of analysis for conceptual analytical visual structures was a visual representation of an entity, including its constituent parts. For instances, in Figure 3.19, there is one representation: the Magdeburg Hemispheres including its constituent parts, such as the hemispheres, the valve and the handles. Therefore, there is an analytical figure, portraying the Magdeburg Hemispheres. The unit of analysis for conceptual symbolic visual structures was an establishment of identity between two visual elements. For instance, in Figure 3.19, there are three identities being established between the visual elements and their linguistic names: Magdeburg hemispheres, valve, and rubber tubing. Therefore, there are three symbolic figures in Figure 3.19.

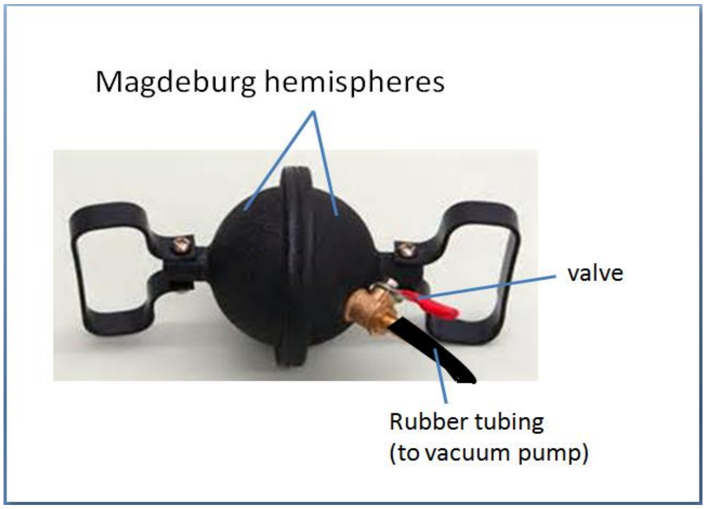


Figure 3.19 The unit of analysis for conceptual visual structures

The unit of analysis for narrative visual structures was the construction of a visual process, characterized by a vector (e.g., an arrow, a gaze, and a gesture). For instance, Figure 3.20 shows a boy and a girl pulling an instrument towards the opposite directions, which is regarded as one narrative action figure.

B17-MH-11

Figure 3.20 The unit of analysis for narrative visual structures

The representational analysis drew on Kress and van Leeuwen's (2006) visual grammar on the construction of experiential meaning in images. An example analysis of the representational meanings in Figure 3.19 is provided in Table 3.9. If the realizations of participants rely not only on images, but also on texts, the mode will be annotated in < >.

Table 3.9 A sample analysis of the representational meanings in Figure 3.19

Image	Visual process	Participant
MH-1	Conceptual: symbolic attributive	Symbolic carrier: Magdeburg hemispheres <text> Symbolic attribute: hemispheres of M. H.<photo>
MH-1	Conceptual: symbolic attributive	Symbolic Carrier: valve <text> Symbolic Attribute: the valve of M. H. <photo>
MH-1	Conceptual: symbolic attributive	Symbolic Carrier: Rubber tubing (to vacuum pump) <text> Symbolic Attribute: a tube with one end connected to M. H. <photo>
MH-1	Conceptual: naturalistic analytical	Carrier: Magdeburg hemispheres Possessive Attributes: shape, color, texture, components of this instrument

While the representational analysis of images adapted from Kress and van Leeuwen's (2006) visual grammar provides a valuable toolkit for unpacking experiential meanings in a single image, it does not touch upon logical meanings in a single image and in multiple images. This study supplemented representational analysis of images with visual linking analysis to reveal what logical meanings were constructed. The analytical framework for logical meanings in images will be elucidated in Section 3.4.4.

3.4.4 The analytical framework for logical meanings in images

The unit of analysis for visual linking is one image, which is distinguishable with frames or empty space to separate the image from its surroundings. Sometimes a PowerPoint slide had one image (as shown in Figure 3.21); at other times, a slide had more than one image (as shown in Figure 3.22).

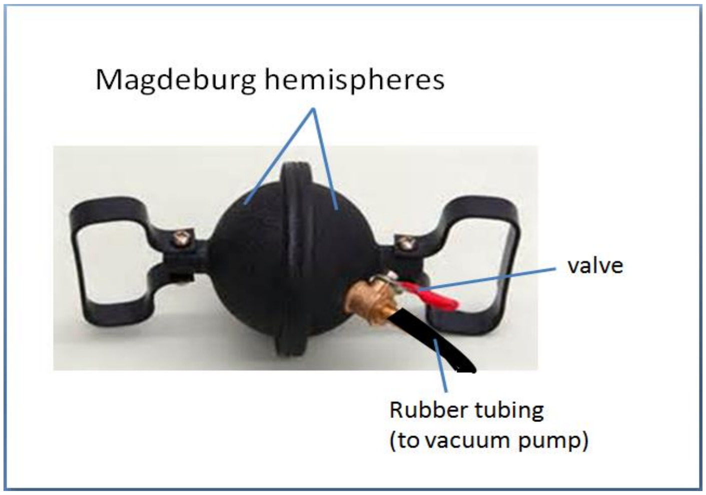


Figure 3.21 The PowerPoint slide with one image

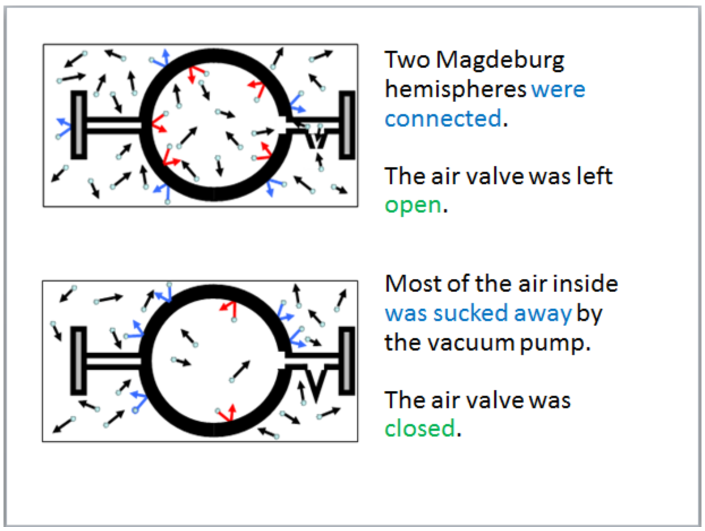


Figure 3.22 The PowerPoint slide with more than one image

The analysis of logical meanings in images was based on van Leeuwen's (2005) framework of visual linking (see Table 2.4 in Section 2.5.2.2), with adaptations made to account for meaning-making in science classrooms. The adapted framework for visual linking analysis is presented in Figure 3.23.

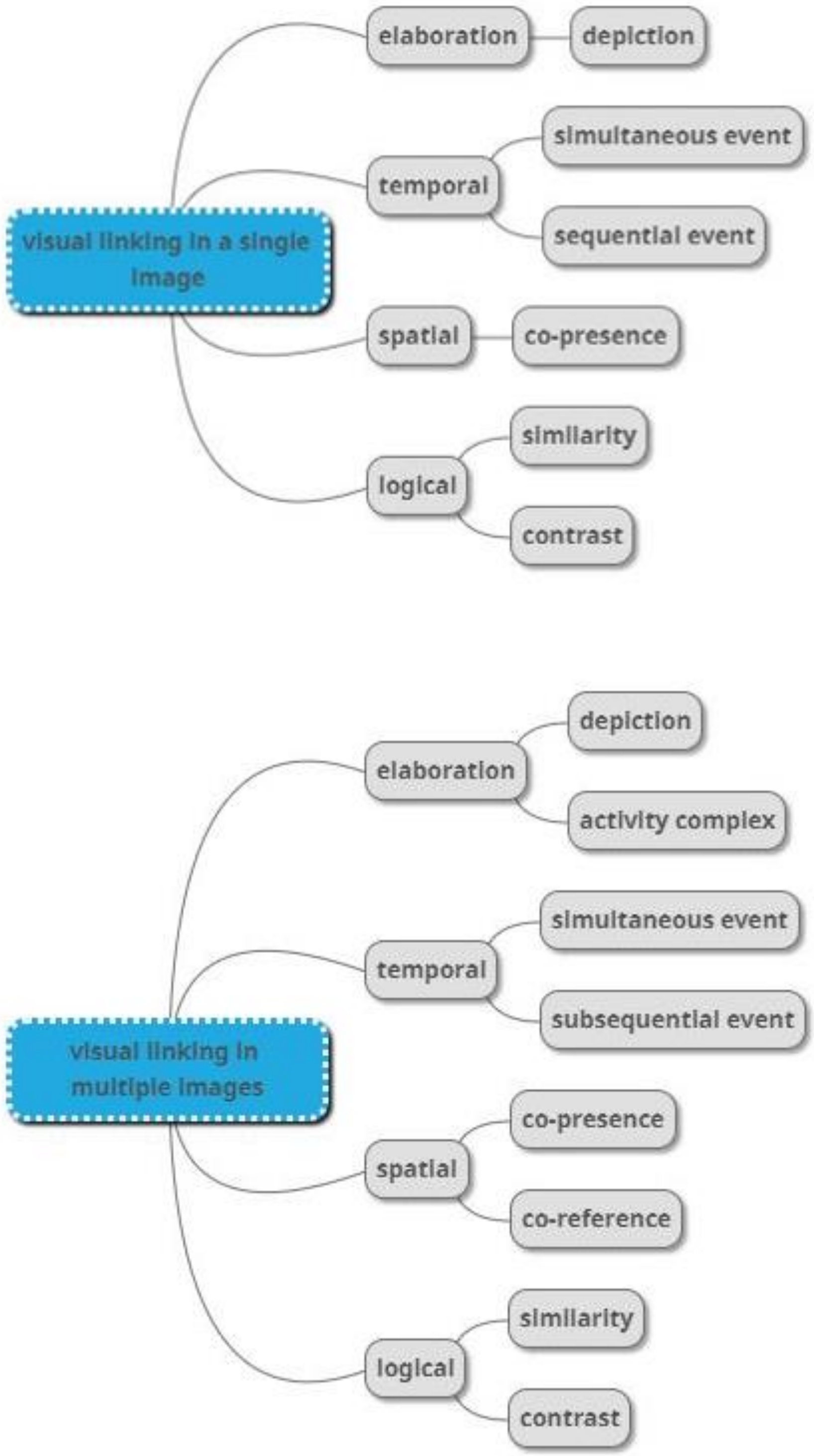


Figure 3.23 The coding schemes of visual linking in a single image and that in multiple images

There are four adaptations to van Leeuwen's First, a further distinction was made between visual linking in a single image (see Table 3.10 for the definitions of categories of visual linking in a single image) and visual linking in multiple images (see Table 3.11 for the definitions of categories of visual linking in multiple images). This distinction enabled an investigation into how the media PowerPoint slide affect the construction of logical meanings in images.

Table 3.10 Visual linking in a single image (adapted from van Leeuwen, 2005)

Type	**Subtype**	**Realization**
Elaboration	Depiction	The link between different depictions of the same subject/object
Temporal	Simultaneous event	The link between simultaneous events
	Sequential event	The link between subsequent events
Spatial	Co-presence	The link between events/subjects in the same location
Logical	Similarity	The link between similar subjects/objects
	Contrast	The link between different subjects/objects

Table 3.11 Visual linking in multiple images (adapted from van Leeuwen, 2005)

Type	**Subtype**	**Realization**
Elaboration	Depiction	The link between different depictions of the same subject
	Activity complex	The link between the overview of an activity complex and its comprising activities
Temporal	Simultaneous event	The link between simultaneous events
	Sequential event	The link between subsequent events
Spatial	Co-presence	The link between events/subjects in the same location
	Co-reference	The link between events/subjects where the location is abstracted from a specific place and a co-referential relation can be deducted from visual cues
Logical	Similarity	The link between similar subjects
	Contrast	The link between different subjects

The second adaptation was made to categorize subtypes of elaboration according to whether they depicted the same subject/object (Depiction) or presented a series of activities (Activity complex). The logical linking of elaboration was established between different depictions of the same subject/object and between the activity complex and its constituting activities. This adaptation thus extends the establishment of elaboration between different depictions of the same subject/object in van Leeuwen's (2005) framework to include the establishment of elaboration between the activity complex and its constituting activities (see Section 5.3.1 for examples of elaboration).

The third adaptation involved the conflation of the subtypes of Previous Events and Next Events into the category of Sequential Events. Unlike moving images, where the identities of a previous event and a next event play an important role in narration, the transaction between events in images in PowerPoint slides is mostly sequential (from a previous event to a subsequent event). The fourth adaptation excluded the spatial linking of Proximity and added a new subcategory called spatial co-reference. The exclusion of spatial proximity was made because the semiotic affordance of the PowerPoint slides was shaped by their social cultural environments, which rarely involved presenting the relative location through a matching angle. The new subcategory, spatial co-reference, was added to address the logical linking based on abstract circumstances, such as the schematic drawings of Magdeburg Hemispheres (see Section 5.3.3 for details).

3.4.5 The analytical framework for language-image relations

This section focuses on the interaction between spoken language and images. The analytic framework adopted for this study drew on the notions of status and logico-semantics in image-text relations (Martinec & Salway, 2005) and semantic integration (Zhao, Djonov, van Leeuwen, 2014). The analytic unit was a figure at the semantic level, that is, a configuration of an event, the entities and setting involved in this event. The congruent realization of a figure in language at the level of lexicogrammar is a clause. But for a clause with grammatical metaphors, several figures are packed into a clause. In this study, clauses with grammatical metaphors were unpacked into figures that could not be further decomposed into other figures. Table 3.12 shows an example of unpacking clauses with grammatical metaphors.

Table 3.12 An example of unpacking the clause with grammatical metaphors

The clause with grammatical metaphors	The decrease of air pressure inside the hemispheres creates an inward net force	
figure 1	The air pressure inside the hemispheres	decreases.
figure 2	This (the decrease of air pressure inside the hemispheres)	creates an inward net force.

Similarly, the figures constructed in images were identified. The experiential meanings in each figure were examined through TRANSITIVITY analysis of language (Halliday & Matthiessen, 2014) and representational analysis of images (Kress & van Leeuwen, 2006). The transitivity analysis of a clause with grammatical metaphors is illustrated in Table 3.13.

Table 3.13 An example analysis for the clause with grammatical metaphors

The clause with grammatical metaphors	The decrease of air pressure inside the hemispheres creates an inward net force	
figure 1	The air pressure inside the hemispheres	decreases.
Transitivity analysis of figure 1	Actor	Process: material: transformative; intransitive
figure 2	This (the decrease of air pressure inside the hemispheres)	creates an inward net force.
Transitivity analysis of figure 2	Actor	Process: material: creative; transitive

Another case to consider was the co-construction of a figure through both language and images. As in such cases, the experiential meaning could not be realized through language alone, the analysis was extended to include the related elements in the accompanying visual images. An example for such a co-construction consisted in using the written text of "Atmospheric pressure" and a yellow arrow to indicate that atmospheric pressure, as shown in Figure 3.24 below.

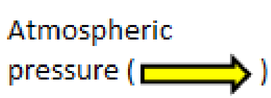
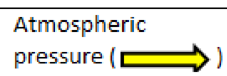


Figure 3.24 An example of the co-construction of a figure through language and imagery elements

The transitivity analysis of the co-construction of a figure using language and images is demonstrated below:

Example 3.5 An example of analyzing a figure co-constructed by language and image

Co-construction of a figure			
Transitivity analysis	Token ["Atmospheric pressure" in written text]	Process: relational: identifying	Value [yellow arrow in the visual]

Based on the experiential meanings of language (uncovered through transitivity analysis) and the representational meanings of images (identified through representational analysis), the language-image relations were examined in terms of the activation of visual and verbal units and the identification of intersemiotic relations. As Zhao, Djonov, and van Leeuwen's (2014) suggest, meanings of different modes can be coordinated by visual or verbal cues to form an integration of semantic meanings. The present study thus identified the activation of visual and verbal units by visual and/or verbal cues (e.g., a pointing gesture, and a verbal reference to the visual elements). These visual and verbal units constituted an integration of semantic meanings, where the multiplication of meanings occurred. The relation between these visual and verbal units were then examined using the framework for analyzing image-text relations (see Figure 3.25).

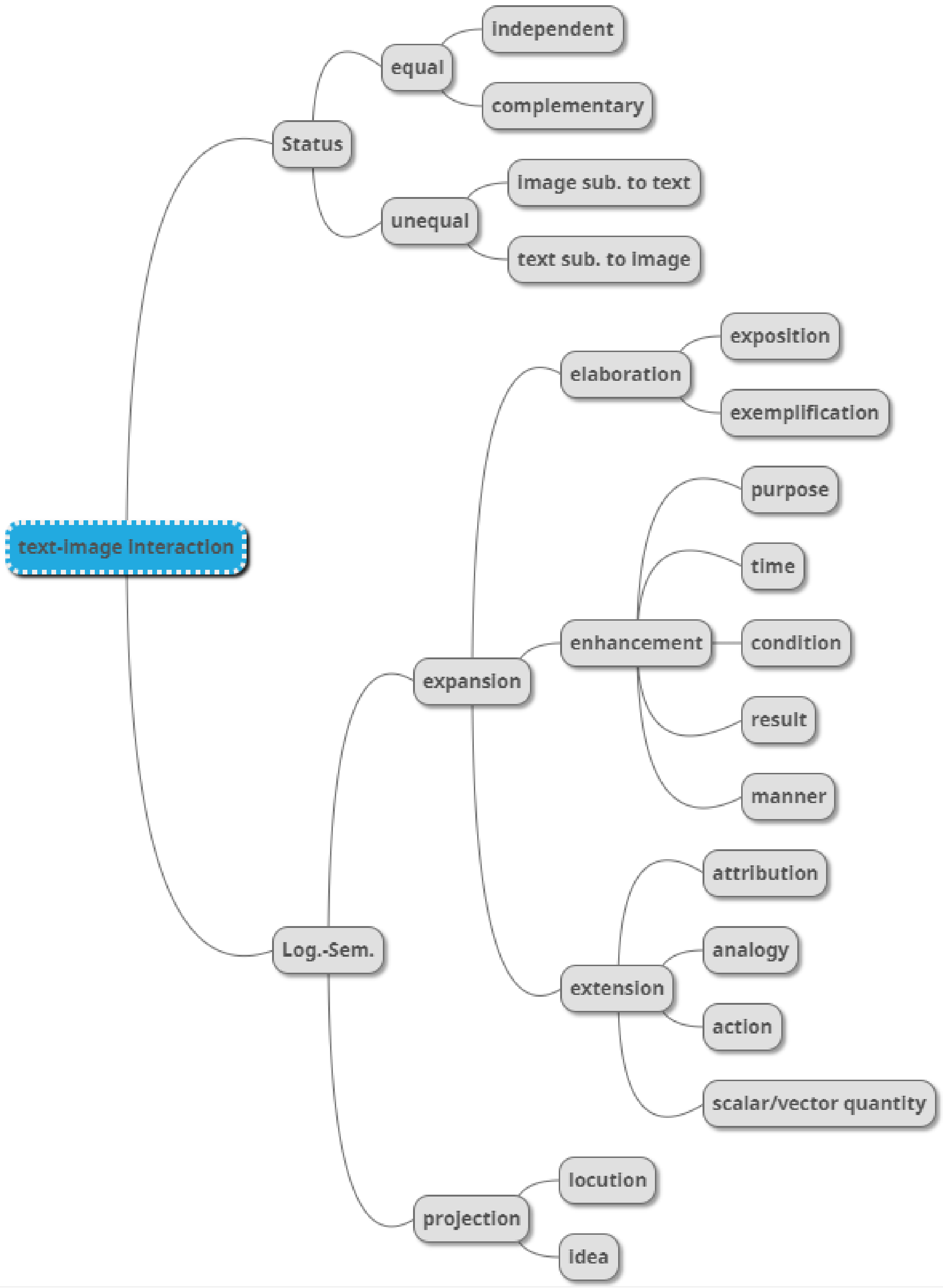


Figure 3.25 The framework for analyzing image-text relations

The framework for analyzing image-text relations (shown in Figure 3.25) was adapted from Martinec and Salway's (2005) system of logico-semantics for image-text relations (see Figure 2.10 in Section 2.5.3). One adaptation to Martinec and Salway's (2005) framework was the addition of the subtypes of condition, result and manner under enhancement, which emerged from the data under investigation. The subtype of condition refers to the relation established between a visual unit and a verbal unit by qualifying the situation for events to occur (e.g., *when* in *When I turn on the vacuum pump*,) (see

Table 5.9 for an example of condition). The subtype of result qualifies a visual/verbal unit by providing information about consequences of an event presented in the images/ spoken texts (see

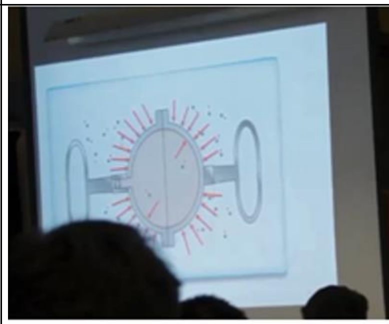
Table 5.10 for an example of result). The subtype of manner provides further information related to the means of an event (see Table 5.11 for an example of manner). Another adaptation to Martinec and Salway's (2005) framework was the inclusion of four subtypes of extension based on the data collected for this study: attribution, analogy, action, and scalar/vector quantity. The subtype of attribution refers to the addition of information to characterize an object (e.g., *common* in *This is not a common instrument*) (see

Table 5.12 for an example of attribution). The subtype analogy involves the inference of a similar structure and a working mechanism from one object/event to another (see Table 5.13 for an example of analogy). The subtype action involves the addition of an action or event to the existing information (see Table 5.14 for an example of action). The last subtype that was introduced to extension is scalar/vector quantity, which provides additional quantitative information, such as amount, size and force (see

Table 5.15 for an example of scalar/vector quantity). These adaptations enable the investigation into the multiplication of meanings between language and images in a delicate way. The new subcategories identified in the present study can benefit future research on image-text relations in scientific communications.

The analysis of image-text relations is illustrated through a sample analysis presented in Table 3.14.

Table 3.14 A sample analysis of image-text relations

Resource for coordination	Visual unit	Verbal unit	Status	Log.-Sem.
Speech	 3s A-8-BL A-6-MH Visual structure: analytical Visual structure: non-transactional (vector: small red arrows) Visual structure: event (vector: large red `arrows)	*There are fewer air molecules inside,* Verbal structure: existential	Unequal: verbal sub. to visual	Extension: scalar/vector quantity

The language-image relations were analyzed in three steps. First, the resource of coordination was identified to determine the link between visual units and verbal units. In the sample analysis, speech was used as the resource for coordinating speech and the diagram shown on the slideshow. The second step was to identify the visual units and the verbal units being activated and to decide their relative status depending on the experiential/representational meaning. In the sample analysis, the visual unit being coordinated were non-transactional actional figures (Actors: grey dots + Vectors: small red arrows), representing the random movement of air molecules. The verbal unit being coordinated was "*There are fewer air molecules inside*", suggesting the number of air molecules inside the instrument. While the representational meanings in the image consist of an analytical structure of Magdeburg Hemispheres, non-transactional action figures (Actor: grey dots + Vector: small red arrows), and event figures (Vector: large red arrows + Goal: a schematic drawing of Magdeburg Hemispheres), the verbal meaning only concerns air molecules, which are the actors of non-transactional action figures. Therefore, the verbal texts were considered subordinating to the visuals as they only linked to part of the representational meanings in the image. Third, the logico-semantic relations between the visual and visual units were identified. In the sample analysis, the logico-semantic relation was considered extension as the verbal texts added new information to the representational meanings in the image. The added information was about the scalar quantity of amount. The results of the analysis of the interaction between texts and images are presented in Section 5.4.

3.5 Summary of Chapter 3

This chapter describes the research design adopted in the present study, including selection of the appropriate research paradigm and research methods, collection and analysis of the data to investigate how meanings were discursively constructed via the use of language and images in science classrooms. The procedures of analysis are presented in three phases: (1) analyzing the textual meanings in the written texts and spoken texts (responding to RQ1), (2) analyzing the representational and logical meanings in the images (responding to RQ2), and (3) analyzing the relations between language and images (responding to RQ3). The following chapter, Chapter 4, presents the findings of the linguistic analysis of the construction of explanations in the two science classrooms, focusing on thematic patterns in both written and spoken texts.

Chapter 4 Thematic patterns in constructing explanations

4.1 Overview

This chapter presents findings related to the realizations of Themes in the written and spoken texts. The 11 written texts were explanations produced by the two teachers and their students to explain the phenomena covered in their science lessons. The spoken texts are transcribed from a total of 35-minite classroom talks between the teachers and their students in two science classes. The results reported in this chapter are intended to address the research question of how language organizes relevant scientific knowledge to construct explanations in written and spoken discourse (RQ1).

The chapter starts by presenting the thematic patterns in the written texts of explanations (Section 4.2), followed by the thematic patterns in the spoken texts (Section 4.3). For both the written and the spoken texts, the thematic patterns are reported at the levels of clause (Section 4.2.1 and Section 4.3.1) and discourse (Section 4.2.2 and Section 4.3.2). At the clausal level, thematic selections are considered in three respects: metafunctional types (Section 4.2.1.1 and Section 4.3.1.1), semantic types of topical Themes (Section 4.2.1.2 and Section 4.3.1.2), and the degree of Theme markedness (Section 4.2.1.3 and Section 4.3.1.3). At the discourse level, thematic structures are examined by analyzing the thematic progression of topical Themes (Section 4.2.2.1 and Section 4.3.2.1) as well as hyperThemes and macroThemes (Section 4.2.2.2 and Section 4.3.2.2). These thematic patterns are summarized to generate three schematic structures, one for the written texts and two for the spoken texts. This chapter ends with a summary of the main findings on thematic patterning in relation to the schematic structures identified in the examined scientific explanations.

4.2 Themes in the written texts

4.2.1 Thematic selection at the clausal level

This section reports the thematic patterns identified at the clausal level by examining the metafunctional types of Themes (in Section 4.2.1.1), the semantic types of topical Themes (in Section 4.2.1.2), and the degree of Theme markedness (in Section 4.2.1.3).

4.2.1.1 Metafunctional types of Themes

A total of 71 clauses were examined in the 11 written texts. Each clause has at least one topical Theme. There are 33 clauses with textual Themes in addition to topical Themes, and interpersonal Themes are not found in all clauses. The distribution of Themes in the written texts from Lesson A and Lesson B are presented in Table 4.1 and Table 4.2 respectively.

Table 4.1 Frequency of Themes in the written texts from Lesson A

	Textual Theme	Interpersonal Theme	Topical Theme
Text A1	3	0	6
Text A2	1	0	5
Text A3	0	0	5
Text A4	1	0	6
Text A5	4	0	5
Text A6	4	0	5
Total	14	0	32

Table 4.2 Frequency of Themes in the written texts from Lesson B

	Textual Theme	Interpersonal Theme	Topical Theme
Text B1	3	0	7
Text B2	5	0	9
Text B3	4	0	8
Text B4	4	0	8
Text B5	3	0	7
Total	19	0	39

As shown in Table 4.1 and Table 4.2, the topical Themes in each written text range from five to nine, with an average of seven, whereas the textual Themes in each written text range from zero to five, with an average of three. The relations in the textual Themes are Causal and Conditional relations (Halliday & Matthiessen, 2014). The majority of the textual Themes (25 out of 33) are Causal ones construing causal links between the clauses. Among the textual Themes constructing causality, the conjunction *so* emerges as the most frequent choice (12 instances), followed by the conjunctive adjunct *as a result* (three instances), the conjunction *and* (three instances), the conjunctive group *and thus* (two instances), the conjunction *since* (two instances), the adverb *therefore* (two instances), and the conjunction *for* (one instance). The second prominent type of relation in the textual Themes is Condition, realized by the conjunction *when* (eight instances).

The 11 written texts were reproduced below to facilitate the discussion of textual Themes (highlighted in bold typeface). The errors was highlighted in red.

Text A1

When *we use the vacuum pump to suck away the air particles inside the Magdeburg hemispheres (M. H.), the number of air particles inside the hemispheres decreases. There are fewer air particles inside to hit the wall of the M. H.,* ***so*** *the air pressure inside the M. H. decreases. Air pressure inside the M. H. becomes lower than the air pressure outside the M. H. We cannot pull the hemispheres apart.*

Text A2

We suck out the air inside the bottle. The number of air particles inside the bottle decreases. The air pressure outside the bottle is higher than that inside. Some air enters the balloon ***and*** *it inflates.*

Text A3

We force out the air inside the rubber sucker by pressing it down. The number of air particles inside the rubber sucker decreases. The air pressure inside the sucker decreases. The air pressure outside the rubber sucker is higher than that inside. The rubber sucker sticks firmly on the wall.

Text A4

We suck out the air inside the bag by a vacuum pump. The number of air particles inside the plastic bag is decreases. The air pressure inside the plastic bag decreases. The air pressure outside the plastic bag is higher than that outside. Some air leaves the plastic bag ***and*** *it inflates.*

Text A5

When *we force out the air inside the rubber sucker by pressing it down, the number of air particles inside the rubber sucker decreases.* ***So*** *the air pressure inside the sucker decreases.* ***So/And thus,*** *the air pressure outside the rubber sucker is higher than that inside.* ***As a result****, the rubber sucker sticks firmly on the wall.*

Text A6

When *the air inside the plastic bag is sucked out by a vacuum pump, the number of air particles inside the plastic bag decreases.* ***So*** *the air pressure inside the plastic bag decreases.* ***And thus,*** *the air pressure outside the plastic bag is higher than that inside.* ***As a result****, the space occupied by the blanket is reduced.*

Text B1

When *we use the vacuum pump to suck away the air particles inside the Magdeburg Hemispheres (M.H.), the number of air particles inside the hemispheres decreases. The smaller number of air particles inside to hit the wall of the M.H. decreases the air pressure inside the M.H. The air pressure inside the M.H. decreases,* ***so*** *the air pressure inside the M.H. becomes lower than the air pressure outside. There is a difference in air pressure,* ***so*** *it is difficult to pull the hemispheres apart.*

Text B2

When *we use the vacuum pump to suck away the air particles inside the Magdeburg Hemispheres (M.H.), the number of air particles inside the hemispheres decreases. The smaller number of air particles to hit the wall of the hemispheres decreases the air pressure inside the M.H. The air pressure inside becomes lower than the gas pressure* *outside. There is a difference in air pressure, **so** it is difficult to pull the hemispheres apart.*

Text B3

***When** we suck out the air inside the plastic bottle from a hole, the number of air particles inside the bottle decreases. There are fewer air particles inside to hit the wall of the bottle, **so** the air pressure inside the bottle decreases. The air pressure inside the bottle decreases, **therefore** the air pressure outside the bottle becomes higher than that inside. There is a difference in air pressure, **so** air enters the balloon **and** the balloon inflates.*

Text B4

***When** we use the vacuum pump to suck away the air particles inside the soft drink can, the number of air particles inside the soft drink can decreases. There are fewer air particles inside to hit the wall of the soft drink can. Air pressure inside the soft drink can decreases. The air pressure inside the soft drink can decreases. Air pressure inside the soft drink can becomes lower than that outside. There is a difference in air pressure. The soft drink can collapses.*

Text B5

***When** we use the vacuum pump to suck away the air particles inside the soft drink can, the number of air particles inside the soft drink can decreases. There are fewer air particles inside to hit the wall of the soft drink can, **so** the air pressure inside the soft drink can decreases. The air pressure inside the soft drink can becomes lower than that outside. There is a difference in air pressure. **As a result,** the soft drink can collapses.*

The 11 written texts can be categorized into four groups. The first group includes Text A1, Text A5, Text A6, Text B1, Text B2, Text B3, and Text B5, with textual Themes constructing both causal and conditional relations.

Using Text A1 as an example, the textual Theme of *when* was used in the beginning to suggest the condition of the experiment. The textual Theme of *so* was used to construct causality between a sequence of events to explain the identified phenomenon, such as *so* in *There are fewer air particles inside to hit the wall of the M.H, so the air pressure inside the M.H. decreases.*.

In the second group of written texts (Text A2 and Text A4), only the relation of Cause is identified. Text A4 is a written text produced by a group of students, with errors shown in red. It is important to notice that although mistakes of grammar and vocabulary were observed in Text A4, the construction of causal relation was successful with the conjunction *and*.

Apart from the overt construction of causality, the conjunction *and* was found in Text A2 and Text A4 to link the explanation sequence to the phenomenon being observed, as illustrated by the use of *and* in *Some air enters the balloon, and it inflates*. The conjunction *and* can perform the multi-functions of constructing additive, contrastive, temporal, and causal relations. It is used here to construct a causal relation between two processes, the entry of air and the inflation of the balloon. However, this causal relation is considered as a weakly constructed one, as the interpretation of *and* may vary among readers, who might simply interpret the use of *and* as an additive relator and overlook its potential for constructing causal relations. Compared with the strong construction of causal relations using conjunctions such as *so*, the weak construction of causality by *and* may present considerable challenges to students who are not familiar with the content knowledge and whose English proficiency is not high.

Text B4 forms a separate category, where a textual Theme only establishes a conditional relation. Similar to the first group of written texts, Text B4 starts with the textual Theme of *when* to state the experiment condition. However, textual themes that construct causal relations in subsequent clauses are missing from Text B4.

Text A3 also forms a separate category, where no relation was constructed by textual Themes, because the whole text is composed of five declaratives, without any textual Themes.

The different ways of using textual Themes in these written texts can be explained by relating the sequence of these texts and their functions. The written texts from Lesson A and Lesson B are discussed in detail respectively. Text A1 to A6 were constructed sequentially in Lesson A, that is, Text A1 was the first constructed explanation, followed by Text A2, Text A3, Text A4, Text A5, and Text A6 in that order. These texts were used to explain four phenomena demonstrated sequentially in Michael's lesson (Lesson A) through experiments. The texts and the corresponding phenomena to be explained are listed in Table 4.3.

Table 4.3 Textual Themes in the written texts from Lesson A

Phenomena to be explained				Textual Themes presenting experiment conditions	Textual Themes constructing causality
The Magdeburg Hemispheres experiment	The balloon experiment	The rubber sucker experiment	The plastic bag experiment		
Text A1				✔	✔
	Text A2				✔
		Text A3			
			Text A4		✔
		Text A5		✔	✔
			Text A6	✔	✔

Both Text A1 (a modelling text) and Text A6 (a student's text) utilize textual Themes to construct causality although the phenomena that they intend to explain are different. Despite the similarity of textual Theme choices in Text A1 and Text A6, it is notable that the functions of these texts were different. Text A1 was co-constructed by the teacher and students in the earlier stage of the lesson and was used as a preliminary model for an explaining text. This model text presents the condition for the experiment in the beginning, which is followed by a sequence of events that are causally linked and ends with a description of the phenomenon that can be observed. Text A6 was independently composed by a student and then presented to the class for comments and evaluations. The similar textual Theme choices suggest the student's awareness of the functions of textual Themes in scientific explanations and his ability to construct causality via the linguistic resource of textual Themes.

The absence of conditional relations and the weak construction of causality in the last sentence in Text A2 were due to its purpose of constructing individual processes rather than causal relations. As shown in Table 4.3, the rubber sucker experiment was explained in both Text A3 and Text A5, while the plastic bag experiment was explained in both Text A4 and Text A6. Compared with the rich distribution of textual Themes constructing causality in Text A5 and Text A6, textual Themes are barely present in Text A3 and Text A4 (except for one instance of the conjunction *and*). One explanation for this observation could be a consequence of teacher's input, as suggested in Table 3.3. Text A4 was constructed to model how causal relations can be realized by adding connectives, such as *so*. Another explanation for the different distribution of textual Themes is that these texts intend to serve different purposes (see Table 3.3). While Text A3 and Text A4 aim to construe events and the sequential relation between them, Text A5 and Text A6 focus on constructing causal links between sequences of events. The complexity of textual Themes is high in Text A1, increases progressively from Text A2 to Text A5, and reaches a similar high complexity level as Text A1 in Text A6. It is argued that the shift in the complexity of textual Themes aids to the accumulation of knowledge in terms of causality. While each written explanation comprises several events that occurred sequentially, some of these events were also causally linked. It is essential for teachers and learners to explicate the causal relations in addition to the sequential ones in the explanations. Therefore, it is suggested that student activities of explicating sequential relations between events be arranged before those of clarifying causal relations, such as the case of Lesson A.

Five written texts were constructed sequentially in Lesson B in the order of Text B1, Text B2, Text B3, Text B4, and Text B5. These texts were used to explain four phenomena demonstrated sequentially in Emily's lesson (Lesson B) through experiments. These five texts and the related phenomena are summarized in Table 4.4.

Table 4.4 Textual Themes in the written texts from Lesson B

Phenomena to be explained				Textual Themes presenting experiment conditions	Textual Themes constructing causality
The Magdeburg Hemispheres experiment	The balloon experiment	The beverage can experiment	The plastic bag experiment		
Text B1				✔	✔
	Text B2			✔	✔
		Text B3		✔	✔
			Text B4	✔	✔
			Text B5	✔	✔

Unlike the written texts from Lesson A, those from Lesson B do not show any shift in the complexity of textual Themes. Textual Themes constructing both causal and conditional relations are found in all five texts, although each text was produced to serve different functions. Similar to Text A1, Text B1 was used as a model text for explanations, which starts with experiment conditions, followed by a sequence of events that are causally linked and the phenomenon being observed. Similar to Text A6, Text B5 was a student product, an explanation independently composed by a student and then projected on the screen for comments and evaluation. While Text A2, Text A3, and Text A4 were used to construct processes, events, and the sequential relations between the events progressively, Text B2 and Text B3 were used to construct sequential relations between events before processes. Text B4 is similar to Text A5, which focuses on the construction of causality. Compared with the accumulative way of constructing causality in Lesson A (processes → sequential relations → causal relations), that in Lesson B (sequential relations → processes → causal relations) is relatively disorganized. Therefore, the development of linguistic literacy in terms of textual Themes is better fostered in Lesson A than Lesson B.

The next section reports findings related to topical Themes in the written texts in terms of sematic types (Section 4.2.1.2) and Theme markedness (Section 4.2.1.3).

4.2.1.2 Semantic types of topical Themes

From the perspective of ideational metafunction, each clause construes an assemble of human experience through the configuration of three types of components: the process, the participants involved in the process, and circumstantial factors such as time, place or manner. The present study follows the guiding principle that the thematic structure contains one and only one of these experiential components (Halliday & Matthiessen, 2014). This means that the topical Theme of a clause can be the constituent of participant, circumstance or process, whichever appears first in a clause. The present study assigns both lexicogrammatical and semantic categories to topical Theme choices. This enables an examination of cross-modal meaning-making at the semantic level (see Section 5.6 for details). An analysis of the topical Themes in the 11 written texts from the two classrooms identified three main semantic categories:

a) People, e.g., *we, all the students, you*
b) Things, e.g., *air particles, gas pressure, Magdeburg Hemispheres*
c) Syntactic, e.g., *there* in existential clauses

The semantic distribution of the topical Themes in the written texts is shown in Table 4.5. Topical Themes in the semantic category of Things were predominant, accounting for 69% of all the topical Themes identified. The other two semantic categories, People and Syntactic, accounted for 15.5% and 15.5% of the topic Themes, respectively. The topical Themes of People were realized through the inclusive pronoun of *we*, referring to the teacher and the students as science investigators. The topical Themes in the Syntactic category were realized through the expletive pronouns, which acted as grammatical Subjects without carrying semantic meanings, such as *it* in *It is difficult to pull the hemispheres apart* and *there* in *There is a difference in air pressure*. The topical Themes of Things were realized through the pronoun *it*, and nouns or nominal groups such as *air, the rubber sucker*, and *the number of air particles*.

Table 4.5 Semantic categories of topical Themes in the written texts

	Frequency	Percentage
Things	49	69.0%
People	11	15.5%
Syntactic	11	15.5%
Total	71	100%

Sub-categories of Things and ways to elaborate Things were identified. These sub-categories were labelled based on their functions: either to be studied (i.e., observational) or as instruments (i.e., instrumental). Another way to sub-categorize Things was based on the scale of observation: Things to be observed at the microscopic scale (i.e., microscopic) and Things to be observed at the macroscopic scale (i.e., macroscopic). For instance, in the Magdeburg Experiment, the Magdeburg Hemispheres and the vacuum pump are instrumental Things at the macroscopic scale, while the air particles are observational Things at the microscopic scale.

Besides the fine-grained classification of Things in terms of their functions and the scale of observation, the present study identified two ways to elaborate them depending on how they can be measured. In classical physics, a distinction has been made between scalar and vector.[8] While a scalar as a physical quantity can only have magnitude without other characteristics, a vector has not only magnitude but also direction. In other words, a scalar has no direction and measures magnitude or quantity alone. A scalar is expressed as a single numerical value, often accompanied by a physical unit of measurement. An example of a scalar quantity is pressure (e.g., 1 *Pa)*: the exertion of a force (1 *N*) on a particular surface (1 m^2) can be shown in a single number (1) and the unit of measurement (*Pa*). This is in contrast to a vector quantity such as force and speed, which cannot be described by a single number but by several numbers, with each characterizing their magnitude, direction or other values, respectively. For instance, the description of a force comprises its magnitude value (e.g., 50 *N*) and its direction (e.g., 30 degrees to the horizontal). The further characterization of Things based on the scale of observation (macroscopic versus microscopic) and the attribution of entity (scalar

[8] It is important to point out that vector is not the only non-scalar physical quantity. There are other non-scalar physical quantities such as tensor and spinor, which were not identified in the data and therefore are not discussed here.

quantity versus vector quantity) allows for a comprehensive investigation into the nature of these topical Theme choices. The classification of the topical Themes in terms of the scale of observation and the nature of measurement, is summarized in Table 4.6.

Table 4.6 Topical Themes about People and Things in the written texts (Lesson A & Lesson B)

Semantic type		**Attribution**			Total (n=62)
Name	Scale	_	Measurement		
			Scalar quantity	Vector quantity	
People	_	11	0	_	11 (18%)
Things: observational	Microscopic	5	36	0	41 (61%)
	Macroscopic	0	0	0	0
Things: instrumental	Microscopic	0	0	0	0
	Macroscopic	9	1	_	10 (26%)
Total		25 (40%)	37 (60%)	0	62 (100%)

As Table 4.6 clearly shows, the scale of observation and attribution of entity mainly contributed to the construction of observational Things, that is, scientific entities to be studied, accounting for 61% of the topical Themes. These scientific entities were observed at the microscopic scale. They were related to air particles, with or without attributions. Those without attributions were realized in nominal groups such as *some air*, *air particles*, and *the air inside the plastic bag*. All instances of attribution concerned scalar quantities for scientific entities, and no vector quantities were found. The scalar quantities attributed to the scientific entities were amount and pressure. Examples of such topical Theme choices are *the number of air particles inside the hemispheres, the air pressure inside the M.H.,* and *the air pressure outside the bottle*. One possible explanation for the absence of vector quantities in the written texts is the crucial roles played by the images and the spoken texts in depicting vector quantities and explicating the role of vector quantities in quantitative reasoning, which will be discussed in detail in Chapter 5 and Section 4.3.1.2.

These observed patterns indicated that the topical Themes in the written texts foregrounded the scalar quantities of observational Things at the microscopic scale. The observational Things of *air particles* are not directly observable with naked eyes, which suggests the abstract nature of attributions such as *the number of air particles* and *the air pressure outside the bottle*. This contrasts with the other type of Things, namely instrumental Things, such as *the rubber sucker*, *it* (referring to the balloon) and *it* (referring to the plastic bag). The majority of the instrumental Things identified are visible (at the macroscopic scale), without scalar or vector attribution. The only exception, found in Text A6, was an instrumental Thing at the macroscopic scale with an attribution of volume (*the space occupied by the blanket*). Similarly, the semantic category of People identified in the written texts had no attribution of measurement, which differs from those identified in the spoken texts (see Section 4.3.2 for a detailed discussion).

The distributions of topical Themes in the written texts from Lesson A and those from Lesson B are summarized in Table 4.7 and Table 4.8, respectively.

Table 4.7 Distributions of topical Themes in Lesson A's written texts by semantic category

	Text A1	Text A2	Text A3	Text A4	Text A5	Text A6	Total (n=33)
Things	4	4	4	5	4	5	26 (79%)
People	2	1	1	1	1	0	6 (18%)
Syntactic	1	0	0	0	0	0	1 (3%)
Total	7	5	5	6	5	5	33 (100%)

Table 4.8 Distributions of topical Themes in Lesson B's written texts by semantic category

	Text B1	Text B2	Text B3	Text B4	Text B5	Total (n=39)
Things	4	6	5	5	4	24 (61%)
People	1	1	1	1	1	5 (13%)
Syntactic	2	2	2	2	2	10 (26%)
Total	7	9	8	8	7	39 (100%)

A written text used one or two topical Theme of People, four to six topical Themes of Things, and one or two topical Themes of the Syntactic type. The topical Theme of People *we* was used in the first clause to introduce the experiment condition, and the topical Themes of Things or Syntactic *there* were used in the subsequent clauses to construct the explanation sequences. An example with the typical realization of topical Themes is shown below (topical Themes in bold).

Text A5

When ***we*** *force out the air inside the rubber sucker by pressing it down,* ***the number of air particles inside the rubber sucker*** *decreases. So* ***the air pressure inside the sucker*** *decreases. So/And thus* ***the air pressure outside the rubber sucker*** *is higher than that inside. As a result,* ***the rubber sucker*** *sticks firmly on the wall.*

As shown in Table 4.7 and Table 4.8, while similar distributions of the topical Themes of People and Things were found in the written texts from Lesson A and Lesson B, the distributions of those in the Syntactic category varied. The written texts from Lesson A rarely used expletive pronouns such as *there*, which contrasted sharply with the use of expletive pronouns in the written texts from Lesson B. The consequences of the use of expletive pronouns are discussed in more detail in Section 4.2.1.3 and Section 4.2.2.1.

4.2.1.3 Theme markedness

This section describes the ways in which a Theme can be marked, using the integrated analytical framework presented in Chapter 3. Among the 71 clauses in the written texts from both lessons, there were 48 free clauses and 23 bound clauses. All the free clauses but one were declaratives, which made Subject the default choice of topical Theme. Topically, the written texts were unmarked as all the topical Themes were conflated with the Subjects of the clauses. As Halliday and Matthiessen (2014) point out, the Subject in declaratives is usually the default Theme choice "unless there is a good reason for choosing something else" (p. 97). By going with the default choice of unmarked topical Themes, an author intends to enhance the coherence of the information flow in the text rather than signaling a shift or a stage in the discourse or invoking a particular angle to interpret the message (Forey, 2009). The only exception of the topical Theme found in the written texts was the expletive pronoun *it* in *so it is difficult to pull the hemispheres apart*, where the complement *difficult* was marked in the clause. It is suggested that the ability to construct a coherent written text via unmarked topical Theme choices be considered as a crucial linguistic literacy skill for students at secondary levels.

Besides being marked topically, the clauses can also be marked inherently or/and characteristically. As pointed out by Halliday and Matthiessen (2014), while topical thematic elements provide "an anchorage in the realm of experience" (p.111), inherent thematic elements "orient the clause within the discourse, rhetorically and logically" (p.111), and characteristical thematic elements "set up a semantic relation with what precedes or express the speaker's angle or intended listener" (p. 111). The Theme choices in the written texts in terms of inherent and characteristical markedness are summarized in Table 4.9.

Table 4.9 Occurrences of inherently and characteristically marked Themes in the written texts (Lesson A & Lesson B)

	Inherently & characteristically unmarked	Inherently marked	Characteristically marked
Free clauses	40	6	2
Bound clauses	10	12	1

Inherently, 18 clauses were marked through the use of conjunctions (*so, and, therefore, since,* and *for*) or conjunctive groups (e.g., *and thus*). These textual elements oriented the clauses with "particular discursive force" (Halliday & Matthiessen, 2014, p. 109) and contributed to two types of relation between clauses: causal and additional. While the conjunctions or conjunctive groups such as *so* and *and thus* embodied explicit causal relations between the clauses, the conjunction *and* simply showed an additional relation between the clauses. Characteristically, there were three instances of the conjunctive adjunct *as a result*, which related the clauses in question to the preceding text causally. The analysis shows that the written texts cohered the message in a clause through unmarked topical Theme choices and built the semantic relation of cause between the clauses through inherently or characteristically marked elements.

Figure 4.1 demonstrates how each text unfolds in terms of Theme markedness. The clauses in each text are numbered according to the sequential unfolding of the text. For instance, the first clause in the first sentence in Text A1 (*When we use the vacuum pump to suck away the air particles inside the hemispheres*) is numbered as "1.1". The clauses marked inherently and characteristically are highlighted in blue and orange, respectively.

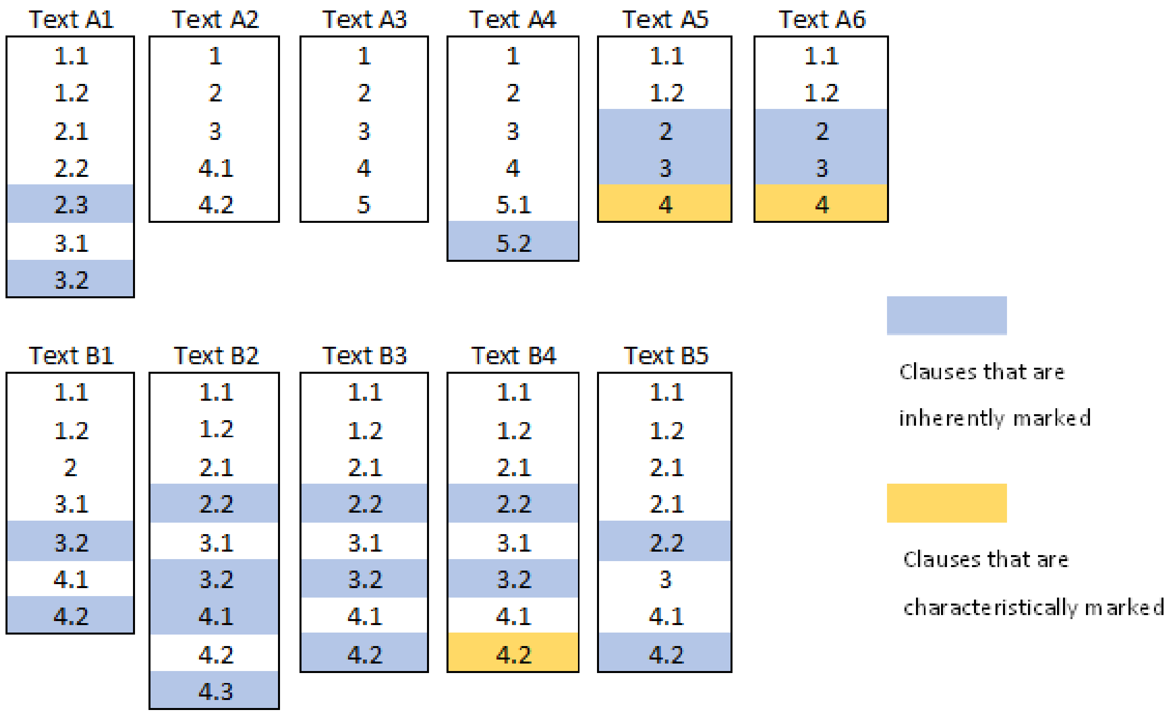


Figure 4.1 The unfolding of texts in terms of Theme markedness

Inherently and characteristically marked Themes were not evenly distributed among these texts. The unfolding of these texts in terms of Theme markedness is interesting in three ways. First, the clauses marked either inherently or characteristically tended to concentrate in the latter part of the texts, where the explanation sequences began (see Section 4.2.3 for details). Second, the development of Theme markedness in the written explanations from Lesson A and that from Lesson B varied. In Lesson A, the degree of Theme markedness from Text A1 to Text A6 witnessed a shift from high (in Text A1) to low (in Text A2, Text A3 and Text A4) and back to high (in Text A5 and Text A6). The shift of Theme markedness in the written explanations from Lesson A suggested a progressive way of developing scientific literacy in its fundamental sense with on-going adaptations to the expected standard of a scientific explanation. This progressive development in Theme markedness resonated with the unpacking and repacking of knowledge through classroom work in Lesson A, which is discussed in more detail in Section 4.3. However, the degree of Theme markedness from Text B1 to Text B5 remained high for all the five texts, suggesting a different way of developing scientific literacy in its fundamental sense. In the case of Lesson B, the expected standard of a scientific explanation was provided in the beginning (Text A1) and reinforced throughout the lesson (Text B2 to Text B5). Third, while it is possible for a clause to be marked topically, inherently and characteristically, the concurrent selection of topical, inherent and characteristical markedness was not observed in the texts. This supports Halliday and Matthiessen's (2014) notion of "quantum of thematicity". The quantum of thematicity in a clause is confined: when certain quantum is taken up by the inherently or characteristically marked items, it is less likely to have topically marked items. As Halliday and Matthiessen (2014) point out:

> …such marked Themes appear to be slightly less frequent when there is some inherently thematic item in the clause, suggesting that some of the 'quantum of thematicity' has already been taken up… This principle also applies to the characteristically thematic items. When these items are present in the Theme, it is still possible to have a marked topical Theme, but rather more seldom.
>
> (Halliday & Matthiessen, 2014, pp. 101-111)

While the notion of quantum of thematicity is used to explain the possibility of collocation between topically marked items and topically unmarked items in a clause (i.e., inherently and characteristically marked items), the findings from the present study show that the notion may also apply to the collocation possibility between inherently marked items and characteristically marked items in a clause in a written text.

So far, the analyses of and discussions on the Theme choices in the written texts are confined within the grammatical and semantic strata of the language system. With the advancement of technology, the presentation of written texts is no longer restricted to the traditional black-and-white format. To analyze the meaning-making of a text, it is necessary to incorporate the extensions of meaning that are realized through the visual display of the text. However, as the existing literature on Themes mainly focuses on the language system, the multimodal aspect is severely overlooked. The present study is the first attempt to introduce the multimodal aspect to Theme markedness. In what follows, ways to mark Themes through visual displays are presented and briefly discussed.

Three ways of visually displaying the written texts were identified: through PowerPoint slides, through printed texts, and through hand-written texts. Table 4.10 summarizes the way(s) in which each text was displayed. The visual display of PowerPoint slides was more frequently selected to present the texts than the other two media: printed texts and hand-written texts. While there was no obvious distinction between the media of printed texts and hand-written texts in how Themes were marked multimodally, the medium of PowerPoint slides afforded more ways to mark the Themes. Three ways were identified for the medium of PowerPoint slides to mark the Themes: the layout organization, the sequential display, and the use of colors. The visual display of Text A5 is used as an example to illustrate these ways (see Figure 4.2). In terms of layout organization, the text was decomposed into clauses, with each clause starting at a new line. Such spatial organization segmented the message in the text and potentially could draw the reader's attention to the point of departure at each clause. Another way that worked similarly was a sequential display of these clauses, with one clause emerging after another. The last way of marking Themes was through the use of colors to highlight them. The inherently or characteristically marked items were highlighted through the background colors of green and blue. As for the printed texts and hand-written texts, only layout organization was observed to mark Themes multimodally (see Figure 4.3 and Figure 4.4).

Table 4.10 Ways of visually displaying the written texts

	PowerPoint slide	**Printed text**	**Hand-written text**
Text A1 (the M.H. experiment)	✔		
Text A2 (the balloon experiment)	✔	✔	
Text A3 (the rubber sucker experiment)	✔	✔	
Text A4 (the vacuum plastic bag experiment)	✔		✔
Text A5 (the rubber sucker experiment)	✔		
Text A6 (the vacuum plastic bag experiment)			✔
Text B1 (the M.H. experiment)	✔		
Text B2 (the balloon experiment)	✔	✔	
Text B3 (the beverage can experiment)	✔	✔	
Text B4 (the vacuum plastic bag experiment)			✔
Text B5 (the vacuum plastic bag experiment)			✔

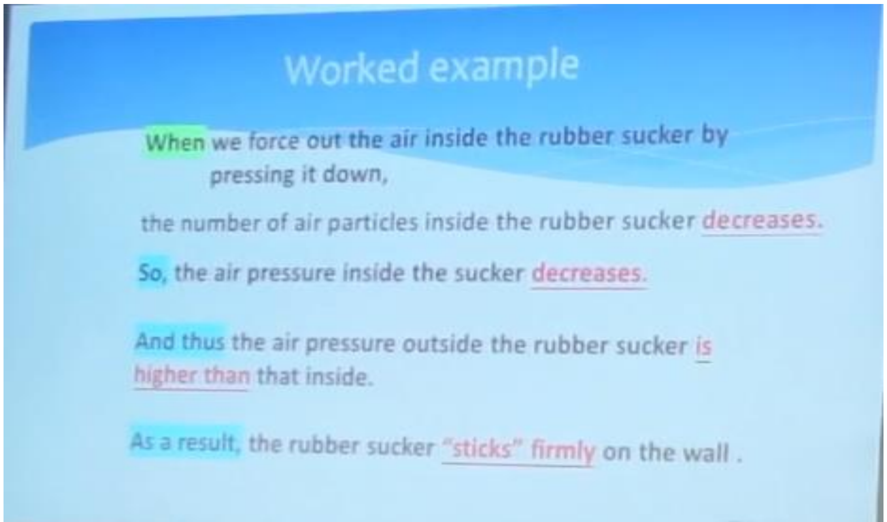


Figure 4.2 The visual display of Text A5 through a PowerPoint slide

Events	Explanation of events	Guiding questions
Cause	We force out the air inside the rubber sucker by pressing it down.	What is the action?
Effect 1	The number of air particles inside the rubber sucker decreases.	What is change in the number of air particles inside the bottle?
Effect 2	The air pressure inside the sucker decreases.	What is the change in the air pressure inside the bottle?
Effect 3	The air pressure outside the rubber sucker is higher than that inside.	Try to compare the air pressure at different regions.
Result	The rubber sucker sticks firmly on the wall.	What will happen due to the air pressure difference?

Figure 4.3 The visual display of Text A3 in a printed text

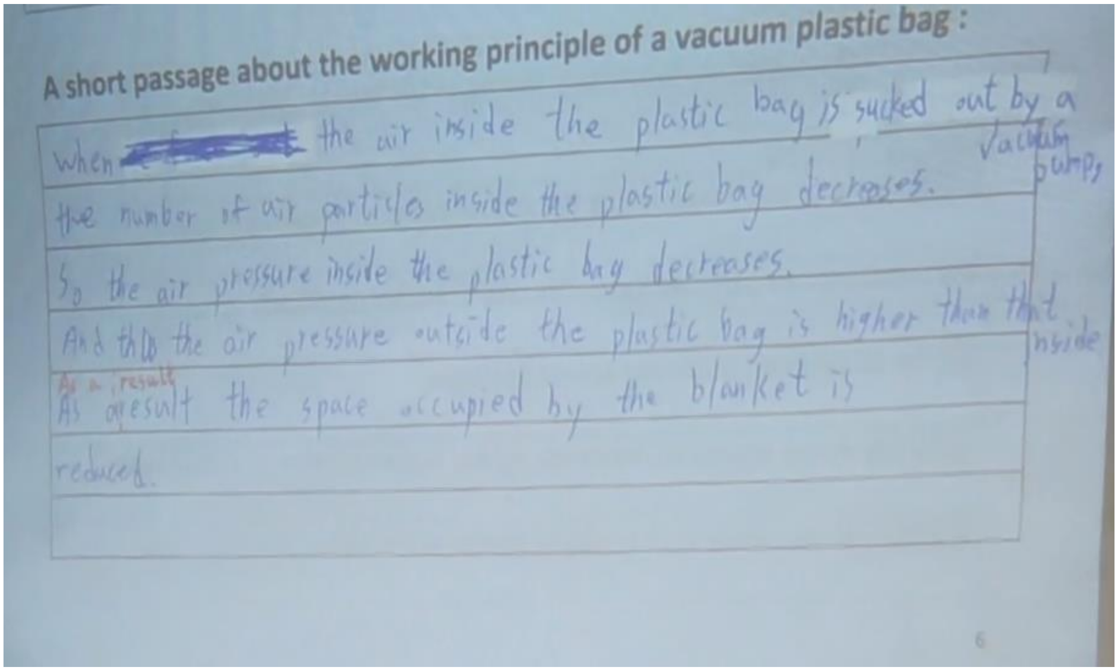


Figure 4.4 The visual display of Text A6 in a hand-written text

The non-topical Themes were more often multimodally marked than the topical Themes in all these media. The non-topical Themes were placed at the beginning of the line, emerged as the first item in the line, and were highlighted in different colors, whereas the topical Themes were located farther from the beginning of the line, emerged after the non-topical items, and were shown in black. This may be largely attributed to the conventional linear order of Themes in the language system, that is, textual Themes ^ interpersonal Themes ^ topical Themes. Such an order means that if the clause is shown in a linear way, as it usually is, non-topical Themes will be shown before topical Themes, gaining more multimodal markedness in terms of layout organization and sequential display. However, multimodal markedness achieved through other means such as the use of color, font size, and animation of certain characters is not bonded by the linearity, which makes it possible to mark other items that appear latter than the non-topical Themes. The practical significance of this option is that producers of texts can play with various ways of marking a Theme multimodally, to which both producers and readers of the texts need to be alert. It is suggested that when preparing teaching materials, teachers should be aware of how Themes can be marked multimodally and leave most Themes unmarked unless there is a need to signal a shift in the discourse or to suggest a particular viewpoint.

4.2.2 Thematic structure at the discourse level

4.2.2.1 Thematic progression

While the previous section reports the findings of the semantic categorization of topical Theme choices, this section focuses on the development of a text by tracing its thematic progression. The fundamental role that Theme choices play in organizing a text is referred to as the method of textual development (Fries, 1981; Hasan & Fries, 1995). The analysis of the thematic progression of a text enables an insight into its texture in relation to the unfolding of discourse. The results of a thematic progression (TP) analysis conducted of the written texts from both lessons are summarized in Table 4.11 according to three parameters: TP paths, Theme sources, and the contingency of progression.

Table 4.11 Thematic progression in the written texts

Constant (Themic)				**Linear (Rhemic)**				**Derived**	
Simple		Multiple		Simple		Multiple			
Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	New	Synt.
24	1	2	2	17	0	2	0	1	11
Total = 29 (49%)				Total = 19 (31%)				Total = 12 (20%)	

Note. cont. = contiguous; gap.= gapped; synt.= syntactic items

As for TP paths, the written texts tended to use constant TP paths more often than linear TP paths. Constant TP paths accounted for 49% of the total thematic progressions, whereas linear represented 31%. For both constant and linear TP paths, the contiguous progression of simple Themes was the prominent pattern. The thematic progression of a written text was a mix of constant, linear and derived TP paths. Among the derived paths, syntactic items (11 instances) were found more prominent than new information (only one instance). The syntactic items identified in the data were expletives, such as *it* in *It is difficult to pull the hemispheres apart.* (Text B1) and *there* in *There are fewer air particles inside to hit the wall of the M.H.* (Text A1). The only instance of new information was found in the use of *the space occupied by the blanket* as the topical Theme in Text A6, which introduced the volume of an object that was not mentioned in the previous text. The different consequences brought by syntactic items and new information will be discussed after presenting the typical pattern of TP in the written texts.

A typical pattern following the order of the semantic categories of topical Themes presented in Table 4.6 was observed in most written texts from both Lesson A and Lesson B. The topical Theme started from the semantic entity of People and moved to observational Things at the microscopic scale and then to the attribution of scalar quantities. Such a progression of topical Themes from People, to observational Things and then to the attribution of scalar quantities to the observational Things was found to constitute a mixed TP pattern.

Table 4.12 presents the thematic analysis of Text A1 as an example of the mixed TP pattern.

Table 4.12 Theme-Rheme analysis of written Text A1

	Clause	Theme	Rheme	TP pattern	Semantic type of the topical Theme
1.1	When we use the vacuum pump to suck away the air particles inside the hemispheres (M.H.),	when we	use the vacuum pump to suck away the air particles inside the M. H.		People
1.2	the number of air particles inside the hemisphere decreases.	the number of air particles inside the hemisphere	decreases	Simple contiguous linear	Things: observational + microscopic; measurement: scalar quantity (amount)
2.1	There are fewer air particles inside to hit the wall of the M. H.,	there	are fewer air particles inside	Derived: syntactic	Syntactic
2.2	so the air pressure inside the M. H. decreases.	so the air pressure inside the M. H.	decreases	Simple contiguous linear	Things: observational + microscopic; measurement: scalar quantity (pressure)
3.1	Air pressure inside the M. H. becomes lower than the air pressure outside M. H.,	Air pressure inside the M. H.	becomes lower than the air pressure outside M. H.	Simple contiguous constant	Things: observational + microscopic; measurement: scalar quantity (pressure)
3.2	so we cannot pull the hemispheres apart.	so we	cannot pull hemispheres apart.	Simple gapped constant	People

The information flew from one clause to the next one through two patterns of thematic progression: linear thematic progression and constant thematic progression (see Figure 4.5). The Theme and the Rheme of a clause are represented as T and R respectively, and progression is shown through arrows.

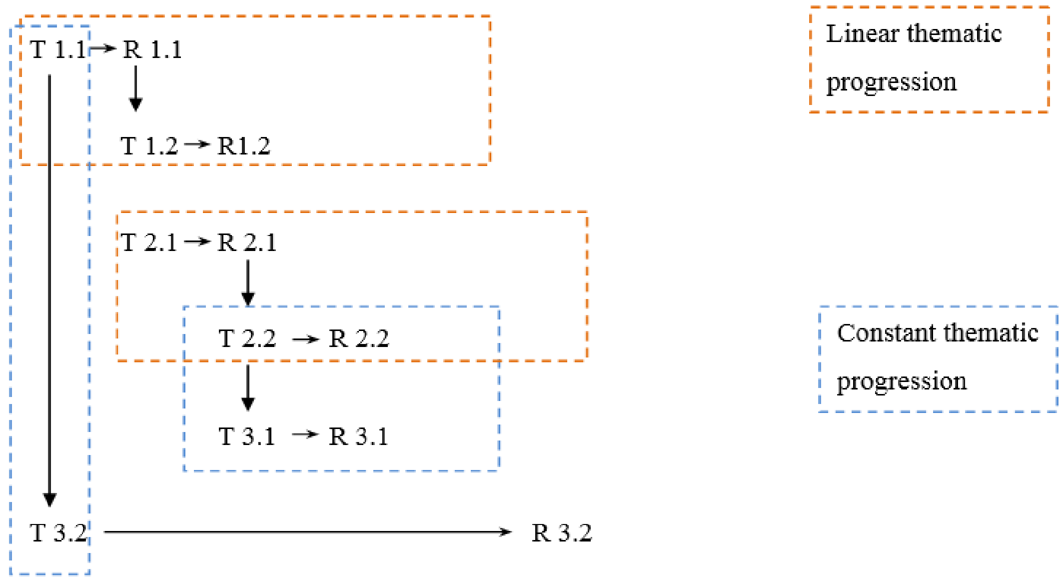


Figure 4.5 The thematic progression in Text A1

As shown in Figure 4.5, the topical Themes in Text A1 progressed in a mix of linear and constant TP paths, with an interruption of the derived Theme *there* in T 2.1. The linear pattern was used at the beginning of the text (from T 1.1 to R 1.2) to describe the experiment condition (using the vacuum pump to suck air from the hemispheres) and the direct effect (i.e., air particles decreases). The topical Themes in the next three clauses progressed linearly (from R 2.1 to T 2.2) and constantly (from T 2.2 to T 3.1) to link two scalar quantities of air particles: amount and pressure. In the last clause, simple gapped constant progression (from T 1.1 to T 3.2) was used to describe the phenomenon that could be perceived.

The development of topical Themes from observational Things (i.e. air particles) to the relations between scalar quantities (i.e., amount, pressure, volume) was also found in a constant TP pattern.

Table 4.13 presents the thematic analysis of Text A6 as an example of the constant TP pattern.

Table 4.13 The thematic analysis of Text A6

	Clause	Theme	Rheme	TP pattern	Semantic Type of topical Theme
1.1	When the air inside the plastic bag is sucked out by a vacuum pump,	When the air inside the plastic bag	is sucked out by a vacuum pump,		Things: observational + microscopic
1.2	the number of air particles inside the plastic bag decreases.	the number of air particles inside the plastic bag	decreases.	Simple contiguous constant	Things: observational + microscopic; measurement: scalar quantity (amount)
2	So the air pressure inside the plastic bag decreases.	So the air pressure inside the plastic bag	decreases.	Simple contiguous constant	Things: observational + microscopic; measurement: scalar quantity (pressure)
3	And thus the air pressure outside the plastic bag is higher than that inside.	And thus the air pressure outside the plastic bag	is higher than that inside.	Simple contiguous constant	Things: observational + microscopic; measurement: scalar quantity (pressure)
4	As a result, the space occupied by the blanket is reduced.	As a result, the space occupied by the blanket	is reduced.	Derived: new	Things: observational + macroscopic; measurement: scalar quantity (volume)

Different from the progression pattern in Text A1, thematic progression in Text A6 exhibited a simple contiguous constant TP pattern (see Figure 4.6). The development of the topical Themes in Text A6 also differed from that in Text A1 in two ways. First, the topical Theme of People was absent in Text A6, which resulted in the development of topical Themes from the semantic type of observational Things to the relation of scalar quantities. Second, the interruption of the TP in Text A6 was realized through the insertion of new information, as compared to the syntactic Themes in Text A1. The inserted new information (i.e., *the space occupied by the blanket*) enabled the extension of quantitative reasoning from the scalar quantities of observational Things (i.e., amount and pressure) to the scalar quantity of instrumental things (i.e., volume).

Figure 4.6 Thematic progression in Text A6

Although linear thematic progression is often used in expository texts (Fries, 1995), the findings of this study confirm Banks's (2008) observation that the themes in scientific texts progress through the hybridization of different patterns rather than "long stretches of a single type of progression" (p. 9). The written texts examined in this study mainly adopted a mix of linear and constant TP paths with a few interruptions of syntactic Themes or new Themes. Although the thematic progression patterns identified in this study showed some variety in constructing the explanations, constant TP paths occurred more frequently than linear ones. This finding differs from Banks's (2008) study of articles in physics which found that the linear thematic pattern was used for interpreting the target phenomenon, while the constant thematic pattern was used for narrating the experiment.

These differences can be explained, largely if not completely, through the register variable of mode (see Section 4.3 for discussions on the theme choices in the spoken texts). Martin and Rose (2008) point out that there are two dimensions of variation in the mode of language. One is the distribution of semiotic labor in language, which is characterized as a cline from language in action to language as reflection. The other variable is the scale of interactivity in the construction of the text, ranging from monologue to dialogue. The texts analyzed in Banks's (2008) study were printed texts, where language was used as the primary source to constitute the field with minimal interactivity in its construction, whereas the written texts examined in this study were constructed in the science classrooms, where the constitution of the field was a collective effort of language and other semiotic resources, and the scale of interactivity was higher than that of the published articles because both the teachers and their students could revise the texts. To what extent the pattern identified in the present study is generalizable calls for further studies involving more data in different contexts.

4.2.2.2 HyperThemes and macroThemes

Neither hyperThemes nor macroThemes were found in the written texts from both Lesson A and Lesson B. This may be due to the short length of the written texts, with an average of seven clauses in a text. As the relationships between these clauses are simple (mainly causal), the textual Themes (e.g., *so*) alone are sufficient for constructing such relationships (e.g., causal relations) between clauses. This contrasts with the observations of both hyperThemes and macroThemes in the spoken texts, which are presented in Section 4.3.2.2 in detail. The following section discusses the schematic structure of an explanation, based on the thematic patterns identified in these written texts.

4.2.3 The schematic structure of an explanation

From the 11 written texts produced in the two science classrooms, a similar schematic structure of an explanation was identified. The structure consists of three obligatory stages: Experiment Condition ^ Explanation Sequences ^ Phenomenon Perception. A written text started by presenting the condition of the experiment, introducing the intervention and the instruments (the Experiment Condition stage), which was followed by sequences of events linked causally to interpret the phenomenon (the Explanation Sequences stage) and ended with a description of the phenomenon that could be perceived (Phenomenon Perception). This schematic structure can be regarded as a derivative of the generic structure of explanation in written texts, that is, Phenomena identification ^ Explanation sequences (Martin & Rose, 2008; 2012). The main deviation concerns the stage of Phenomena identification, which was separated into two parts in the data examined in the present study: Experiment Condition and Phenomenon Perception. While the generic structure of explanation shows a shift from concrete (the intervention, the instruments and the phenomena under investigation) to abstract (the causality between observational things), the derivative schematic structure identified in this study tended to construct the explanation based on a sequential unfolding of events in a scientific investigation. To a certain extent, such a construction resembles the natural occurrence of the processes: from the intervention by the experimenter to model the phenomena, to abstract activities that are causally chained, and the phenomena that can be observed. It is suggested that the schematic structure of explanations identified in the present study can be used as a model for introducing scientific explanations at junior secondary level as it resembles how knowledge is produced in scientific investigations. Other schematic structures of scientific explanations, such as the one identified by Martin and Rose (2008), can be presented at senior secondary level to offer students alternative ways of constructing explanations.

The schematic structure of explanations was identified based on thematic patterns in the written texts. Therefore, it is requisite to understand the typical thematic patterns in relation to the schematic structure of explanations. The typical patterns of Theme selection at the clausal level and the thematic structure at the discourse level are summarized in relation to the schematic structure of explanations in Table 4.14.

Table 4.14 Typical patterns of Themes and the schematic structure of explanations

Schematic structure	Experiment Condition	Explanation Sequences	Phenomenon Perception
Relations in textual Themes	Condition	Cause	Cause
Semantic types of topical Themes	People	Observational Things with scalar quantities; Syntactic *there*	Instrumental Things
Theme markedness	Unmarked	Topically unmarked; Inherently/characteristically marked	
Thematic progression	N/A	Simple Theme progressed contiguously through a mix of constant and linear TP paths	
Hyper-/macro-Themes	N/A		

The stage of Experiment condition usually started with a textual Theme showing Condition and an unmarked topical Theme of People. In the stage of Explanation sequences, unmarked topical Themes of observational Things with scalar quantities progressed contiguously through a mix of constant and linear TP paths, although the thematic progression could be interrupted by the use of syntactic *there*. Relations in the textual Themes in this stage were causal ones. In the third stage of Phenomenon Perception, unmarked topical Themes of instrumental Things progressed contiguously through a mix of constant and linear TP paths. The textual Themes in this stage were used to link causally to the explanation sequences in the second stage. These thematic patterns identified in the present study shed light on what a well-established written explanation looks like in terms of thematic selection at the level of a clause and thematic structure at the level of discourse. Therefore, the choices of Themes in a written explanation can be taught and learned in an explicit way.

4.3 Themes in the spoken texts

This section presents the thematic patterns found in four spoken texts that explained the Magdeburg Experiment in the two science lessons. The thematic patterns of these texts at the clausal level are presented in Section 4.3.1, while those at the discourse level are addressed in Section 4.3.2.

4.3.1 Thematic selection at the clausal level

4.3.1.1 Metafunctional types of Themes

A total of 357 clauses, each having at least one topical Theme, were identified in the four spoken texts. These spoken texts covered two parts of classroom talks between the teachers and their students: experiment demonstrations, where the phenomenon to be explained was identified through conducting experiments; and explanation constructions, where the explanations were constructed by the teacher and students to explain the identified phenomenon. Text A-1 and Text B-1 concerned experiment demonstrations, while Text A-2 and Text B-2 dealt with explanation constructions.

Table 4.15 and Table 4.16 show the Theme selection according to the three metafunctional types in the spoken texts about experiment demonstrations in Lesson A and Lesson B respectively. As shown in Table 4.15, there were 37 (24%) textual Themes, 25 (16%) interpersonal Themes, and 94 (60%) topical Themes in Text A-1. Among the 94 clauses, 55 (58%) contained non-topical Themes (a textual Theme and/or an interpersonal Theme), whereas 40 (42%) had only topical Themes. A high frequency of textual Themes was also observed in Text B-1. As shown in Table 4.16, there were 25 (40%) non-topical Themes, 4 (7%) interpersonal Themes, and 33 (53%) topical Themes. Of the 33 clauses identified in Text B-1, 8 (24%) had topical Themes only, and 25 (76%) clauses contained textual Themes and, in four case, additional interpersonal Themes as well. To sum up, the clauses with non-topical elements occurred more frequently than the clauses with only topical Themes in both Text A-1 and Text A-2. Of the on-topical elements, textual Themes predominated, though some of the clauses contained all three types of Themes.

Table 4.15 Theme selection in Text A-1 (experiment demonstrations in Lesson A)

	Frequency	Percentage
Textual Themes	37	24%
Interpersonal Themes	25	16%
Topical Themes	94	60%
Total number of Themes	157	100%
Clauses with only topical Themes	40	42%
Clauses with textual or/and interpersonal Themes	55	58%
Total number of clauses	94	100%

Table 4.16 Theme selection in Text B-1 (experiment demonstrations in Lesson B)

	Frequency	Percentage
Textual Themes	25	40%
Interpersonal Themes	4	7%
Topical Themes	33	53%
Total number of Themes	62	100%
Clauses with only topical Themes	8	24%
Clauses with textual or/and interpersonal Themes	25	76%
Total number of clauses	33	100%

The choices of Themes in the spoken texts related to explanation constructions in Lesson A and in Lesson B are summarized in Table 4.17 and Table 4.18, respectively. In Text A-2, there were 72 (27%) textual Themes, 35 (12%) interpersonal Themes and 171 (61%) topical Themes, yielding a total of 278 Themes in 171 clauses. Among these 171 clauses, 95 (56%) contained non-topical elements, whereas 76 (44%) had only topical Themes. Text B-2 had 99 Themes in 59 clauses. Of the 99 Themes, 38 (38%) were textual Themes, two (2%) interpersonal Themes, and 59 (59%) topical Themes. Although Text B-2 was shorter than Text A-2, a higher frequency of non-topical elements was found in Text B-2. Among the 59 clauses in Text B-2, 37 (63%) clauses were found to have at least an additional textual Theme or interpersonal Theme, whereas 22 (37%) clauses had only topical Themes. Similar to thematic choices in the spoken texts about experiment demonstrations, a greater number of non-topical elements occurring in conjunction with topical Themes than the sole use of topical Themes was found in the texts about explanation constructions. Textual Themes occurred more frequently than interpersonal Themes in both Text A-2 and Text B-2.

Table 4.17 Theme selection in Text A-2 (explanation constructions in Lesson A)

	Frequency	**Percentage**
Textual Themes	72	27%
Interpersonal Themes	35	12%
Topical Themes	171	61%
Total number of Themes	278	100%
Clauses with only topical Themes	76	44%
Clauses with textual or/and interpersonal Themes	95	56%
Total number of clauses	171	100%

Table 4.18 Theme selection in Text B-2 (explanation constructions in Lesson B)

	Frequency	**Percentage**
Textual Themes	38	38%
Interpersonal Themes	2	2%
Topical Themes	59	60%
Total number of Themes	99	100%
Clauses with only topical Themes	22	37%
Clauses with textual or/and interpersonal Themes	37	63%
Total number of clauses	59	100%

In general, the distributions of textual, interpersonal and topical Themes in experiment demonstrations and explanation constructions were consistent in each lesson. While textual Themes were preferred in both Lesson A and Lesson B, there was a slightly higher frequency of textual Themes in both Text B-1 and Text B-2, the spoken texts from Lesson B. Compared with the high frequency of textual Themes, the interpersonal Themes occurred less frequently in both Lesson A and Lesson B. This contrast was more obvious in Lesson B, where only a very small number of interpersonal Themes were used in Text B-1 (4 instances out of 33 instances) and Text B-2 (2 instances out of 59 instances).

The distributions of specific textual Themes in the four spoken texts are presented in

Table 4.19. The top ten most frequent textual Themes are: *now*, *okay*, *so*, *and, and then*, *okay now*, *yes/yeah*, *when/whenever*, *because* and *but.* The function of these textual Themes can be considered at the clausal level and at the discourse level. At the clausal level, five types of logical relations were constructed: reason (marked by *so* and *because*), temporal sequence (marked by *then*), addition (marked by *and*), condition (marked by *when/whenever* and *if*), and concession (marked by *but*) (see Section 4.3.1.3 for detailed discussions). These results were consistent with the typical logical semantic relations that are favoured in narratives and arguments. While narrative texts prefer the relation of temporal sequence, argumentative texts in everyday reasoning typically involve the relations of condition, reason, and concession (Halliday & Matthiessen, 2014).

Table 4.19 The occurrence of textual Themes in the spoken texts

Textual Theme	Frequency	Percentage
now	40	23%
okay	25	15%
so	18	10%
and	17	10%
and then	16	9%
okay now	11	6%
yes/yeah	11	6%
when/whenever	6	3%
because	4	2%
but	4	2%
as	2	1%
if	2	1%
so before	2	1%
so if	2	1%
alright then	1	<1%
and now	1	<1%
finally	1	<1%
now actually	1	<1%
okay and	1	<1%
okay and then	1	<1%
okay then	1	<1%
so finally	1	<1%
so that	1	<1%
then	1	<1%
well	1	<1%
yes now	1	<1%
Total	172	100%

At the discourse level, continuatives, such as *now*, *okay* and *yeah/yes*, functioned as discourse markers. According to Halliday and Hasan (1976), the continuative *now* can indicate a new stage in the communication. Specifically, the continuative *now* can function as an opening frame marker to initiate the discourse (Castro, 2006), emphasize the sequentially accumulative nature of a discourse, and display a change in the speaker's orientation (Schiffrin, 1987). The discourse marker *okay* is seen as a multifunctional discourse operator which can perform several functions simultaneously at the discourse level, such as showing acknowledgement or acceptance, checking the progression of a topic, signaling a transition of a topic, and challenging the other speaker's opinions (Schiffrin, 1987). The instances of *okay* in this study functioned mainly in two ways. First, it helped to structure the discourse by indicating a change in the topic, such as *okay* in *okay, let's go on.* Second, it was used to show acknowledgement or acceptance of the students' responses, such as *okay* in *okay, you are right this time.* The use of *okay* to preface a challenge in confrontational situations in Gaines's (2011) study of police interviews was not observed in this study, suggesting an equalitarian style of communication in the classroom rather than a confrontational one as in Gaines' study. The use of *yeah/yes* served either as a direct response to a question or as a discourse marker. The discourse marker *yeah/yes* can perform three major functions in the classroom: agreeing/acknowledging, discourse structuring and backchannelling (House, 2013). It was found in this study that the primary use of *yeah/yes* was as a marker of the teacher's positive evaluation of students' answers in constructing explanations. One example of *yeah/yes* as a marker of positive evaluation in spoken Text A-2 is shown below:

T: *There are less particles, so will they hit the wall more frequently or less frequently?* [A-2_1_3_24]
Ss: *less frequently*. [A-2_1_3_25]
T: *Yes, less frequently*. [A-2_1_3_26]

The other function of *yeah/yes* was to structure the discourse, juxtaposed with an imperative showing a command, such as *yes* in the clause *Yes now show this.* The use of *yeah/yes* as a conversation continuer was not observed in the data examined in this study. Continuatives used as discourse markers are discussed in relation to Theme markedness in Section 4.3.1.3.

4.3.1.2 Semantic types of topical Themes

An analysis of the topical Themes in the four spoken texts from the two lessons identified six main semantic categories:

1) People, e.g., *we, all the students, you*

2) Things, e.g., *air particles, gas pressure, Magdeburg Hemispheres*
3) Semiotic, e.g., *the result, the cause, this question*
4) Actions, e.g., *think, try, compare*
5) Circumstances, e.g., *in many science experiments like this, why, here*
6) Syntactic, e.g., *there* in existential clauses

The semantic categories of topical Themes in these four spoken texts are presented in Table 4.20, Table 4.21, Table 4.22, and Table 4.23, respectively. The distributions of the semantic categories tended to vary depending on the field of knowledge, that is, either demonstrating the phenomenon (as in Text A-1 and Text B-1) or explaining it (as in Text A-2 and Text B-2). The most frequent semantic category in the spoken texts giving experiment demonstrations was People, followed by Things, Circumstances and Actions (see Table 4.20 and Table 4.21). In contrast, the most frequent semantic category in the spoken texts constructing explanations was Things, followed by People, Semiotic and Syntactic items (see Table 4.22 and Table 4.23). The topical Themes of Things and People are the most prominent semantic categories in all four spoken texts, accounting for more than 50% of all identified Themes. However, the texts demonstrating an experiment and those explaining a phenomenon differed in whether the Themes of Things or the Themes of People were dominating. In the spoken texts of experiment demonstrations, the Themes of People had a higher presence than the Themes of Things, while the opposite trend was observed in the spoken texts of explanation constructions. From the texts of experiment demonstrations to these of explanation constructions, a decrease in the topical Themes of Actions and an increase in the topical Themes of Semiotic were observed in both Lesson A and Lesson B. However, the topical Themes of Circumstances and Syntactic items showed no constant patterns.

Table 4.20 Semantic categories of topical Themes in Text A-1 (experiment demonstration, Lesson A)

	Frequency	Percentage
Things	12	13%
People	54	57%
Circumstances	12	13%
Actions	11	12%
Semiotic	2	2%
Syntactic	3	3%
Total	94	100%

Table 4.21 Semantic categories of topical Themes in Text B-1 (experiment demonstration, Lesson B

	Frequency	Percentage
Things	6	18%
People	19	58%
Circumstances	2	6%
Actions	5	15%
Semiotic	0	0%
Syntactic	1	3%
Total	33	100%

Table 4.22 Semantic categories of topical Themes in Text A-2 (explanation construction, Lesson A)

	Frequency	Percentage
Things	74	43%
People	54	31%
Circumstances	8	5%
Actions	7	4%
Semiotic	15	9%
Syntactic	13	8%
Total	171	100%

Table 4.23 Semantic categories of topical Themes in Text B-2 (explanation construction, Lesson B)

	Frequency	Percentage
Things	22	37%
People	9	15%
Circumstances	4	7%
Actions	5	8%
Semiotic	8	14%
Syntactic	11	19%
Total	59	100%

Due to the prominence of the topical Themes of People and Things in the spoken texts, they were further categorized in terms of the scale of observation and the attribution of measurement. The subcategories are presented in Table 4.24, Table 4.25, Table 4.26, and Table 4.27 respectively.

Table 4.24 Topical Themes of People and Things in Text A-1

Semantic type		**Attribution**			**Total (n=124)**
Name	Scale	–	Measurement		
			Scalar quantity	Vector quantity	
People	–	54	0	0	54 (82%)
Things: observational	Microscopic	0	2	0	2 (3%)
	Macroscopic	0	0	0	0
Things: instrumental	Microscopic	0	0	0	0
	Macroscopic	10	0	0	10 (15%)
Total		64 (97%)	2 (3%)	0	66 (100%)

Table 4.25 Topical Themes of People and Things in Text B-1

Semantic type		**Attribution**			**Total (n=124)**
Name	Scale	–	Measurement		
			Scalar quantity	Vector quantity	
People	–	19	0	0	19 (76%)
Things: observational	Microscopic	2	1	0	3 (12%)
	Macroscopic	0	0	0	0
Things: instrumental	Microscopic	0	0	0	0
	Macroscopic	3	0	0	3 (12%)
Total		24 (96%)	1 (4%)	0 (0%)	25 (100%)

Table 4.26 Topical Themes of People and Things in Text A-2

Semantic type		**Attribution**			**Total (n=124)**
Name	Scale	–	Measurement		
			Scalar quantity	Vector quantity	
People	–	51	3	0	54 (42%)
Things: observational	Microscopic	4	46	22	72 (56%)
	Macroscopic	0	0	0	0
Things: instrumental	Microscopic	0	0	0	0
	Macroscopic	2	0	0	2 (2%)
Total		57 (45%)	49 (38%)	22 (17%)	128 (100%)

Table 4.27 Topical Themes of People and Things in Text B-2

Semantic type		**Attribution**			**Total (n=124)**
Name	Scale	–	Measurement		
			Scalar quantity	Vector quantity	
People	–	9	0	0	9 (29%)
Things: observational	Microscopic	0	21	0	21(68%)
	Macroscopic	0	0	0	0
Things: instrumental	Microscopic	0	0	0	0
	Macroscopic	1	0	0	1 (3%)
Total		10 (32%)	21 (68%)	0 (0%)	31 (100%)

As shown in Table 4.24 and Table 4.25, topical Themes of People were foregrounded, while Themes of Things were backgrounded in Text A-1 and Text B-1. Within the topical Themes of Things, Themes of instrumental Things had a slightly higher frequency than Themes of observational Things. The topical Themes of People were realized through personal pronouns such as *I, you and he* and nouns such as *volunteers*. Most of these topical Themes were used to organize classroom activities where two roles were involved: a teacher/learner, and a(n) scientist/ experimenter. The role of a teacher/learner typically involved using *I* or *we* in declaratives and *you* in interrogatives to introduce the activities (e.g., *I* in *I want to show you one part of the M.H. here.*). The role of a(n) scientist/experimenter was typically realized through the use of *we* in declaratives and *you* or *anyone/anybody* in interrogatives to invite students' participation in the experiment (e.g., *anybody* in *Now would anybody want to try?*).

The topical Themes of observational Things were *air particles*, which were manipulated through the experimental instruments (e.g., *the air* in *The air is sucked away by the vacuum pump.*). The instrumental Things were the equipment for conducting experiments, such as *vacuum pumps* and *Magdeburg Hemispheres*. The instrumental Things for experiments were manipulated (e.g., *the hemispheres* in *But the hemispheres still could not be pulled apart.*), introduced and elaborated (e.g., *It* in *It is just like a door, which closes or connects to the vacuum pump*). The attribution of measurement in these two texts was minimal. Although scalar quantities of observational Things (i.e., *air pressure*) were found, no quantitative reasoning was identified in the two spoken texts of experiment demonstrations.

By contrast, topical Themes of observational Things were foregrounded, while Themes of instrumental Things and People were backgrounded in Text A-2 (see Table 4.26) and Text B-2 (see Table 4.27). The realizations of the topical Themes of People were similar to those in Text A-1 and Text B-1, though their functions differed slightly. The topical Themes of People in the texts of explanation constructions also involved two roles: a teacher/leaner and a(n) scientist/experimenter. The role of a teacher/learner typically involved using *we* or *I* in declaratives and *you* in interrogatives to introduce the activities (e.g., *I am giving you some guiding questions*) and/or to invite the students' demonstration of cognitive and semiotic abilities (e.g., *I want you to think about it* and *Can you use a complete sentence again?*). It is important to point out that the introduction of activities and the request of cognitive/verbal actions could happen simultaneously in one utterance (e.g., *now we look at question three*). The role of a(n) scientist/experimenter was typically realized through the use of *you* or *we* in declaratives, for example:

So if you have more particles, you have a high gas pressure. [A-2_1_6_3]
We suck out the air inside the M.H. [A-2_1_1_2]

In both examples, the students were portrayed as if they were able to physically manipulate the abstract entities. This differed from the texts of experiment demonstration, where the items being manipulated were experimental instruments.

As for the Themes of instrumental Things, apart from the experimental instruments, another type of instrument was identified in the texts of explanation construction, that is, the medium of presentation. The presentational instruments were used to represent information from other sources, such as *these slides* in *Now actually, these slides represent the long passage on page thirty.*

Another important difference between the texts of explanation construction and those of experiment demonstration was the attribution of measurement. While the attribution of measurement was not prominent in Text A-1 and Text B-1 (both about experiment demonstrations), the attribution of measurement to observational Things was noteworthy in both Text A-2 and Text B-2, contributing to the quantitative reasoning. However, the complexity of the quantitative reasoning varied in these two texts. In Text A-2, the reasoning started with the movement of air particles before it moved to the scalar quantities of air particles (i.e., the amount of air particles and air pressure) and then to the vector quantities of air particles (i.e., air force and net force). During the reasoning about the change of amount after vacuuming, the scalar quantity of People was used to facilitate this process via the use of an analogy. The analogy between the number of air particles and the number of students related the abstract entities to tangible and concrete ones directly observable in the classroom (Jornet & Roth, 2015; Won et al., 2014). The excerpt of this analogy is shown below:

F: *If em if all the students here are particles,* [A-2_1_2_23.1]
and you take a lot of the particles out from the room, [A-2_1_2_23.2]
how many students do you have? [A-2_1_2_23.3]
So the number of air particles… [A-2_1_2_24]
S1: *decrease.* [A-2_1_2_25]

The quantitative reasoning in Text B-2 was less comprehensive than that in Text A-2. Although a similar reasoning process was observed in Text B-2, from the amount of air particles to the size of air pressure to the direction of net force, there was no explicit mention of the vector quantities of air particles (i.e., air force and net force). Thus, the students had to infer that *There is a difference in air pressure* meant there was a net force and that the direction of the net force was inward because the *air pressure outside is larger than that inside*.

Connecting everyday discourse and science discourse is widely regarded helpful to develop students' understanding of scientific knowledge (e.g., deAndrade, Freire, &

Baptista, 2019; Gilbert, Boulter, & Rutherford, 2000). Using analogy is one of the ways to connect everyday knowledge and technical knowledge (Airey &Linder, 2009; Braaten &Windschitl, 2011; Klein &Unsworth, 2014). This process of connection involves both the strategy of unpacking the technical knowledge to more commonsense knowledge (i.e., from the technical meaning to the congruent meaning) and the strategy of repacking the commonsense understanding back to the technical one (i.e., from the congruent meaning to the technical meaning). It is important that both unpacking and re-packing strategies are incorporated so that the students are able to integrate their everyday knowledge in science classrooms and elevate their congruent understanding to a scientific way of thinking and talking. If only the unpacking strategy is adopted, discussing the everyday examples can lead to students' lower achievement in constructing scientific explanations (McNeil & Krajcik, 2008).

4.3.1.3 Theme markedness

This section presents the results of the Theme markedness analysis of the spoken texts. Based on the analytical framework presented in Section 3.4.2, Theme markedness of an independent clause was measured through the choices of the topical and textual Themes. This section presents the findings about inherent and characteristical markedness in textual and interpersonal Themes before reporting the results about topical markedness in topical Themes. The occurrences of Theme choices in the spoken texts in terms of inherent and characteristical markedness are shown in Table 4.28.

Table 4.28 Occurrences of non-topical Themes in the spoken texts

	Inherently & characteristically unmarked	**Only Inherently marked**	**Only Characteristically marked**	**Inherently & characteristically marked**	**Total**
Declaratives	141	93	2	15	251 (74%)
Interrogatives: yes/no	23	13	0	0	36 (11%)
Interrogatives: wh-	16	5	0	1	22 (7%)
Imperatives	9	16	0	3	28 (8%)
Total	189 (56%)	127 (38%)	2 (<1%)	19 (6%)	337 (100%)

The majority of the free clauses in the spoken texts were declaratives (251 instances), followed by yes/no interrogatives (36 instances), imperatives (28 instances), and wh-interrogatives (22 instances). While 56% of the free clauses were inherently and characteristically unmarked, the remaining 44% of them were either inherently or characteristically marked. Inherent marking was the most frequent marked choice (38%), while the least frequent marked choice was characteristically marked alone (less than 1%). It is interesting to notice that the non-topical Themes that were both inherently and characteristically marked (6%) occurred more frequently than those that were only characteristically marked (less than 1%) in most clauses except yes/no interrogatives, where no instances of the former type of marking were identified.

Most inherent markers and characteristical markers were used to establish temporal relations in classroom activities or the sequential relation between events in the explanations. Across the four mood types of free clauses, although inherent and characteristical themancity varied, declaratives were more likely to be marked inherently and characteristically than yes/no interrogatives, WH-interrogatives, and imperatives. Most declaratives were inherently and/or characteristically marked to establish temporal relations between events in the explanations. The only instance of WH- interrogative with an inherently & characteristically marked Theme signaled a discourse move through a hyperTheme (*so finally* in *So finally what is the direction of net force?*). A detailed discussion of hyperThemes and macroThemes is presented in Section 4.3.2.2. The three instances of imperatives were marked inherently and characteristically through the adverbial phrase *and then* to introduce subsequent classroom activities, such as *and then* in *And then we will do the experiment*.

The relatively high occurrence of inherently marked Themes and the predominance of temporal relations can be explained largely by the nature of the data, that is, classroom talks between the teachers and the students. The spoken texts were planned to a certain extent by the teachers through lesson preparation and constructed linearly by the teachers and the students in the classroom. To maintain a clear organisation of the spoken texts appeared to be the main driving force for the frequent use of inherent textual markers, especially those textual markers that expressed temporal relations. Another interesting pattern concerned the use of causal conjunctions, such as *because* and *so*, to reveal the causal relations between the scalar/vector quantities of air particles. For instance, in Text A-2 and Text B-2, quantitative reasonings were established from the number of air particles inside the instrument (e.g., *fewer*), to the size of pressure inside the instrument (e.g., *lower*), and to the comparison between the pressure inside the instrument and the pressure outside (e.g., *lower* versus *higher*). The use of causal conjunctions between the scalar quantities (i.e., amount and pressure) constitute an important component of a quantitative reasoning. However, it is important to point out that using causal conjunctions did not necessarily contribute to the quantitative reasoning. The construction of a logical quantitative reasoning should involve both the identification of relevant scalar/vector quantities, and the establishment of valid causal relations from one scalar/vector quantity to another. Therefore, in the construction of a quantitative reasoning, it is important to consider whether relevant scalar/vector quantities have been identified and whether the causal relations between them have been valid. For instance, in Text A-2, wrong causal relation was assigned to the number of air particles and the size of air pressure by one student (shown as S2):

T: *The number of particles inside the MH decreases.* [A-2_1_3_10]
So will the pressure go up or go down? [A-2_1_3_11]
S2: *Go up.* [A-2_1_3_12]

In this example, although a causal relation was suggested between the number of particles inside the instrument and the size of pressure (all being unmarked Themes), the student did not establish a valid quantitative reasoning that the decrease in the number of particles would cause the decrease in air pressure.

The findings of Theme markedness in the present study support Halliday and Matthiessen’s (2014) observation that the unmarked thematic pattern is highly motivated as the basic means to carry the message, although the marked choices do occur out of contextual pressure. The following paragraphs present the details of the textual Theme choices illustrated with examples.

The clauses that were only inherently marked employed the following markers: (1) conjunctions, (2) continuatives, and (3) combinations of continuatives and conjunctions. Three types of logical relations were identified in the conjunctions: reason (marked by *so* and *because*), addition (marked by *and*) and concession (marked by *but*). The causal conjunctions were closely linked to the reasoning of causal relations between the scalar/vector quantities of air particles in the texts of explanation construction. The quantitative reasoning proceeded from the number of the air particles to the size of gas pressure and then to the size and direction of net force. An example of such reasoning is provided below, with the textual Theme of conjunctions shown in bold:

T: *There are less particles inside,* [A-2_1_5_20.1]
so *they hit the wall less frequently*, [A-2_1_5_20.2]
and *the outward force will be low*. [A-2_1_5_20.3]

The causal conjunctions were also used to justify the procedures in the texts of experiment demonstration. An example of such justification is shown below, with the textual Theme of conjunctions shown in bold:

T: *Our vacuum pump is weaker than his,* [A-1_1_2_26.1]
so *we need to suck for one or two minutes.* [A-1_1_2_26.2]

The additional conjunction *and* was used as an implicit way to link two concepts without specifying the exact relation expressed – for example, simultaneous, temporal or causal relations. Two examples of the additional conjunction used in this way are shown below:

T: ***And*** *this goes on for three times.* [A-2_1_7_10]
And *we will get the final answer that they cannot be separated.* [A-2_1_7_11]

While no clear pattern was observed for the concessional marker *but*, one instance of a problematic usage was noted. This problematic use of *but* is shown below with all the textual Themes highlighted in bold:

T: ***Why, why*** *do you think it will go up?* [A-2_1_3_21]
S2: *Ermm…**because**. ermm, no air inside the MH* [A_1_3_22.1]
but *more air outside the MH* [A-2_1_3_22.2]

In this example, the question asked by the teacher was about the change of air pressure inside the Magdeburg Hemispheres after vacuuming. The aim of this question was to unveil the relation between two scalar quantities: the decrease in the number of air particles led to the decrease in gas pressure. In the student's response, an adversative relation between Clause A-2_1_3_22.1 and Clause A-2_1_3_22.2 was constructed, showing that the student was attempting to compare the scalar quantity, that is, the number of air particles inside M.H. and the number of air particles outside M.H. However, the causal relation targeted by the teacher's question was not validated by the student's answer: the use of *because* appeared to be merely an intuitive response to a why-question. This example suggests that simply using a causal conjunction does not necessarily guarantee a clear understanding or articulation of the causal relation between scientific concepts.

The second way to inherently mark a clause was through continuatives, such as *now*, *okay* and *yes/yeah*. The continuatives in the spoken texts served two main functions: to structure the discourse and to express the speaker's angle on a matter. It is important to point out that these two functions could be performed simultaneously. As a discourse organizer, the continuative *now* signaled a move in the discourse, which could be a shift in interaction type or a transition in teaching stages, teaching phases or moves in a teaching phase. An example of using *now* to signal the shift from monologue to dialogue is shown below:

T: ***Now*** *can you use a complete sentence again?* [A-2_1_4_7]

An example of using *now* to signal the transition from one teaching phase to another one is shown below:

T: ***Now*** *we look at question three.* [A-2_1_4_1]

The continuative *yes/yeah* functioned as an evaluation marker to project the teacher's angle on the topic and to provide feedback on the students' responses. The continuative *okay* served a dual function: as a discourse organizer to check the progress of the topic or to orient the transition in discourse, and as an affirmative marker to show acknowledgement or agreement. An example of using *yes/yeah* as an evaluation marker and using *okay* as a discourse organizer and a signal of transition is shown below:

T: *So the number of the particles...*[A-2_1_2_25]
S1: *Going down* [A-2_1_2_26].
T: *Yeah, the number of particles decreases or goes down.* [A-2_1_2_27]
Okay now we look at question two. [A-2_1_2_28]

In this excerpt from Text A-2, the continuative *yeah* was used in Clause A-2_1_2_27 to affirm the student's answer that the number of particles is *going down*. The continuative *okay* in Clause A-2_1_2_28 signaled a transition of the spoken texts from addressing the first guided question (about the changes in the number of air particles) to the second guided question (about the changes in the size of air pressure).

The third way to inherently mark a Theme was through combinations of continuatives and/or conjunctions. Combinations that only marked a Theme inherently in the spoken texts included *okay and* (one instance), *yes now* (one instance) and *okay now* (11 instances). The combination of a continuative and a conjunction (i.e., *okay and*) and the combination of two conjunctives (i.e. *yes now* and *okay now*) functioned differently. The former was used in the dialogue between the teacher and the facilitator from the Science Learning Circle supporting team to clarify the relation between the change in air pressure and the action of vacuumizing. The dialogue between the teacher and the facilitator where *okay and* occurred is shown below:

F: ***So*** *to decrease the pressure* [A-2_1_6_14.1]
I have to take particles out. [A-2_1_6_14.2]

T: *yes* [A-2_1_6_15]

F: ***Okay and*** *I did that with the vacuum pump.* [A-2_1_6_16]

T: ***Yes****, that's right.* [A-2_1_6_17]

The use of *okay and* signaled a move in the discourse, that is, as a response in dialogue (the function performed by *okay*), and linked the clause structurally to another clause with the semantic relation of addition (the function performed by *and*). This differed from the combination of continuatives *okay now* and *yes now*, which were used in the teacher's monologue to signal a new move within a teaching phase or to signal a transaction to a new teaching phase, for example:

T: ***Okay now*** *this is cause-and-effect one, effect one.* [A-2_1_2_28]
Okay now *we look at question two.* [A-2_1_3_1]

In this example, *okay now* was used both in the end of teaching phase 2 and in the beginning of teaching phase 3 in spoken Text A-2.

There was only one instance of the conjunctive adjunct *finally* identified in the spoken texts to characteristically mark a Theme. Similar to the transitional function of *now*, the use of *finally* signaled a move in the discourse. However, the use of *finally* appeared to be more constrained than the use of *now*, as *finally* signaled the beginning of a particular interaction towards the end of a teaching phase while *now* could signal the beginning of any of those interactions. The example is provided below, with the textual Themes in independent clauses highlighted in bold:

T: ***Finally*** *we get the result.* [A-2_1_5_23]
We can say [A-2_1_5_24.1]
why the MH can't be separated. [A-2_1_5_24.2]

Now *I am giving you some guiding questions* [A-2_1_5_25]
to help you explain the reason or the causes and effects in the explanation. [A-2_1_5_26]

The textual Themes were both inherently and characteristically marked through *so finally*, *and then,* and *now actually*. The teaching stage where the Magdeburg Experiment was explained in Lesson A (Text A-2) is used as an example of the relation between Theme markedness and teaching phases. The combination of a conjunction and a conjunctive adjunct *so finally* was used in the beginning of teaching phase 5 in a WH-interrogative (*So finally what is the direction of net force?*), which was one of the hyperThemes (see details of hyperThemes in Section 5.3.2.1). This combination constructed a temporal causal relation between two scalar quantities of air particles: the direction of net force (in teaching phase 5) and the gas pressure (in teaching phase 4). Another combination of a conjunction and an adjunctive adjunct *and then* was used in the middle of teaching phase 7 to elaborate the explanation text for the Magdeburg Hemisphere experiment shown on a slide. The relation constructed by *and then* was temporal, which corresponded to the visual elements, such as the use of words *first event* and *second event*, the layout of the texts within two boxes, and the use of an arrow pointing from one box to another. This is one of the examples where the spoken texts interacted with the visuals on the slides to co-construct the meaning (see Section 5.6 for further discussion).

The spoken texts and the slide (see Figure 4.7) are reproduced below, with the textual Themes highlighted in bold:

T: *This is the cause.* [A_1_7_7]
This is the effect. [A_1_7_8]
And then*, in the second box this effect will become the cause of another effect.* [A_1_7_9]

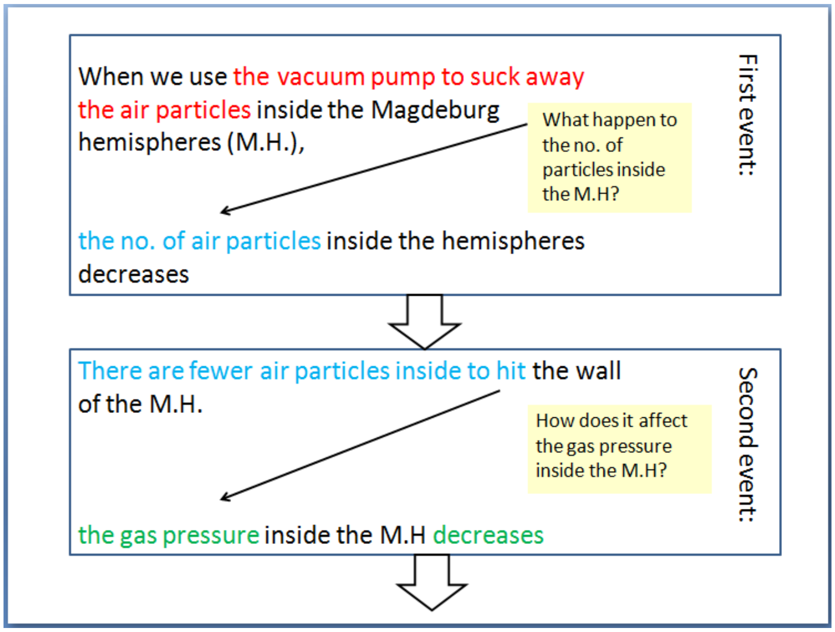


Figure 4.7 The slide presenting the explanation for the Magdeburg Hemisphere experiment

As for topical markedness, the occurrences of topical Themes in terms of markedness in the spoken texts are shown in Table 4.29. The dominating choices were unmarked topical Themes, with only 24 instances of marked topical Themes. Topical markedness was heavily influenced by mood types because all the marked topical Themes were found in declaratives. The semantic categories of the unmarked topical Themes included People (e.g., *we*, *I*, and *you*) and Things (e.g., *the pressure*, *the inward force*, and *these slides*). These unmarked choices contributed to the information flow from the investigators (i.e., the teacher and the students) to the scientific items to be studied (i.e., air particles and their physical properties), with an increasing level of abstractness and complexity.

Table 4.29 Occurrences of topical Themes in the spoken texts

	Topically unmarked	Topically marked	Total
Declaratives	227	24	251
Interrogatives: yes/no	36	0	36
Interrogatives: wh-	22	0	22
Imperatives	28	0	28
Total	313 (93%)	24 (7%)	337 (100%)

The marking of the topical Themes in declaratives were achieved by circumstantial adjuncts (17 instances) or complements (seven instances). The circumstantial adjuncts had to do with time (eight instances) and place (nine instances). While the circumstantial adjuncts of time pointed to time in reality, focusing on the present moment, the circumstantial adjuncts of place were used for actual locations and abstract ones. Three examples of circumstantial adjuncts are shown below, with the textual Themes bolded, and the topical Themes underlined:

T: ***Okay*** <u>*today*</u> *we are going to use the temporal explanation to explain why.* [B-2_1_1_2]
T: ***Now*** <u>*in emm many science experiments like this*</u>*, we have a cause.* [A-2_1_1_1]
T: ***Now*** <u>*here*</u> *we use a special word compare.* [A-2_1_4_3]

In Clause B-2_1_1_2, the circumstantial adjuncts *today* pointed to a time in reality when the teacher oriented the students to the construction of a scientific explanation (*Okay today we are going to use the temporal explanation to explain why*). The circumstantial adjuncts *in emm many science experiments like this* in Clause A-2_1_1_1 and *here* in Clause A-2_1_4_3 referred to either an abstract location (*in emm many sciecnce experiments like this*) or an actual location in the classroom (*here*).

The complements marking topical Themes included the semantic types of actions, semiotic, and syntactic items. The complements of actions were the material processes of air particles or the changes in the scalar quantities of air particles. The complements of semiotic items were locutions mentioned in the previous clauses. The complements of syntactic items were three instances of *it* in the sentence structure *it is difficult to do something*, where *it* helped to foreground the complement *difficult.* The examples of these complements as marked topical Themes are shown below, with the textual Themes bolded, and the topical Themes underlined:

T: ***And then*** <u>*decreases the air pressure inside the hemispheres, this*</u> *is C.* [B-2_1_6_5]
T: ***Now*** <u>*this question*</u> *I will speak in a simpler way*. [A-2_1_3_3]

T: ***So*** *<u>it</u> is difficult to pull the hemispheres apart.* [B-2_1_7_4]

The main motivation for such marked choices appeared to come from the textual and contextual environments. For instance, the nominal group *this question* in Clause A-2_1_3_3 was selected to highlight the question mentioned in the previous textual environment, which is shown below:

T: ***Okay now*** *<u>we</u> look at question two.* [A-2_1_3_1]
<u>How</u> does it affect the gas pressure inside? [A-2_1_3_2]
Now *<u>this question</u> I will speak in a simpler way.* [A-2_1_3_3]
Will the gas pressure increase or decrease inside the MH? [A-2_1_3_4]

In this example, the marked choice of *this question* rather than the unmarked one of *I* emphasized the hyperTheme in teaching phase 3, the second guiding question of how the decrease in the number of air particles would affect the gas pressure inside the MH. The link to the textual environment can be interpreted at two levels: the local textual environment and the global textual environment. Locally, by placing *this question* in the initial position of a clause, the speaker chose to orient the listeners' attention to this question, the content of which was mentioned in the proceeding clause A-2_1_3_2, *How does it affect the gas pressure inside?* and in the subsequent clause A-2_1_3_4, *Will the gas pressure increase or decrease inside the MH?* Globally, the marked choice of *this question* referred to one of the hyperThemes in the teaching stage, that is, the second guiding question, *question two.* This helped to strengthen the discourse structure, which organized the text according to a macroTheme and four hyperThemes, with the macroTheme signaling the start of a teaching stage and each hyperTheme corresponding to the start of a teaching phase (see Section 4.3.2.2 for details of macroThemes and hyperThemes in the spoken texts).

The motivation for marked topical Theme choices could also come from the context outside the textual environment, that is, cross-modal motivation. As shown in Clause B-2_1_6_5, the verbal phrase *decreases the air pressure inside the hemispheres* shared the topical Theme position with the pronoun *this*, as the content of event C, which was shown as part of the written text on a slide (see Figure 4.8). In this way, this marked choice of topical Theme highlighted the relation between event C (i.e., the decrease of air pressure inside the MH) and event B (i.e., the decrease of the number of air particles) as well as the relation between event C and event D (i.e., comparison between the air pressure inside and outside). This marked topical Theme also located event C within the schematic structure of explanation as a part of two explanation sequences, event B to event C, and event C to event D. The explanation sequence from event B to event C was that the decrease of the number of air particles led to the decrease of air pressure inside the M.H. The explanation sequence from event C to event D was that the decrease of air pressure inside the M.H resulted in a difference between air pressure inside and outside M.H. Within the casual chain, the function of event C was dual: as the consequence of event B and as the cause of event D.

The relations between events and the relations between explanation sequences were further accentuated by visual cues, such as the repeated use of color, the topological arrangement of the text, and the use of arrows. For instance, the same color of purple was used to represent event B in the first explanation sequence (*When we use the vacuum pump to suck away the air particles inside the Magdeburg hemispheres (M.H), the number of air particles inside the hemispheres decreases.*) and in the second explanation sequence (*The smaller number of air particles to hit the wall of the hemispheres decreases the air pressure inside the M.H.*). This text followed the traditional topological arrangement of a written text, where readers are expected to read from left to right and from top to bottom. However, this text was segmented into three parts, each showing an explanation sequence. One explanation sequence was separated from the next one by some blank space, while the sequential progression from one explanation sequence to the subsequent one was represented through the red arrows. However, it is important to point out that the use of color in the third explanation sequence (*The air pressure inside the M.H decreases so the air pressure inside the M.H becomes lower than the gas pressure outside*) was not consistent with the previous explanation sequences. Specifically, only the first four words in event C in the third explanation sequence were shown in green to coordinate with event C in the second explanation sequence. The other words in event C in the third explanation sequence were shown in black, which disrupted the correspondence between colors and events. Another disruption in the third explanation sequence was the use of red to represent event D. This choice of color was problematic because it repeated the color of event A. Using the same color to represent both event A and event D could lead the students to misinterpret these two different events as the one and same event.

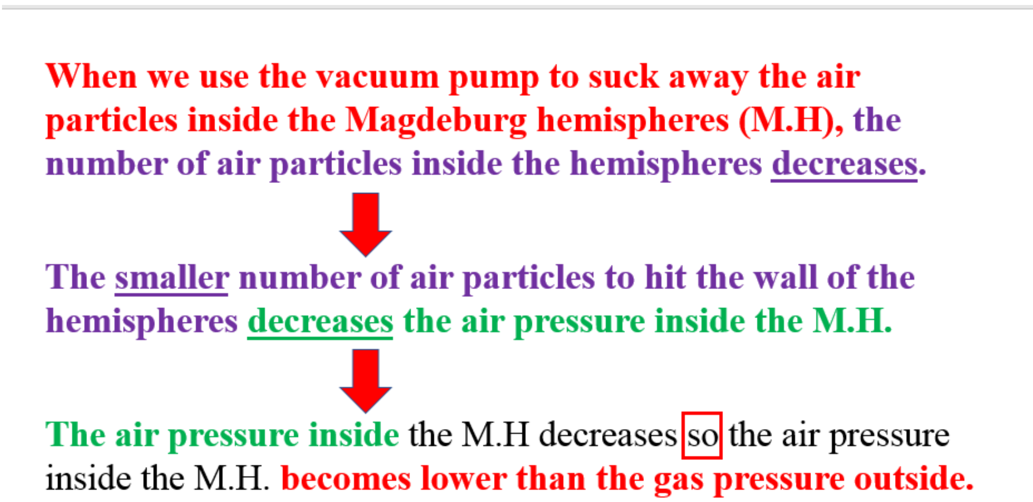


Figure 4.8 Written text shown on the slide when Clause B-2_1_6_5 was uttered

Another important aspect to consider in Theme markedness is the "quantum of thematicity" in a clause (Halliday & Matthiessen, 2014, p.110). The quantum of thematicity is the thematic potential of a clause, ranging from minimal, when the Theme is an unmarked choice, to maximal, when the clause is marked topically, inherently, and characteristically. Since the unmarked choices of Themes and the variations of marked choices have been presented and discussed, the quantum of thematicity has been partly addressed. However, what is still missing is the maximal thematic potential of a clause, that is, how a clause can be marked through the combination of topically, inherently and characteristically marked Themes.

Table 4.30 presents the occurrences of the combined marked Themes in Text A-1, Text B-1, Text A-2, and Text B-2.

Table 4.30 Combinations of topically, inherently, and characteristically marked Themes

	T + I	T + C	I + C	T + I + C
Text A-1	3	0	3	0
Text B-1	0	0	4	0
Text A-2	4	0	4	1
Text B-2	4	0	11	2
Total	11	0	22	3

Note. T = topically marked; I = inherently marked; C = characteristically marked

Among the four types of combinations, combinations of inherently and characteristically marked Themes occurred most frequently (22 instances), followed by combinations of topically and inherently marked Themes (11 instances) and combinations of topically, inherently and characteristically marked Themes (three instances). No combination of topically and characteristically marked Themes was found in the four texts. One important finding was that the marked topical Themes tended to co-occur with inherently/characteristically textual markers (i.e., *now*, *okay*, *so* and *and then*). This finding differed from Halliday and Matthiessen's (2014) observation that marked topical Themes appear less frequently when there is an inherently or characteristically marked Theme in the clause (p. 111). As pointed out by Martin (1993), "the relative selective nature of thematic choices" provides the text's angle on its field in relation to its social purpose (p. 267).

The explanation for the co-occurrence of marked topical Themes and inherently/characteristically marked textual Themes lies in the nature of the data analyzed in this thesis. Although the spoken texts were classroom talks between the teachers and the students, they were clearly organized based on the macroTheme and hyperThemes (see Section 4.3.2.2 for details). These spoken texts unfolded with the frequent use of inherently textual Themes to signal the moves in the discourse. When an element needed to be highlighted through a marked topical Theme, it was usually a move in the discourse. This finding shows the heavy dependence of Themes in the spoken texts on the textual environment and the context where they were produced (e.g., Taboada &Lavid, 2003)

4.3.2 Thematic structure at the discourse level

While Section 4.3.1 presents the findings about Themes at the clausal level, this section presents the discourse features of Themes, that is, thematic progression and macro/hyperThemes. The results of the thematic progression analysis are presented in Section 4.3.2.1, and the findings about macroThemes and hyperThemes are presented in Section 4.3.2.2.

4.3.2.1 Thematic progression

The results of the thematic progression (TP) analysis of the four spoken texts are summarized in Table 4.31, Table 4.32,

Table 4.33, and Table 4.34 respectively. Each table shows the TP patterns of a text according to three parameters: TP paths, Theme sources, and the contingency of progression. The reason for presenting the TP analysis of each text separately rather than combining the TP results of four texts in one table is that these four texts differed in either their functions or their contexts of production. Examining the TP patterns of each text separately enabled an investigation into the distinct TP patterns in each text and the impacts of contextual factors.

Table 4.31 Thematic progression in spoken Text A-1 (n=93)

Constant (Themic)				**Linear (Rhemic)**				**Complex**		**Derived**	
Simple		Multiple		Simple		Multiple		Multiple			
Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	New	Synt.
32	22	0	0	7	2	0	0	1	0	28	1
Total = 54 (58%)				Total = 9 (10%)				Total = 1 (1%)		Total = 29 (31%)	

Table 4.32 Thematic progression in spoken Text B-1 (n=32)

Constant (Themic)				**Linear (Rhemic)**				**Complex**		**Derived**	
Simple		Multiple		Simple		Multiple		Multiple			
Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	New	Synt.
13	5	0	0	3	1	0	0	0	0	9	1
Total = 18 (56%)				Total = 4 (13%)				Total = 0 (0%)		Total = 10 (31%)	

Table 4.33 Thematic progression in spoken Text A-2 (n=171)

Constant (Themic)				Linear (Rhemic)				Complex		Derived	
Simple		Multiple		Simple		Multiple		Multiple			
Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	New	Synt.
64	45	0	1	18	8	2	2	4	0	21	6
Total = 110 (64%)				Total = 30 (18%)				Total = 4 (2%)		Total = 27 (16%)	

Table 4.34 Thematic progression in spoken Text B-2 (n=57)

Constant (Themic)				Linear (Rhemic)				Complex		Derived	
Simple		Multiple		Simple		Multiple		Multiple			
Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	Cont.	Gap.	New	Synt.
6	8	0	1	13	1	2	1	1	0	17	6
Total = 15 (26%)				Total = 18 (32%)				Total = 1 (2%)		Total = 23 (40%)	

Both Text A-1 and Text B-1 were produced during experiment demonstrations. Although they were produced in two lessons by different speakers and varied in length, the TP patterns were similar. The TP paths in both texts were predominately constant (58% and 56%, respectively), followed by linear (10% and 13%, respectively), derived (31% for both texts), and complex (1% and 0, respectively) paths. The mix of constant and linear progression paths had to do with the semantic types of People and instruments. The semantic type of People mainly included the teachers and students in the classrooms, with six exceptions in Text B-1, where the topical Themes of People referred to the protagonists of the story in 1654, when the first Magdeburg Hemisphere experiment was conducted. The only instance of a complex TP path of semiotic topical Themes was found in Text A-1, used by the teacher to positively evaluate the fact that the students were self-learning the contents (*that* in *Alright then that's good.*).

It is also interesting to examine the derived TP paths, where no thematic progression was observed. These paths helped to unveil where and how the interruptions occurred, as well as what consequences they might bring. The interruptions were either from new information or from syntactic items. The occurrence of syntactic items was less frequent than that of new information. The syntactic items were mainly existential there, such as *there* in *There is a valve here*. The interruptions from new information pointed to three types of information sources outside the text. The first new information source was the context where the spoken texts were produced. This type of information was mostly found in imperatives organizing classroom activities, such as *Try your best to pull it apart*. The second new information source was the students' prior knowledge, which included both commonsense and technical knowledge. This type of information was typically presented through interrogatives, such as *Where did you see it?* The third new information source was cross-modal reference, where the spoken texts were used to elaborate the message from other modes, such as images on slides. The interactions between the spoken texts and the images on slides are discussed in detail in Chapter 5.

The sources of Themes fell predominantly in the "simple" category in both texts with only one exception in Text A-1. The predominance of simple Theme sources could be due to the fact that most of the topical Themes were about People or instruments, which did not need to be rephrased (e.g., *we*, *you*, and *our vacuum pump*). This finding is consistent with Taboada and Lavid's (2003) observation that in spoken texts scheduling meetings, simple Theme sources occurred more frequently than multiple Theme sources. The only instance of multiple Theme sources co-occurred with the complex TP path of the topical Theme of semiotic items (*Alright then that's good*.). The topical Theme *that* can be traced back to both the Theme and Rheme of the proceeding clause (*Okay if you have seen the video, you will see it when you are self-learning.*). Such a co-occurrence suggested the power of generalization and abstraction in semiotic items.

As for the continuity of thematic progression, the type of contiguous progression was more frequent than the type of gapped progression in both texts. However, the span of each contiguous progression was not long, from two to three clauses on average. The longest contiguous progression identified in Text A-1 and Text B-1 spanned seven clauses. The extract, where the longest contiguous progression occurred, is shown below with the textual Themes bolded, interpersonal Themes wave underlined, and the topical Themes underlined:

T: ***Now before*** *we start*, [A-1_1_2_36.1]

I want to show you one part of the M.H here. [A-1_1_2_36.2]

Do you see it? [A-1_1_2_37]

We call it a valve, V-A-L-V-E, valve of the M.H. [A-1_1_2_38]

It is just like a door, which closes or connects to the vacuum pump. [A-1_1_2_39]

Now *it is open* [A-1_1_2_40.1]

so it is connected to the vacuum pump. [A-1_1_2_40.2]

We are sucking out the air particles inside the M.H. [A-1_1_2_41]

So before *we start*, [A-1_1_2_42.1]

We should close this valve, [A-1_1_2_42.2]

And then *we can turn on the vacuum pump.* [A-1_1_2_43]

Okay now are ***you*** *ready for it?* [A-1_1_2_44]

S: *Yes.* [A-1_1_2_45]

T: *Be careful.* [A-1_1_2_46]

Don't hurt yourself. [A-1_1_2_47]

In this extract from Text A-1, the topical Theme of *I* in Clause A-1_1_2_36.2 progressed constantly from the topical Theme of *we* in its immediately preceding clause. The topical Themes of People (i.e., *we* and *you*) maintained the simple constant progression pattern till Clause A-1_1_2_39, where the topical Theme shifted to the component of an instrument (i.e. *it*, referring to the valve). This resulted in the change of the TP path from constant to linear, and the picking up of the topical Theme *it* from the Rheme of its proceeding clause, Clause A-1_1_2_38. The simple constant pattern continued from Clause A-1_1_2_39 to Clause A-1_1_2_40.2], where the topical Themes in these three clauses were *it*, referring to the valve. This simple contiguous progression with a mix of constant and linear TP paths was disrupted when the speaker shifted from the teacher to the students. With the teacher's invitation in Clause A-1_1_2_44 (*Okay now are you ready for it?*), the answer *yes* introduced the students' perspectives into this text. In the next two clauses, the progression was interrupted by the imperatives, which activated the field of activity that was outside the spoken text itself.

Although both Text A-2 and Text B-2 were produced in the construction of spoken explanations, the TP patterns varied significantly with respect to TP paths. For this reason, the distributions of TP paths in Text A-2 and Text B-2 are elaborated and discussed separately. In Text A-2, constant paths (64%) were the predominant type of TP paths, followed by linear (18%), derived (16%) and complex (2%) ones. The mix of constant and linear progression paths mainly involved the semantic types of People, observational Things and the scalar/vector quantities of observational Things. All the topical Themes of People referred to the teacher and the students in the classroom. The observational Things were air particles, whose actions could not be directly perceived by naked eyes. The scalar quantities of air particles consisted of amount and pressure, while the vector quantities were force and net force. The mix of constant and linear progression paths related air particles and their scalar and vector quantities: from the movement of air particles, to the quantitative reasoning from amount to pressure, to force and finally to net force. The four clauses with complex TP paths comprised interrogatives (e.g., *Is that right?*) and declaratives (e.g., *Yeah, that's right.*) that occurred in pairs. The topical Themes were locutions referring to the previous utterance from the other speaker. The topical Themes of locutions in complex TP paths were used by the teacher and the facilitator to check and confirm their understandings of the quantitative reasoning.

When no TP progression was observed, the interruptions were either from new information or from syntactic items. Similar to Text A-1 and Text B-1, the interruptions from new information in Text A-2 pointed to three types of information sources outside the text itself: the classroom context, students' prior knowledge, and cross-modal references. However, the information sources in Text A-2 showed more variations than those in Text A-1 and Text B-1. While the information source of classroom contexts in Text A-1 and Text B-1 was found in imperatives that demanded students' actions in conducting the experiment, this type of information source in Text A-2 was found in imperatives that demanded not only physical actions (i.e., *show*) but also cognitive skills (i.e., *look*, *compare* and *think*) and language proficiency (i.e., *try again* to rephrase the explanation). The information source of prior knowledge in Text A-2 differed from that in Text A-1 and Text B-1 in that while the prior knowledge in the texts of experiment demonstration (i.e., Text A-1 and Text B-1) was commonsense knowledge related to the students' out-of-school everyday lives, the prior knowledge in Text A-2 was technical knowledge developed in previous science lessons. The cross-modal information source of topical Themes occurred more frequently in Text A-2 (six instances) than in Text A-1 (two instances) and Text B-1 (zero instance). The information that the spoken texts elaborated differed in that while Text A-1 was used to elaborate the experiment and the experimental instruments, Text A-2 was used to crystalize the causal chain in the explanation. The interactions between spoken texts and the images on slides are discussed in detail in Chapter 5. Similar to Text A-1 and Text B-1, interruptions of TP progression from syntactic items occurred less frequently than the introduction of new information in Text A-2. While the syntactic items in Text A-1 and Text B-1 were used to locate the components of the instrument (e.g., *there* in *There is a valve*), the syntactic items in Text A-2 mainly functioned to compare scalar quantities (e.g., *there* in *And there are more particles outside.*).

The distributions of TP paths in Text B-2 differed significantly from those in Text A-2. The most prominent type of TP path in Text B-2 was the derived path (40%), followed by linear (32%), constant (26%), and complex (2%) paths. The prominence of the derived TP paths meant that compared with Text A-2, there were more interruptions of thematic progression in Text B-2. The interruptions can be attributed to both new information and syntactic items. Although three types of new information sources were identified in both Text A-2 and Text B-2, Text B-2 had less variation in classroom contexts. While classroom contexts in Text A-2 ranged from physical actions to cognitive skills and language proficiency, those in Text B-2 only involved cognitive skills (e.g., *look*, *think* and *compare*). As for the second type of information source, students' prior knowledge, technical knowledge was prominent in both Text A-2 and Text B-2. The major contributor to the salience of interruptions in Text B-2 was actually the third type of new information, that is, cross-modal references. The frequent use of cross-modal references in Text B-2 lent the semiotic labor to other semiotic resources, in this case, the contents shown on slides. Therefore, comprehension of technical knowledge here relied on both the ability to trace the development of the spoken text itself and the capability to identify the cross-modal links to the visuals. How the multimodal resources were linked and how the meanings interacted and multiplied are discussed in detail in Chapter 5. As for the interruptions from syntactic items, they were slightly more frequent in Text B-2 than Text A-2 (accounting for 26 % and 22% of the overall interruptions, respectively). The syntactic items in Text B-2 functioned similarly as those in Text A-2 to compare scalar quantities (e.g., *there* in *So there is a difference in air pressure.*).

Similar to Text A-2, the mix of constant and linear TP paths in Text B-2 mainly involved People, observational Things and the scalar/vector quantities of observational Things. Like Text A-2, the People included the teachers and their students, and the observational Things were air particles. However, the quantitative reasoning concerning scalar/vector quantities differed between Text A-2 and Text B-2. While the quantitative reasoning in Text A-2 proceeded from the scalar quantities of amount, to pressure, and to the vector quantities of force and net force, the quantitative reasoning in Text B-2 only involved scalar quantities and proceeded from amount to pressure. This difference suggested that the quantitative reasoning in Text A-2 was more complex than that in Text B-2. The topical Theme of the only clause with a complex TP path in Text B-2 was semiotic: locution. The topical Theme of locution, *that*, referred to the previous clause to elaborate the interpretation of the phenomenon being observed (*That means there is a difference in air pressure.*).

As for the Theme sources, simple Theme sources predominated in both Text A-2 and Text B-2. The simple Theme sources were People, air particles and their scalar or vector quantities. These results suggest that simple Theme sources tend to be the preferred choice in spoken texts, such as classroom talks and meeting scheduling dialogues (Taboada & Lavid, 2003). Despite the predominance of simple Theme sources, there were 14 instances of multiple Theme sources in the two texts of explanation construction (Text A-2 and Text B-2). Multiple Theme sources can be categorized as integration (where the topical Theme is an integration of previous Themes and/or Rhemes) or separation (where the topical Theme derives from part of the previous Theme or Rheme). While only instances of multiple integration were found in Text A-1 and Text B-1, instances of both multiple integration and multiple separation were identified in Text A-2 and Text B-2. With only one exception, the multiple integrations co-occurred with the complex TP paths of semiotic topical Themes, such as *that* in *Yes, that's right.* The only exception was the use of *this question* in *Now this question I will speak in a simpler way*, where the topical Theme *this question* progressed linearly from the Rheme of a previous clause. All the multiple separations progressed from part of the Rheme of a previous clause. An example of multiple separation is presented below, with the textual Themes bolded and the topical Themes underlined:

F: ***Okay and*** *I did that with the vacuum pump.* [A-2_1_6_16]
T: ***Yes*** *that's right.* [A-2_1_6_17]
F: ***So*** *the vacuum pump draws out all the particles.* [A-2_1_6_18]

In this example, the topical Theme in Clause A-2_1_6_18, *the vacuum pump,* was picked up from the Rheme of Clause A-2_1_6_16, *did that with the vacuum pump*. While the Rheme of Clause A-2_1_6_16 narrated the action of suction by means of the vacuum pump, the topical Theme in Clause A-2_1_6_18 concerned only the means of this action (*vacuum pump*).

As for the continuity of thematic progression, contiguous progression was more frequent than gapped progression in both Text A-2 and Text B-2, a pattern similar to that found in Text A-1 and Text B-1. However, the span of each contiguous progression was about four clauses and was longer than that found in the two spoken texts of experiment demonstration (Text A-1 and Text B-1). Most of these contiguous progressions were found in dialogues between the teachers and the students to co-construct quantitative reasoning. One example of such co-construction of quantitative reasoning is shown below:

T: *There are less particles inside,* [A-2_1_3_24.1]

so *will they hit the wall more frequently or less frequently?* [A-2_1_3_24.2]

Ss: *Less frequently*. [A-2_1_3_25]

T: *Yes less frequently*. [A-2_1_3_26]

So *will the pressure be higher or lower?* [A-2_1_3_27]

S2: *Lower* [A-2_1_3_28]

T: ***Now*** *this time you are right.* [A-2_1_3_29]

In this example, the topical Theme of air particles progressed contiguously from the Rheme of Clause A-2_1_3_24.1 to the topical Theme of Clause A-2_1_3_28, where the elliptical topical Theme was air pressure, the scalar quantity of air particles. In this short excerpt, the quantitative reasoning proceeded from the amount of air particles to the size of air pressure.

4.3.2.2 HyperThemes and macroThemes

While no hyperThemes or macroThemes were found in the spoken texts of experiment demonstration (i.e., Text A-1 and Text B-1), both types of Themes were identified in the two spoken texts of explanation construction (i.e., Text A-2 and Text B-2).

Text A-2 had a macroTheme and four hyperThemes, which were used to organize the classroom talks around four guiding questions, each corresponding to an explanation sequence. The macroTheme (*we are asking you some guiding questions*) was stated after an introduction of the schematic structure of an explanation (phenomenon identification ^ explanation sequences). The macroTheme was presented before assigning the four hyperThemes, which were introduced through four guiding questions. Each hyperTheme oriented to the construction of an explanation sequence in the written explanation text (Text A1). The macroThemes and hyperThemes are listed below:

MacroTheme	*We are asking you some guiding questions.*
HyperTheme 1	*Number one, now think about it.*
HyperTheme 2	*Okay, now we look at question two.*
HyperTheme 3	*Now we look at question three.*
HyperTheme 4	*So finally what is the direction of net force?*

Similar to Text A-2, Text B-2 also had one macroTheme and four hyperThemes, each hyperTheme corresponding to an explanation sequence in the written explanation text (i.e., Text B1). The macroTheme was introduced after presenting the schematic structure of explanations on a slide (phenomena identification ^ explanation sequences), where the target phenomenon was identified for the students, and the explanation sequences were left for them to fill in. Different from the use of macroThemes and hyperThemes in Text A-2 as classroom activity organizers, the macroThemes and hyperThemes in Text B-2 served the function of orienting students' attention to the slideshow. This difference occurred because while the teacher in Lesson A chose to co-construct the explanation sequences through dialogues before presenting them on a slide, the teacher in Lesson B started by making direct references to the written text presented on the slide.

Apart from the macroThemes and hyperThemes identified above, Text-2 also had three hyperNews summarizing local text segments (each corresponding to an explanation sequence) and a macroNew summarizing the whole spoken text (corresponding to the written explanation text, Text B1). The macroTheme, hyperThemes, macroNew, and hyperNews are presented below:

MacroTheme	*Okay now we are going to use the temporal explanation, A to B, B to C, C to D, and D to E to explain what happened, okay?*
HyperTheme 1	*Okay first thing is cause.*
HyperNew 1	*And then this is A to B.*
HyperTheme 2	*And then take a look at B.*
HyperNew 2	*Okay A to B, B to C.*

HyperTheme 3	*And then another C.*
HyperNew 3	*C to D*
HyperTheme 4	*And then next part, the D part is because the air pressure inside is smaller than the pressure outside.*
MacroNew	*Okay you can see the sequence, A to B, B to C, C to D and D to E.*

4.3.3 The schematic structures of spoken texts

Based on the thematic features in the four spoken texts, the schematic structures of the spoken texts were identified. The spoken texts of experiment demonstration (Text A-1 and Text B-1) and the spoken texts of explanation construction (Text A-2 and Text B-2) adopted different schematic structures. The schematic structure of the spoken texts of experiment demonstration comprised two obligatory stages: Experiment Introduction ^ Experiment Demonstrations. These two spoken texts started with an introduction to the experiment, such as the experimental instruments or the background of this experiment. The introduction to the experiment was followed by the demonstration of the experiment, where one or two groups of students were invited to perform the experiments on the stage with instructions from the teachers. The typical patterns of Theme selection in the spoken texts of experiment demonstration are summarized in relation to the schematic structure of the explanations in Table 4.35.

Table 4.35 Typical patterns of Themes and the schematic structure of the spoken texts of experiment demonstration (Text A-1 and Text B-1)

Schematic structure	**Experiment Introduction**	**Experiment Demonstration**
Relations in textual Themes	Temporal	Temporal; Condition
Semantic types of topical Themes	People; Circumstances; Instrumental Things	People; Actions
Theme markedness	Topically mainly unmarked; More inherently/characteristically unmarked Themes than marked ones	
Thematic progression	Simple Themes; A mix of constant and linear TP path, with interruptions from new information or syntactic items; Contiguous and gapped	
Hyper/macro-Themes	N/A	

The stage of Experiment introduction typically involved textual Themes showing temporal relations and topical Themes of People, Circumstances and instrumental Things. The stage of Experiment demonstration had textual Themes showing temporal and conditional relations, as well as topical Themes of People and Actions. The topical Themes in both stages were mainly unmarked, and there were more inherently /characteristically marked Themes than unmarked ones. The thematic progression patterns were similar in both stages: simple Themes progressed through a mix of constant and linear TP paths with interruptions from new information or syntactic items. Both contiguous progressions and gapped ones were identified. Neither hyperThemes nor macroTheme were found in the spoken texts of experiment demonstration.

The schematic structure of the spoken texts of explanation construction (i.e., Text A-2 and Text B-2) comprised three obligatory stages: Phenomenon Identification ^ Explanation Sequences Construction ^ Coda. These spoken texts explained a phenomenon typically by first identifying the phenomenon, including both the experiment condition and the phenomenon that could be observed. This was then followed by the stage of Explanation Sequences Construction, where four explanation sequences were formed through the teacher-student interactions. In the final stage of Coda, both the identification of phenomenon and the explanation sequences were reviewed and presented as written texts to explain the experiment (Text A1 and Text B1). The typical patterns of Theme selection in the spoken texts of explanation construction are summarized in relation to the schematic structure of the explanations in

Table 4.36.

Table 4.36 Typical patterns of Themes and the schematic structure of the spoken texts about explanation constructions (Text A-2 and Text B-2)

Schematic structure	Phenomenon Identification	Explanation Sequences Construction	Coda
Relations in textual Themes	Temporal	Temporal; Condition; Cause	Temporal; Cause
Semantic types of topical Themes	People; Actions; Semiotic; Circumstances	People; Actions; Semiotic; Circumstances; Observational Things with scalar/vector quantities;	People; Semiotic; Observational Things with scalar/vector quantities
Theme markedness	mainly topically unmarked; More inherently/characteristically marked Themes than unmarked ones		
Thematic progression	More simple Themes than multiple Themes; A mix of constant and linear TP paths, with interruptions from new information or syntactic items; Contiguous and gapped		
Hyper-/macro-Themes	N/A	MacroThemes HyperThemes (Hypernews)	(MacroNews)

The stage of Phenomenon Identification had textual Themes showing temporal relations and topical Themes of People, Actions, Semiotic items and Circumstances. Both the textual Themes and the topical Themes showed the greatest variation in the second stage, Explanation Sequences Construction. The relations of the textual Themes found in this stage were temporal, conditional, and causal ones. The semantic types of topical Themes included People, Actions, Semiotic items, Circumstances, and Observational Things with scalar or vector quantities. In the final stage of Coda, textual Themes showing either temporal or causal relations were found. The topical Themes found in this stage belonged to the semantic types of People, Semiotic and Observational Things with scalar or vector quantities. The patterns of Theme markedness and thematic progression were similar in these three stages. As for Theme markedness, while the majority of the topical Themes were unmarked, there were more inherently/characteristically marked Themes than unmarked ones. As for thematic progression, more simple Themes were identified than multiple Themes. These Themes progressed through a mix of constant and linear TP paths, with occasional interruptions from the insertion of new information or syntactic items. Thematic progression was contiguous or gapped. Apart from the observed differences in textual Themes and topical Themes, these three stages also differed in hyperThemes and macroThemes.

While no hyperThemes or macroThemes were found in the stage of Phenomenon Identification, both hyperThemes and macroThemes were presented in the stage of Explanation Sequences Construction. HyperNews were also found in this stage to summarize the local text. The optional structure of macroNew was used in the stage of Coda to summarize the whole text.

The spoken texts about experiment demonstrations are similar to the written texts of a "demonstration genre" (Christie & Derewianka, 2008, p. 158), which document the well-established procedures of a scientific experiment. Both demonstration texts establish the issue to be investigated and propose a series of steps to be followed in conducting the experiments. This is reflected in the choices of textual Themes of Condition and Temporal (to clarify the chorological order of steps), and of topical Themes about People, Actions, Instrumental things and Circumstances (to provide an account of what should be done to conduct the experiment). Therefore, the relations in textual Themes and the semantic categories of topical Themes could be used as measures for a well-established demonstration text.

The major differences between the experiment demonstration texts and the explanation construction texts in terms of thematic patterns are: textual Themes, topical Themes, and hyper-/macro-Themes. The textual Themes in explanation construction texts were used to establish Causal relations in addition to Temporal and Condition relations, whereas the textual Themes in experiment demonstration texts only created the latter two relations. Constant reference to the causal relations between events, in which textual Themes played the primary role, proved illuminating to successful quantitative reasoning from one variable to another one (e.g., from the decrease in the number of air molecules to the decrease in air pressure). The topical Themes in explanation construction texts covered a wide range of semantic categories: People, Actions, Semiotic, Circumstances and Observational Things with scalar/vector quantities. Among these semantic categories, Semiotic and Observational Things with scalar/vector quantities were characteristic for the topical Themes in the explanation construction texts. The Semiotic topical Themes revealed the constant co-construction of knowledge between teachers and students through questions (e.g., *Now this question …*), answers (e.g., *the cause is…*), and evaluations (e.g., *Yes good answer)*. The topical Themes about Observational Things with scalar/vector quantities formed an indispensable constituent to the quantitative reasoning by providing names of the quantitative variables (e.g., *the number of particles*, *air pressure,* and *net force*). The presence of both hyperThemes and macroThemes in the explanation construction texts can be explained by the insufficiency of textual Themes to establish the intricate logical relations involved in the texts. While textual Themes create relations between clauses, hyperThemes and macroThemes organize the clauses and their relations hierarchically in a text. Therefore, it is suggested to highlight those three thematic features (i.e., textual Themes, topical Themes, and hyper-/macro- Themes) in spoken texts related to explanation construction.

4.4 Summary of Chapter 4

This chapter reports the results of thematic patterns in the written and the spoken texts. The thematic patterns were examined at both clausal and discoursal levels. At the clausal level, the thematic features of metafuntional types, semantic types of topical Themes and Theme markedness were examined. Specifically, six semantic types of topical Themes were identified in the spoken texts, while only three types (i.e., People, Things, and Syntactic) were found in the written texts. Both textual Themes and topical Themes performed significant roles in the construction of an explanation. The markedness of a Theme was investigated from a multimodal perspective, something that has not been done in previous research. At the discourse level, the features of thematic progression and hyper-/macro-Themes were investigated. In the written texts, the contiguous progression of simple Themes through a mix of constant and linear TP paths was the dominant thematic progression pattern. In the spoken texts, this dominant thematic pattern was occasionally interrupted by derived new information or syntactic items, with frequent gapped progressions from previous clauses. While no hyper-/macro-Themes were found in the written texts, both hyperThemes and macroThemes performed important roles in the spoken texts to organize the whole text.

This chapter has explored the thematic features in both written and spoken texts that characterize scientific explanations. Based on these thematic patterns, three schematic structures were identified. The first schematic structure was found in the written explanations, and consisted of three obligatory stages: Experiment Condition ^ Explanation Sequences ^ Phenomenon Perception. The second schematic structure was identified in the spoken texts that demonstrated the experiments, and had two obligatory stages: Experiment Introduction ^ Experiment Demonstrations. The third schematic structure was discovered in the spoken texts that constructed explanations, and was composed of three obligatory stages: Phenomenon Identification ^ Explanation Sequences Construction ^ Coda. The relevance of the findings to classroom teaching and learning will be discussed in detail in Chapter 6.

Chapter 5 Images in constructing explanations

5.1 Overview

The present study examined the construction of explanations from three aspects: the development of meaning, the representation of meaning and the multiplication of meaning. Chapter 4 presents findings on the development of meaning in the construction of explanations through Theme analysis of spoken and written texts. Complementary to Chapter 4, this chapter provides a multimodal account of the construction of explanations. Specifically, this chapter presents findings on the representation of meanings in images and the multiplication of meanings between language and images. Findings of this chapter are from the multimodal analysis of a 159-minutes video recording of two science lessons, where a total of 46 images were used to facilitate understandings of air pressure.

The results reported in this chapter are intended to address two research questions. The first research question to be addressed in this chapter is how images represent and link the scientific knowledge to construct explanations in the classroom (RQ2). The second research question to be addressed in this chapter is how language and images interact to construct scientific explanations in the classroom (RQ3).

This chapter has two main components: the representation of meanings in images (responding to RQ2) and the multiplication of meanings between language and images (responding to RQ3). The first main component concerns the ideational meanings that are constructed in the images, consisting of representational meanings in the images realized by visual structures (Section 5.2) and the ways these visual structures are connected to each other, namely, logical meanings in the images (Section 5.3). The second main component focuses on the multiplication of meanings, where representational or/and logical meanings in images are activated to interact with those in spoken texts, and therefore, multiplied (Section 5.4). This chapter ends with a summary of the main findings on representational and logical meanings in images as well as the multiplication of meanings between spoken texts and images.

5.2 Representational meanings in images

This section presents the analysis of representational meanings in images, that is, how human experience of scientific investigations are construed in images. This section particularly focuses on how scientific knowledge related to air pressure, such as air molecules/air particles, is represented in the images through visual structures. Adopting the analytical framework for representational analysis in Section 3.4.3, visual structures were coded as either narrative visual structures or conceptual visual structures. While Section 5.2.1 reports findings on narrative meanings, Section 5.2.2 presents results of conceptual meanings. This section ends with a discussion on how representational meanings contribute to the recontextualization of scientific knowledge related to air pressure in Section 5.2.3.

5.2.1 Narrative meanings

Narrative visual structures serve to present scientific knowledge as unfolding actions, events and processes of change. A total of 74 narrative visual structures were identified in 46 images. These narrative visual structures were categorized under five main types: actional figures, reactional figures, mental figures, verbal figures, and activity sequences. Action figures present actions or movements and consist of four subcategories: transactional action figures, non-transactional action figures, event figures, and elliptical event figures (see Section 5.2.1.1 for examples of actional figures). Reactional, mental, and verbal figures convey the viusal meanings of “looking”, “thinking”, and “saying” respectively (see Section 5.2.1.2 for examples of reactional figures). An activity sequence is a meta visual structure, consisting of a chain of transactional action figures (see Section 5.2.1.3 for examples). Among these five main categories of narrative structures, mental and verbal figures were not observed in the data.

The distribution of narrative visual structures is shown in Table 5.1 and the proportion of each main category is illustrated in Figure 5.1.

Table 5.1 Distributions of narrative visual structures and their proportions

Narrative visual structure		Occurrence	Percentage (%)
Action figures	Transactional action figures	25	34%
	Non-transactional action figures	15	20%
	Event figures	27	37%
	Elliptical event figures	1	1%
Reactional figures		5	7%
Mental figures		0	0
Verbal figures		0	0
Activity sequences		1	1%
Total		74	100%

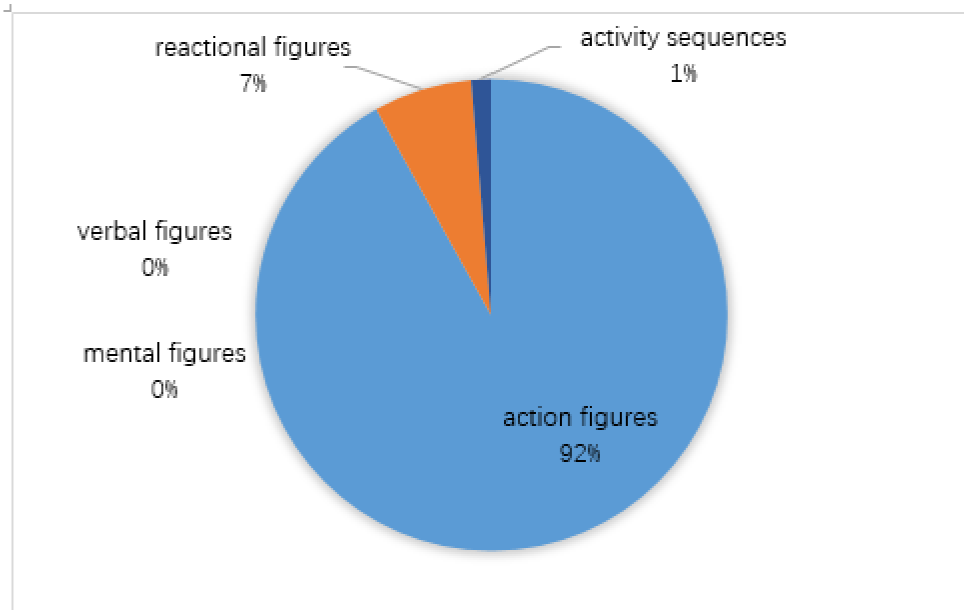


Figure 5.1 The distribution of narrative visual structures

As Table 5.1 and Figure 5.1show, the predominant choice of narrative visual structure is action figures (92%), followed by reactional figures (7%) and activity sequences (1%). Under the main category of action figures (92%), four sub-categories were identified: transactional action figures (34%), non-transactional action figures (20%), event figures (37%) and elliptical event figures (1%). The dominance of action figures and the absence of verbal and mental figures suggest that the focus is on perception, rather than speech or inner mental thoughts. The dominant choice of action figures orients to the interpretation of air pressure as a collective result of actions by molecules that can be perceived through human interferences. While reactional figures serve to construe the perception of a phenomena related to air pressure, activity sequences visualize apparent features in instruments after intervention so that the non-obvious variables of air pressure can be observed.

In what follows, each category of narrative visual structure will be illustrated with examples to facilitate the discussions on how air pressure-related phenomena can be visually depicted in images.

5.2.1.1 Action figures

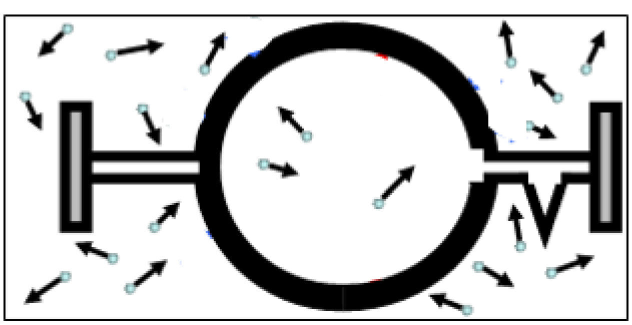
Action figures can be recognized with the vectors suggesting the actions or movements, such as arrows. The present study distinguishes four subcategories of action figures on the basis of the number and type of participants involved.

The first subcategory of action figure is transactional action figure, where both Actor and Goal of an action are presented. Figure 5.2 illustrates the typical realizations of transactional action figures, which were used to present two types of actions. The first type was the collision of molecues to the surfaces of the instrument, where the actor air molecules (shown as grey dots) rebounded to the opposite direction of their initial directions after colliding with the surfaces of Magdeburg Hemispheres (shown as a schematic drawing). The bound arrows in red and blue formed the vectors of this transactional action figure, which emanated from grey dots representing molecules (Actors), and targeted at the ring representing internal and external surfaces of Magdeburg Hemispheres (Goal). The second type was the actions by humans, such as the pulling action to separate the Magdeburg Hemispheres in B17-MH-11. In this case, the body gesture of pulling formed the vector of this transactional action figure — a boy and a girl (Actors) were pulling Magdeburg Hemispheres (Goal). Compared with the action of pulling, the collision between molecules and surfaces of an object is more abstract and less obvious to perceive. Therefore, visualizing the actors and the goal of this type of abstract process can help students recognize non-obvious variables such as air molecules.

(A3-MH-3 partly shown) (B17-MH-11)

Figure 5.2 Examples of transactional action figures

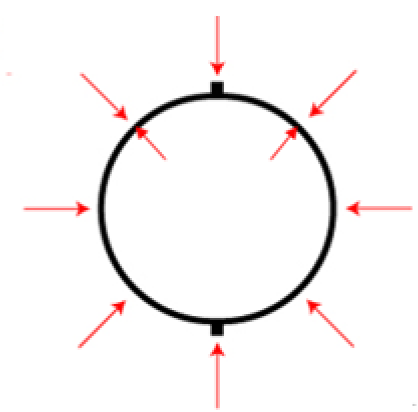
The second subcategory of action figure is non-transactional action figure, where only Actor of an action is presented. Figure 5.3 illustrates the typical realizations of non-transactional action figures, which were used to depict the omni-directional movement of molecules. Unlike transactional action figures using bound arrows as vectors, non-transactional action figures deployed straight arrows as vectors. These vectors emenated from grey dots representing molecules (Actors) without clear indication of their destinations as all the arrows were distant from the schematic drawing of Magdeburg Hemispheres. As the omni-directionality of air molecules' movement is counter-intuitive to students (Basca & Grotzer, 2003), visualizing such behavior of air molecules through a collection of arrows pointing to random directions can help shift students' understanding from intuitions to scientific reasoning.



(A3-MH-3 partly shown)

Figure 5.3 Examples of non-transactional action figures

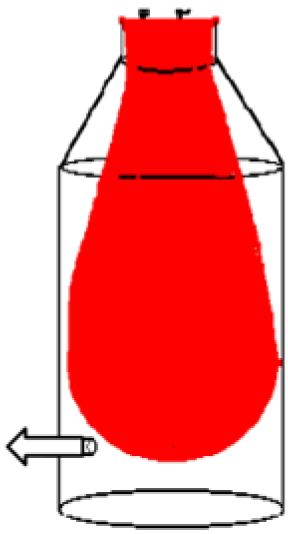
The third subcategory of action figure is event figure, where only Goal of an action is presented. Figure 5.4 shows the typical realizations of event figures, which were used to depict the exersion of air pressure on the surfaces of an object. As illustrated in Figure 5.4, ten red arrows constituted the vectors of ten event figures, directing at different areas of a ring representing the internal and external surfaces of Madgeburg Hemispheres (Goal). While the goal of these event figures were apparent, the actors were not visualized and can only be infered: it was the collective result of molecules bouncing around and exerting forces against any surfaces with which they have contact. It is perhaps more difficult to appreciate the visual meaning of this type of action figures than transactional and non-transactional action figures as students typically serach for active causal agents (Actors) in a process (Basca & Grotzer, 2003). Another possible difficulty is to understand air pressure as a collective behavior of air molecules, which was typically represented as a group of red arrows rather than an individual arrow in this study. For instance, Figure 5.4 shows two groups of red arrows: red arrows pointing centripetally (representing air pressure outside the object) and red arrows pointing centrifugally (representing air pressure inside the object). To obtain the understanding of air pressure as a collective result, students need to be alert in the visual linking between visual structures and to decipher the visual meaning of these visual structures collectively. How to recognize logical meanings in images are discussed in detail in Section 5.3.



(B17-MH-10 partly shown)

Figure 5.4 Examples of event figures

The fourth subcategory of action figure is elliptical event figure, where neither Actor nor Goal of an action is presented. This is a new type of narrative visual structure identified in this study. An example of an elliptical event figure is presented in Figure 5.5.



(A8-BL-2 partly shown)

Figure 5.5 An example of an elliptical event figure

Unlike any other action figures, an elliptical event figure presents only the vector of an action, such as the hallow arrow pointing horizontally to the left in Figure 5.5. Both the actor and the goal of this elliptical event figure need to be inferred, which leads to great uncertainty in correctly interpreting the visual meaning by itself. In the lesson, teacher resorted to spoken language to specify the actor (we) and the goal (air): *We suck air out from the hole* (from Text A-2).

It is important to point out that this newly identified type of action figure differs from the type of geometrical symbolism (see Figure 5.6 for an example), although neither of them involve any participants. Geometrical symbolism typically shows a process in isolation, whose meaning is constituted by its symbolic value, such as the vector of helix in Figure 5.6 to symbolize communication (see Kress and van Leeuwen, 2006 for detailed discussions of geometrical symbolism).

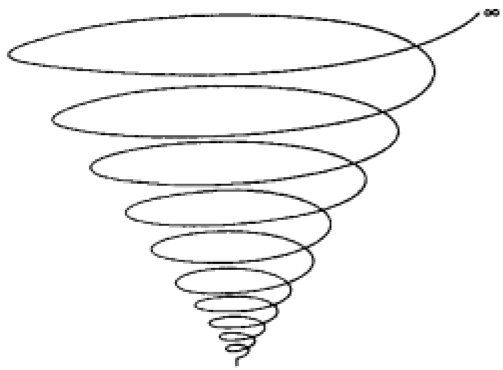


Figure 5.6 An example of geometrical symbolism (cite from Kress and van Leeuwen, 2006, p. 70)

Dissimilarly, the vector in an elliptical event figure does not carry such symbolic meanings, instead, it represents an elliptical version of an action where both Actor and Goal are not shown. To interpret the visual meaning of an elliptical event figure, it is essential to recover its Actor and Goal. This is one of the most typical cases where information from other resources are essential, such as visual structures in other images that are linked to this one and spoken language accompanying the presentation of this visual structure. The ways of connection between visual structures will be discussed in detail in Section 5.3 and the ways of interaction between images and spoken language will be presented in Chapter 6.

These four subcategories of action figures (i.e. transactional action figures, non-transactional action figures, event figures and elliptical event figures) contribute to the construction of air pressure as a collective outcome of actions by molecules, which can be perceived when this non-obvious variable is foregrounded through human action. The next section, Section 5.2.1.2 will focus on another type of narrative visual structure, namely, reactional figures.

5.2.1.2 Reactional figures

Reaction figures can be recognized with the vectors formed by glances of human or human-like creatures, with the visual meaning of "looking". A reactional figure involves two types of participants: Reacter (the human who does the looking) and Phenomenon (the people or event that are being observed). Depending on the involvement of partcipants, reactional figures can be further specified as transactional reactional figures (involving both Reacter and Phenomenon) or non-transactional (only involving Reacter). The present study only identfied the type of transactional reactional figures in the data. A typical example of a transactional reactional figure is shown in Figure 5.7.

(B19-MH-13)

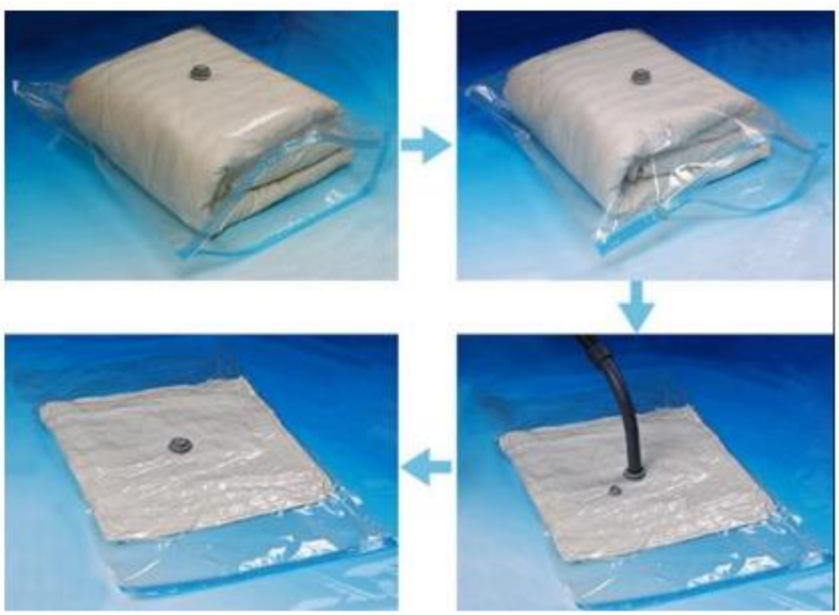
Figure 5.7 An example of a reactional figure

In Figure 5.7, two groups of horses were Actors in a transactional action figure in which Magdeburg Hemispheres was Goal as both the red arrows and the body orientations of these horses formed a strong vector of pulling towards the opposite directions. This transactional action figure can be transcoded as: two groups of horses were pulling Magdeburg Hemispheres towards the opposite directions. This action (horses pulling Magdeburg Hemispheres) then became the Phenomenon of a transactional reactional figure in which the man standing in the middle was Reacter. This transactional reactional figure can be transcoded as: A man was watching two groups of horses pulling Magdeburg Hemispheres to the opposite directions.

An interesting finding is that all Phenomena in transactional reactional figure were action figures (e.g. Horses were pulling Magdeburg Hemispheres), rather than participants alone (e.g. horses or Magdeburg Hemispheres). This is due to the passive nature of air pressure: air pressure does not actively cause any changes but rather to maintain the status quo (Basca & Grotzer, 2003). Air pressure is an ambient variable that always present and remain balanced. When air pressure is balanced, it does not appear to bring any effects. It is more likely to notice the effect of air pressure when the balanced state is disrupted through human intervention, resulting in events or changes. This explains why the reactional figures under analysis focus on the perceptions of actions and events to disrupt the balanced state of air pressure, so that the effects of air pressure can be observed.

5.2.1.3 Activity sequences

An activity sequence is a meta visual structure, which is constituted by a chain of transactional action figures. An activity sequence involves three types of participants: Actor, Goal and Relay. The participant of Relay is distinguished from Actor and Goal in that it acts as both the Actor of one transactional action figure and the Goal of another one. An example of an activity sequence is presented in Figure 5.8.



(B33-VG-1)

Figure 5.8 An example of an activity sequence

In Figure 5.8, four photographs of a quit in a vacuum bag were placed clockwise with three arrows pointing from one photograph to another. Starting from the upper left corner, these four photos are called Photo 1, Photo 2, Photo 3 and Photo 4 for easy reference. Photo 1 was the Actor, Photo 2 and Photo 3 were the Relays, and Photo 4 was the Goal of this activity sequence while three blue arrows formed the Vectors. Each photo was a conceptual representation of instruments, which consisted of analytical figures to attribute properties (see Section 5.2 for details of conceptual visual structures). For instance, the conceptual figures in Photo 1 were (1) The quilt (Carrier) has the properties such as color, volume, shape and texture (Attributes); and (2) The vacuum bag (Carrier) has the properties such as color, size and shape (Attributes). Three blue arrows formed the vectors connecting Photo 1 to Photo 2, Photo 2 to Photo 3, and Photo 3 to Photo 4, where each photo was the participant (Actor, Relay or Goal) of an activity sequence. In other words, these conceptual structures were embedded in a larger narrative structure (see Figure 5.9).

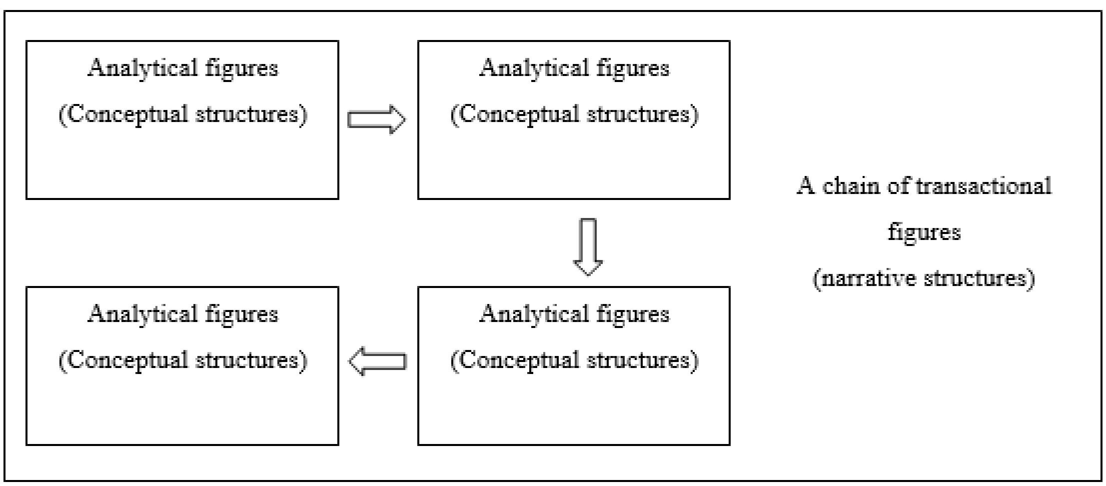


Figure 5.9 The embedding of conceptual structures and narrative structures

As shown in Figure 5.9, analytical figures in each photo were embedded in a chain of transactional figures (i.e. an activity sequence), acting as participants (Actor, Goal or Relay). This embedded visual structure shows how the phenomena of air pressure can be observed by comparing the properties of a quit (i.e. volume) before vacuum and that after vacuum. To interpret this complex visual structure, the readers are expected to recognize the embedded conceptual and narrative meanings as well as the logical links between them (see Section 5.3 for details on the logical links). For instance, although the volume of the quilt differed in these photos, the readers are expected to assume that it was a change of state in the same object as the quilts were displayed in the same position with the same background. It is then possible for the readers to question why the volume of the quilt changed after being vacuumed. This again requires the ability to link the conceptual structures depicting perceivable features of an object (in this case, the volume of a quilt) to the narrative structures constructing a process of change in the features (in this case, the decrease in the volume of a quilt).

Another interesting observation in Figure 5.9 is the use of conceptual structures to suggest an action. Photo 3 presented a black tube connecting to a vacuum bag with a flat quilt sealed inside. All the visual structures in Photo 3 were conceptual ones, attributing properties to objects, such as color, shape and volume of the quilt. It is the connection between the conceptual structures (i.e. a black tube is connected to a vacuum bag) suggests the action of vacuuming (i.e. a vacuum pump is extracting the air out from a vacuum bag), rather than any vectors. To recognize this action of vacuuming, one needs to infer that the black tube is part of a vacuum pump, and that the connection of the tube and the vacuum bag represents the process of vacuuming.

Perhaps now we begin to realize what complex visual meanings were compacted in this activity sequence. It represents the identification of air pressure-related phenomena, including observable features of an object (in this case, the volume of a quilt), that go through a process of change (in this case, the decrease in the volume of a quilt) and human interventions (in this case, the action of vacuuming). However, recognizing the complex meaning of this visual structure is just the first step in the construction of a scientific explanation. Simply attributing the outcome (i.e. the decrease in the volume of a quilt) to the action of human intervention (i.e. vacuuming the bag) is tempting as both are observable. As pointed out by Basca and Grotzer (2003), students typically explained air pressure-related phenomena in terms of either pressure or a vacuum pump actively sucking or pulling, rather than the unbalance of air pressure exerted on different areas of an object (in this case, a lower pressure inside the vacuum bag and a higher pressure outside the vacuum bag). To successfully explain air pressure-related phenomena, students are expected to move from observable features that are demonstrated or visualized in an image, to behaviors of non-obvious variables, such as the movement of air molecules that are showed in other images. Therefore, it is crucial to appreciate the visual meanings in a collection of images, where visual linking can be established between visual structures in one image or several images. How visual structures are connected to each other will be discussed in detail in Section 5.3.

To sum up, three main categories of narrative visual structures were identified on the basis of the types of vectors and the types of participants. These narrative visual structures are action figures (Section 5.2.1.1), reactional figures (Section 5.2.1.2) and activity sequences (Section 5.2.1.3). The next section, Section 5.2.2 will focus on the construction of conceptual meanings.

5.2.2 Conceptual meanings

Different to narrative visual structures, which present unfolding actions, events or processes of change, conceptual visual structures represent participants in terms of structure, class or meaning. A conceptual visual structure can be recognized when no vector is involved in the construction of visual meaning. Conceptual visual structures consist of three subtypes: analytical figures, classificational figures, and symbolic figures, which represent participants with part-whole relations, taxonomic relations, and identifying or attributive relations respectively.

A total of 77 conceptual visual structures were identified in the 46 images under investigation. The distribution of conceptual visual structures is shown in

Table 5.2 and the proportion of each main category is illustrated in Figure 5.10.

Table 5.2 Distributions of conceptual visual structures and their proportions

Conceptual visual structures		Occurrence	Percentage (%)
Analytical figures	Naturalistic analytical figures	18	22%
	Schematic analytical figures	29	35%
Symbolic figures	Symbolic attributive figures	34	42%
	Symbolic suggestive figures	0	0
Classificational figures	Covert classificational figures	1	<1%
	Overt classificational figures	0	0
Total		82	100%

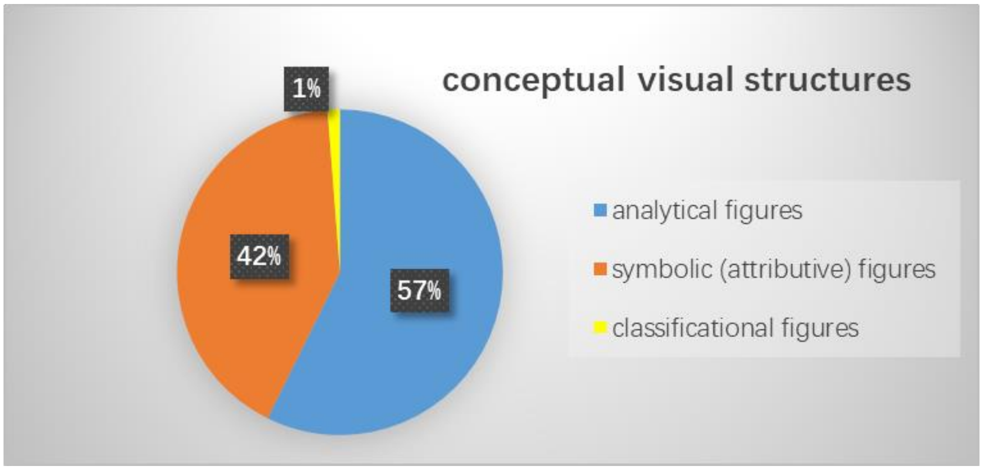


Figure 5.10 The distribution of conceptual visual structures

As

Table 5.2 and Figure 5.10 illustrate, the most salient type of conceptual visual structure was analytical figures (57%), followed by symbolic figures (42%) and classificational figures (1%). Under the main category of analytical figures (57%), two sub-categories were identified: naturalistic analytical figures (22%) and schematic analytical figures (35%). All symbolic figures fell into the subcategory of symbolic attributive figures (42%), with the absence of symbolic suggestive figures. The only instance of classificational figure was a covert classificational figure. The prominence of analytical figures and symbolic figures and the few instances of classificational figure suggest that the focus was on a part-whole relation between participants and the establishment of meaning or identity of a participant, rather than the construction of taxonomy. Specifically, analytical figures were typically found to present the essential features of instruments used to demonstrate air pressure-related phenomena, such as shape, volume and components. Symbolic attributive figures were found to establish a relation of identity between a visual and a verbal realization of the same participant.

In what follows, each category of conceptual visual structure will be illustrated with examples to facilitate the discussions on the conceptual depiction of air pressure-related phenomena.

5.2.2.1 Analytical figures

An analytical figure can be recognized when neither a vector (narrative structures) nor compositional symmetry and/or a tree structure (classificational figures) is presented. This study distinguishes two subcategories of analytical figures depending on the inclusion of propertities or chariceristics (i.e. Possive Attributes) of a participant (i.e. Carrier).

The first subcategory of analytical figures is naturalistic analytical figures, where all Possive Attributes of a Carrier are presented. Figure 5.11 demonstrates the typical realzations of naturalistic analytical figures in two photographs.

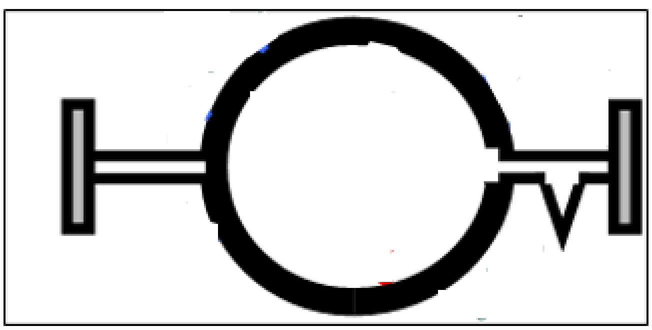
(B25-BL-2)

(B4-AP-4)

Figure 5.11 Examples of naturalistic analytical figures

Image B25-BL-2 presented two naturalistic analytical figures, in which each balloon in a bottle was Carrier in relation to a number of Possisive Attributes (color, shape, texture etc.) to highlight the difference in shape of these two balloons. These naturalistic analytical figures help visualize air pressure equilibrium and differentials (i.e., the balances and unbalances between air pressure in different areas of an object) through perceivable features of an instrument, such as the shape of balloons in Image B25-BL-2. Although naturalistic analyticalfigures were typically found to present instruments of air pressure-related experiments, they were also used to show other participants, such as animals and the earth (see Image B4-AP-4 in Figure 5.11). Image B4-AP-4 is a photograph of two elephants standing on grassland. In Image B4-AP-4, there is an analytical figure, where two elephants were Carrier of Possisive Attributes that characterize the appearance of an elephant. This analytical figure can be translated as "An elephant has the typical appearance, such as two fan-like ears, four pillar-like legs, and a long nose.". Naturalistic analytical figures presenting other participants, such as elephants in Image B4-AP-4, serve to bridge commonsense knowledge and scientific knowledge. For instance, the intension of the analytical figure in Image B4-AP-4 was to analogue the size of atmospheric pressure to the size of pressure exerted by a leg of an elephant. Students may not aware the existence of atmospheric pressure due to its passive nature, and therefore it can be difficult for them to understand how large atmospheric pressure is. However, students are familiar with an elephant, which makes it easier for them to infer that the size of pressure exerted by a leg of an elephant is large. With the use of analogue in naturalistic analytical figures in photographs (e.g., elephants), the science teacher effectively introduced the size of atmospheric pressure, which was abstract and not familiar to students. Findings from this study suggests that the use of analogy in accompany with naturalistic analytical figures are effective devices to connect abstract scientific knowledge to concrete everyday knowledge.

The second subcategory of analytical figures is called schematic analytical figures in the present study. A schematic analytical figure can be recognized when Possessive Attributes of Carrier are partly presented, which is typically shown in schematic drawings. Figure 5.12 illustrates the typical realization of a schematic analytical figure in a schematic drawing of an instrument.



(B12-MH-6 partly shown)

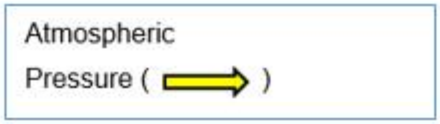
Figure 5.12 An example of a schematic analytical figure

Figure 5.12 shows a schematic drawing of Megdeburg Hemispheres, where only the essential Possessive Attributes (i.e. shape, componets of handles and valve) of Carrier (i.e. Magdeburg Hemispheres) were presented. The deletion of other Possesive Attributes help draw the viewer's attention to the Possessive Attributes that are most relavant for the analytcial purpose. This schematic analytical figure was presented together with a number of action figures depicting the movment of air molecues inside and outside Magdeburg Hemispheres (see examples of action figures in Secton 5.2.1.1). The purpose of this schematic analytical figure was to provide supplementary information for these action figures (i.e. circumstances and Goal of action figures). With this understanding, the Possessive Attributes of Madegurg Hemispheres, such as color and texture were irrelavant here and thus were ignored in the schematic drawing.

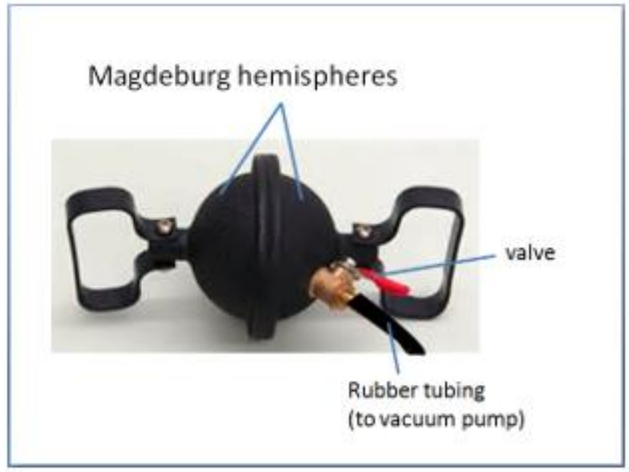
The present study found while naturalistic analytical figures typically appeared in phtographs, schematic analytical figures were presented in schematic drawings. It is important to point out that the difference between these two subcategories lies not in their part-whole strucuture, but in their interpersonal strucutures, such as modality (see Kress & van Leeuwen, 2006 for detailed discussions on modality). Naturalistic analytical figures in photographs are concrete because they depict people, objects and places in great detail as how they actually exist. Dissimilarly, schematic analytical figures in shematic drawings are abstract and conventionized as they only show selective features of a participant following the conventions of a community (in this case, the science community). The next section will focus on another salient type of conceptual structure, namely, symbolic figures.

5.2.2.2 Symbolic figures

Symbolic figures can be used to establish meaning or identify of a participant, where the participant whose meaning is established is Carrier, and the meaning or identity itself is Symbolic Attribute. Depending on whether Symbolic Attribute is presented or not, symbolic figures can be further categorized into symbolic attribute figures (with the presence of Symbolic Attribute), and symbolic suggestive figures (with the absence of Symbolic Attribute). All the symbolic figures identified in this study were symbolic attribute figures, where both Carrier and Symbolic Attribute were shown. Figure 5.13 illustrates typical examples of symbolic attribute figures.



(A8-BL-2 partly shown)

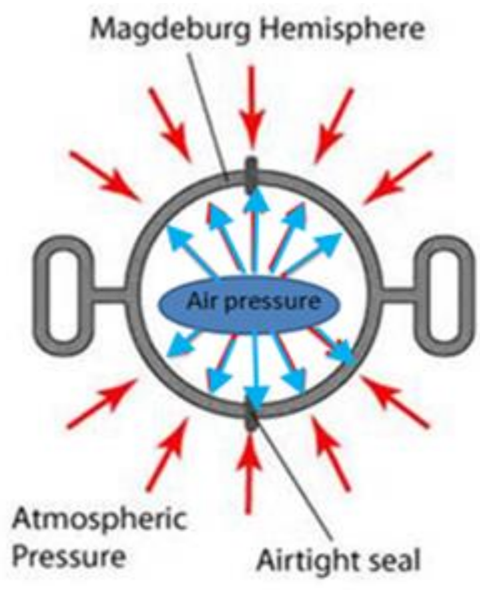


(A1-MH-1)

Figure 5.13 Examples of symbolic attribute figures

Figure 5.13 shows two types of realizations of symbolic attribute figures. First, symbolic attribute figures can be co-constructed by written texts and visual symbols (as the case in A8_BL-2). For instance, in Image A8-BL-2 which is partially shown, the meaning of a yellow arrow (Carrier) was established through the written text "Atmospheric pressure" (Symbolic Attribute), forming the symbolic attribute figure that "the yellow arrow represents air pressure". Second, symbolic attribute figures can be co-constructed by written texts and a photograph, where instruments including their components were named linguistically. For instance, in Image A1-MH-1, three symbolic attribute figures were used to link the visual representations of instruments in a photograph (Carrier) to their names in English (Symbolic Attributes). These symbolic attribute figures can be transcoded as the following: (1) This is Magdeburg Hemispheres; (2) This is a valve; and (3) This is a rubber tubing that are connected to vacuum pump.

Two ways of establishing the symbolic attributive relation between Carrier and its Symbolic Attribute were identified: (1) symbols suggesting a link and (2) spatial proximity. The examples shown in Figure 5.13 employed symbols of bracket and lines to establish the symbolic attributive relation. The other way to link Carrier and Symbolic Attribute was through spatial proximity, as the case in Figure 5.14.



(A4-MH-4)

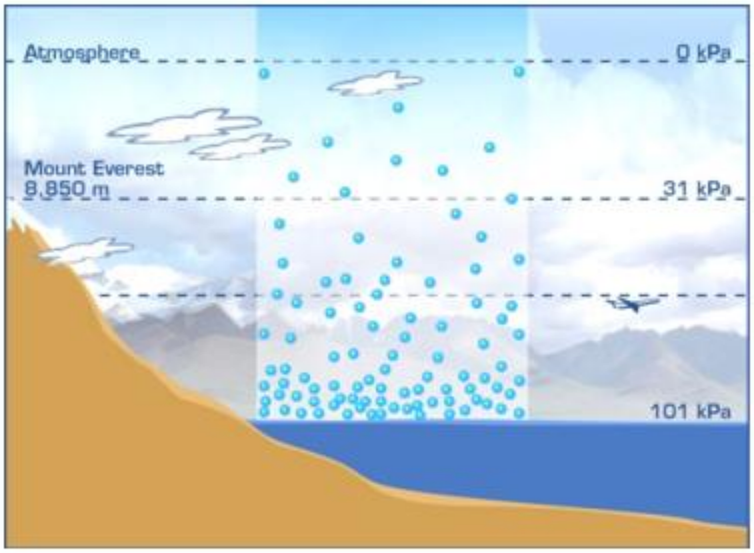
Figure 5.14 An example of spatial proximity to establish symbolic attribute relations

As shown in Figure 5.14, the meaning of red arrows was established by displaying the written text "Atmospheric Pressure" nearby those red arrows. Similarly, the spatial proximity between the blue arrows and the written text "Air pressure" introduced a symbolic attribute figure, that "blue arrows represent air pressure".

The next section, Section 5.2.2.3 will introduce the third type of conceptual visual structure, namely classificational figures.

5.2.2.3 Classificational figures

Classification figures relate participants in terms of a taxonomy, where the participants representing the subcategories are Subordinates and the participant representing the overarching category is Superordinate. The crucial visual characteristic to realize a classificational figure is a symmetrical composition between Subordinates or a tree structure, showing Superordinate in a higher degree. Depending on the presence of Superordinate, classificational figures can be covert classificational figures (with the absence of Superordinate) or overt classificational figures (with the presence of Superordinate). The only instance of a classificational figure identified in this study was a covert one, which is shown in Figure 5.15.



(B3-AP-3)

Figure 5.15 An example of a covert classificational figure

In Image B3-AP-3, the space above the sea were vertically divided into four domains through three dash lines. The blue dots in each domain formed Subordinates, representing the size of atmospheric pressure in different heights. Through this classificational figure, the variation of atmospheric pressure in different heights were elucidated.

To sum up, three types of conceptual visual structures were identified in this study, namely, analytical figures to present essential features of an instrument (Section 5.2.2.1), symbolic attributive figures to identify realizations of the same participant (Section 5.2.2.2), and covert classificational figures to represent variations of atmospheric pressure at different heights (Section 5.2.2.3).

In Section 5.2.3, how representational meanings were constructed in two classes will be discussed in relation to the recontextualization of air pressure-related concepts.

5.2.3 Recontextualizing scientific knowledge through representational meanings in images

While previous sections demonstrate how representational meanings can be constructed, this section shifts the focus on the realization of representational meanings in two classes. The realization of narrative meanings in two classes will be compared before moving on to the comparison of conceptual meanings.

The distribution of narrative visual structures in Lesson A and that in Lesson B are shown in Figure 5.16.

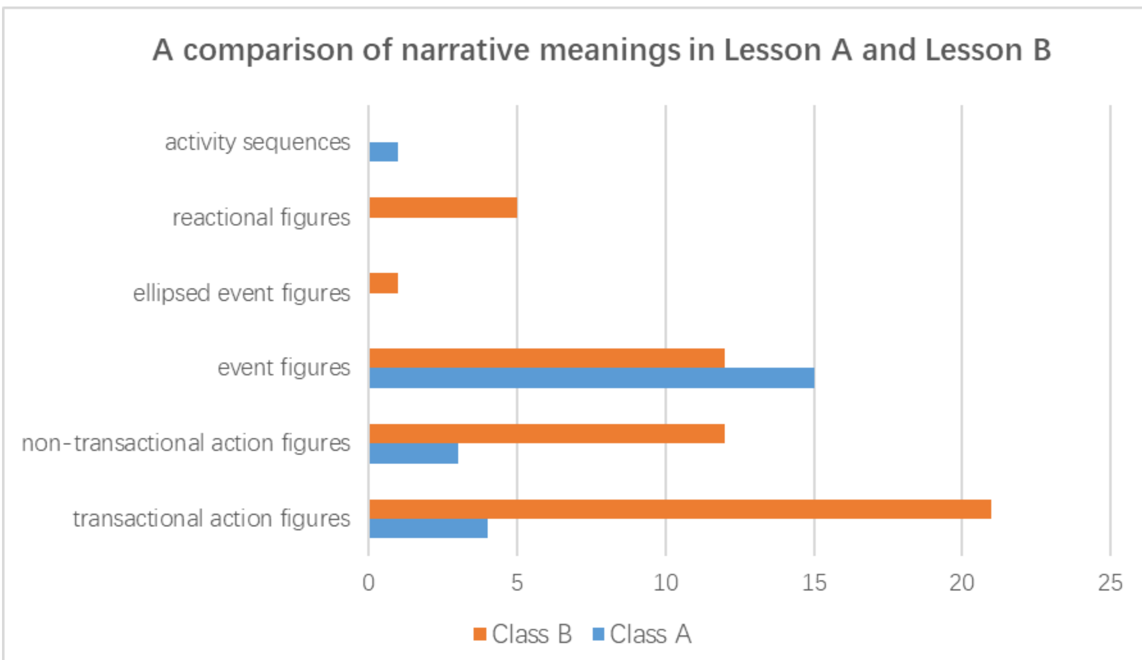
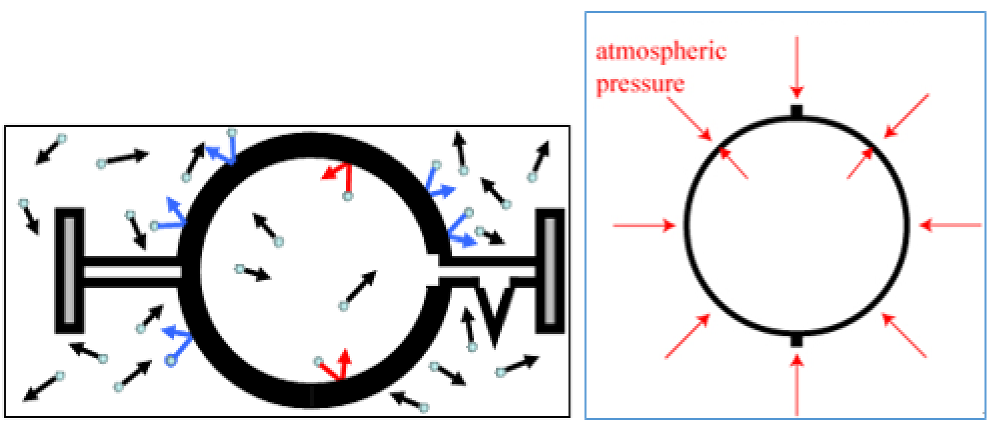


Figure 5.16 A comparison of narrative meanings

It is clear that more narrative visual structures were used in Lesson B than those in Lesson A because more images are used in Lesson B. Despite the difference in the number of images, it is observed that action-related structures (i.e. activity sequences, elliptical event figures, event figures, non-transactional action figures and transactional action figures) were dominant in both Lesson A and Lesson B. The most salient narrative structures in both classes were transactional action figures, non-transactional action figures and event figures. This is because air pressure is produced by air molecules colliding to the surfaces of an object. This type of action by air molecules is typically realized by transactional action figures (see Figure 5.2 for examples). Closely related to the collision between air molecules and an object is another type of action by air molecules, that is, the random movement of air molecules. While all air molecules perform the actions of moving in random directions, some of them collide to surfaces of an object, resulting in the exertion of air pressure. The random movement of air molecules was typically realized by non-transactional action figures (see Figure 5.3 for examples). The exertion of air pressure on the surfaces of an object was typically realized by event figures (see Figure 5.4 for examples). The prominence of action-related structures results in frequent use of arrows as vectors. The production of air pressure as the collective efforts by air molecules, was shown through the co-presence of several arrows, whose meanings could differ significantly. Figure 5.17 illustrates examples of the co-presence of arrows to represent actions by air molecules and air pressure.



(A3-MH-3) (B17-MH-10)

Figure 5.17 Examples of the co-presence of arrows

In Image A3-MH-3, the co-presence of arrows depicted the omnidirectional movement of air molecules and the collision between air molecules and surfaces of an object. The omnidirectional movement of air molecules were realized in black arrows. The collision was realized in red arrows (representing the collision between air molecules and the internal surface), and blue arrows (representing the collision between air molecules and the external surface). In Image B17-MH-10, the co-presence of arrows depicted the exertion of air pressure inside and outside an object. While the red arrows pointing centripetally represented the exertion of air pressure outside an object, the ones pointing centrifugally represented the exertion of air pressure inside an object. The direction of these arrows is crucial in understanding the ominidirectional nature of air pressure. In other words, air pressure exists in all directions equally, so that air pressure is not a vector quantity but a scalar quantity. However, as arrows are typically associated with actions and movements, it can bring considerable challenges for students to appreciate air pressure as a scalar quantity. Apart from using arrows to represent air pressure, air pressure can be represented through dots (Basca & Grotzer, 2003), as shown in Figure 5.18.

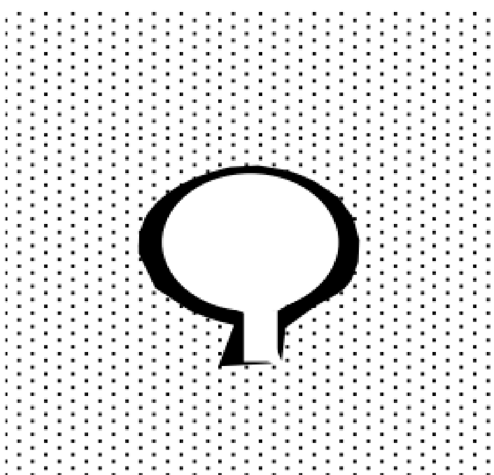


Figure 5.18 Representing air pressure through dots (Basca & Grotzer, 2003, p. 52)

As shown in Figure 5.18, air pressure was no longer represented as arrows pointing centripetally but as a number of dots. Representing air pressure through dots enables understand air pressure as a scalar quantity, whose value is shown by the density of dots. Perhaps it is better to use both arrows and dots as representations of air pressure. While the use of arrows highlights the relation between the movement of individual air molecules and the collective result of air pressure, the use of dots clarities the scalar nature of air pressure. Therefore, it is suggested to introduce dots as the representation of air pressure after using arrows as the representation of air pressure to demonstrate the emergence of air pressure as the collective results of air molecules moving around and colliding to surfaces of an object.

Other narrative visual structures, including activity sequences, relational figure and elliptical event figures, are typically associated with the perception of air pressure-related phenomena (see Section 5.2.1 for details). Air pressure is difficult to perceive because it is omnipresent, and involves non-obvious variables of air molecules. Therefore, human intervention is required to make the effects of air pressure observable so that people can perceive it. Human intervention can be realized by activity sequences (see Figure 5.8 for an example) and elliptical event figures (see Figure 5.5 for an example). The perception of air pressure-related phenomena was realized in reactional figures only in Lesson B. This suggest that both teachers in Lesson A and Lesson B consider the narrative visual meanings related to the production of air pressure more important than those related to the perception of phenomena. One possible reason is that the perception of air pressure-related phenomena can be achieved by experiment demonstrations, where students can observe the effects of air pressure, so that visualizing these effects in images becomes optional.

The distribution of conceptual visual structures in Lesson A and that in Lesson B are shown in Figure 5.19.

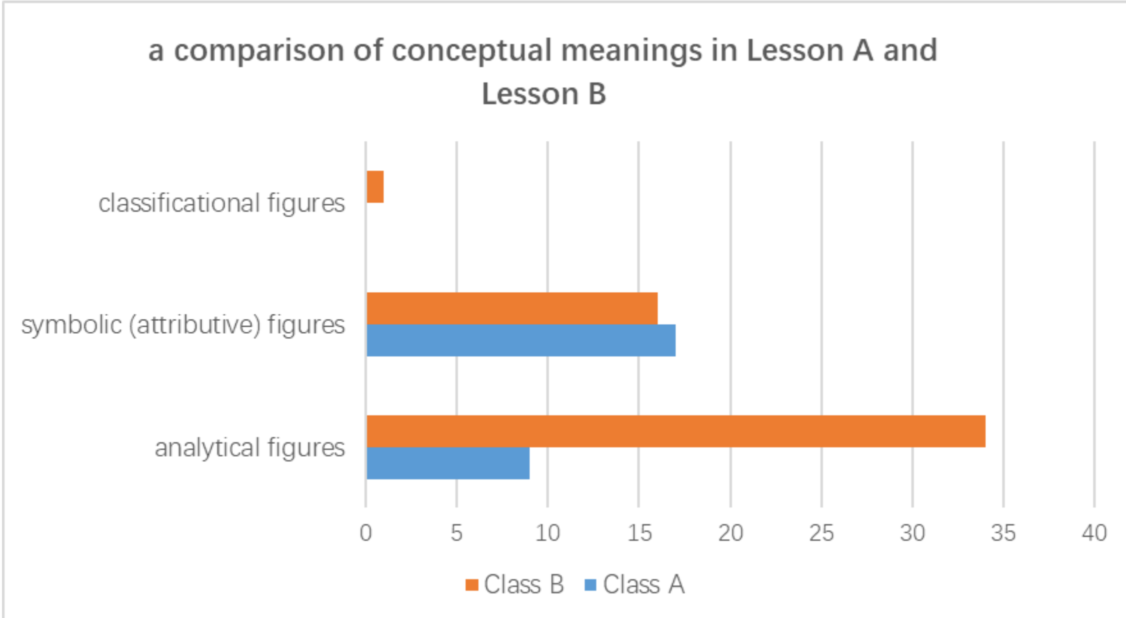
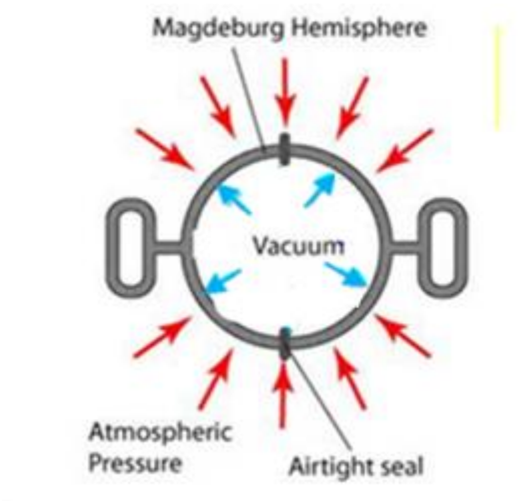


Figure 5.19 A comparison of conceptual meanings

The prominent conceptual visual structures were symbolic (attributive) figures and analytical figures in both Lesson A and Lesson B. The number of symbolic (attributive) figures in Lesson A was similar to that in Lesson B. Because more images were used in Lesson B than Lesson A, resulting in more analytical figures in Lesson B.

Symbolic (attributive) figures served to identify realizations of the same participant, which could be either an object (i.e. an instrument/components of an instrument) or a science concept (see Figure 5.13 for examples). If the participant was an object, the symbolic attributive relation was established between a written text and a photograph, to name this object in language. If the participant was a science concept, the symbolic attributive relation was established between a written text and a symbol, suggesting that they were the representations of the same science concept. These two types of participants show two levels of abstractness, one being more concrete (the participant of an object), and the other being more abstract (the participant of a science concept).

The difference in the level of abstractness was also observed in analytical figures. While naturalistic analytical figures typically associated with concrete representations of participants, such as instruments and animals in photographs (see Figure 5.11 for examples), schematic analytical figures tended to associate with abstract representations of an object in schematic drawings (see Figure 5.12 for an example). It is important to note that both exhaustive and schematic analytical figures functioned with other visual structures. Naturalistic analytical figures portrayed the details of instruments, that were used for air pressure-related experiments. The crucial components of these instruments were labelled with names via symbolic attributive figures. Schematic analytical figures schematized the essential features of an instrument, so that this instrument was decontextualized and could function as circumstances or Goal of abstract action figures, such as the movement of air molecules. This suggests that one needs to constantly shunts between concrete observable phenomenon and abstract scientific representations in a scientific investigation (Yao & Gilbert, 2014). To fully appreciate the visual meanings in images, one needs to comprehend the meanings of different types of visual structures and to connect these visual meanings. This can be challenging for both teachers and students. Figure 5.20 illustrates an example of confusing visual structures in one of the images used in Lesson B.



(B23-MH-16)

Figure 5.20 An example of confusing visual structures

As Figure 5.20 shows, there were an analytical figure (realized by a schematic drawing of Magdeburg Hemispheres), a number of action figures (Vectors: blue and red arrows + Goal: a schematic drawing of Magdeburg Hemispheres) and four symbolic attribute figures to assign linguistic names for an instrument or its components. In the middle of this image was a symbolic attribute figure, with the Symbolic Attribute of "Vacuum". However, this symbolic attribute figure is highly confusing as it contradicts with the action figures (Vector: blue arrows + Goal: a schematic drawing of Magdeburg Hemispheres), which represents the exertion of air pressure on the internal surface of Magdeburg Hemispheres. If the internal space of this instrument is vacuum, it is impossible to have any air pressure as there is no air molecules colliding to the surface and exerting pressure. These two contradictory visual structures may cause confusion or even misconceptions of air pressure. One of the solutions can be to simply remove one of the contradictory visual structures. It is suggested to remove the symbolic attribute figure rather than these action figures because this image functions to compare the size of air pressure inside the instrument and that outside the instrument. Removing the action figures representing the exertion of air pressure inside the instrument will inevitably affect the comparison between air pressure.

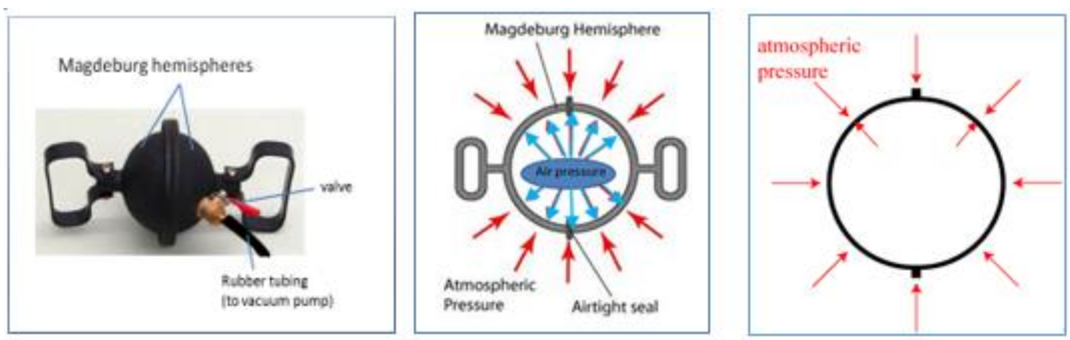
How visual meanings can be connected is discussed in Section 5.3.

5.3 Logical meanings in images

This section presents findings on logical meanings in images, that is, how constructions of human experience of scientific investigations are connected in the images. The types of visual linking identified were: elaboration, temporal, spatial and logical, which are presented in Section 5.3.1, Section 5.3.2, Section 5.3.3 and Section 5.3.4 respectively. Section 5.3.5 discusses how these logical meanings in images were recontextualized in two classes.

5.3.1 Elaboration linking

The visual linking of elaboration concerns the cases where the information is repeated or reformulated for purposes of clarification. The type of elaboration linking consists of two sub-types: depiction and activity complex. The subtype of depiction was used to link different depictions of the same object, which was typically associated with analytical figures. This subtype is similar to van Leeuwen's (2005) type of elaboration, which involves the transition between a close shot (CS) and a long shot (LS) of the same subject in the film. However, the subtype of depiction covers a broader range than the filming technique of CS or LS. The recognition of this visual linking is based on an analytical figure to present this object and symbolic attributive figures to assign linguistic labels. Figure 5.21 presents examples of the visual linking of depiction.



(A1-MH-1) (A4-MH-4) (B17-MH-10)

Figure 5.21 Examples of depiction

Figure 5.21 presents three visual representations of Magdeburg Hemispheres, one in photographs (Image A1-MH-1) and the others in schematic drawings (Image A4-MH-4 and Image B17-MH-10). Although these visual representations are not identical, the essential features of this instrument, such as the shape of this instrument, remain in all three depictions, enabling the viewers to recognize them as the same instrument, Magdeburg Hemispheres. Another way to realize the visual linking of depictions is through symbolic attributive figures. For instance, the symbolic attribute figures in Image A1-MH-1 and Image A4-MH-4 established the identity of the visual representations through linguistic labels "Magdeburg Hemispheres". Based on the same linguistic labels, we know that Image A1-MH-1 and Image A4-MH-4 represent the same object. The effect of these labels is twofold. First, such label suggests a synonymous relation between the linguistic label and the visual elements being labeled. Second, it enhances the synonymous relation between the visual elements that share the same label.

While the sub-type of depiction links conceptual structures, the sub-type of activity complex links narrative structures. The sub-type of activity complex was used to link different depictions of the same activity, which was typically associated with action figures. Activity complex can be realized through the grouping of action figures and the grouping of symbolic attributive figures. Figure 5.22 presents the example of an activity complex that was realized through the grouping of narrative figures. The type of narrative figures and their realizations are shown in bracelet to facilitate discussions.

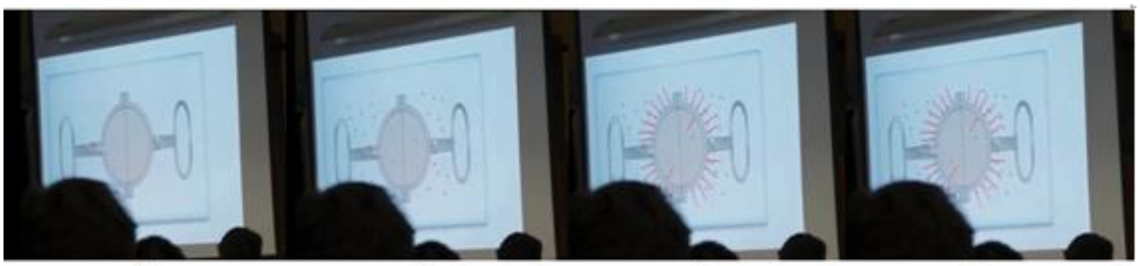
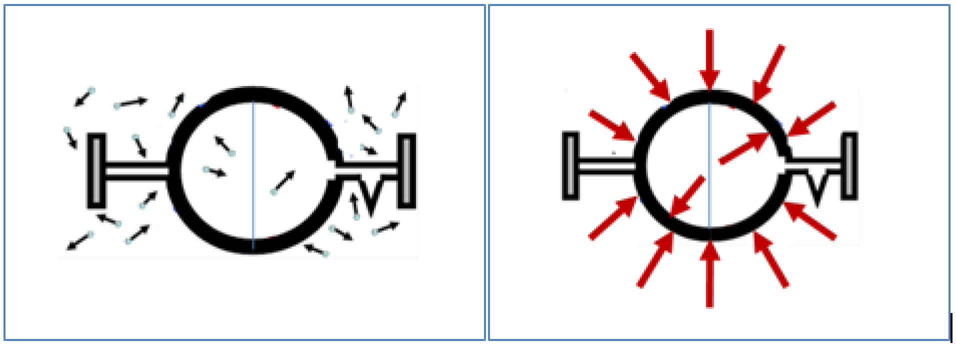


Figure 5.22 An example of activity complexes realized through the grouping of narrative figures

Figure 5.22 shows the unfolding of an animated force diagram. This animation started with a schematic representation of Magdeburg Hemispheres. Then several grey dots with small arrows emerged inside the outside the hemispheres, representing the random movement of air molecules (non-transactional figures, Actor: grey dots + Vector: small arrows). In what follows, the red large arrows pointing to the internal and external surfaces of hemispheres emerged, representing that the air pressure is exerting on the internal and external surfaces of hemispheres (event figures, Vectors: red large arrows + Goal: schematized hemispheres). These red large arrows disappeared and reemerged for another time, representing that the air pressure continuously acts upon the hemispheres (event figures, Vectors: red arrows + Goal: schematized hemispheres).

In this animated diagram, there were two activity complexes (see Figure 5.23).

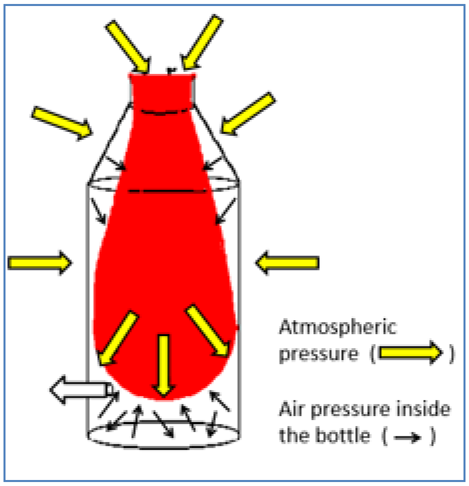


(reproduced from A6-MH-6)

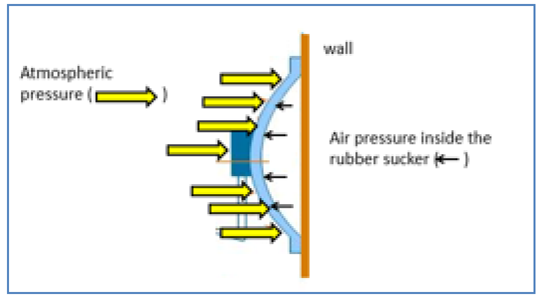
Figure 5.23 Examples of activity complexes realized by groups of action figures

The first activity complex was a group of non-transactional action figures (Actors: grey dots + Vectors: small arrows) to represent the random movement of air molecules. Each action figure represented the movement of an air molecule towards one direction, and collectively they represented the omnidirectional movement of air molecules. The second activity complex was a group of event figures (Vectors: red large arrows + Goal: a schematic drawing of Magdeburg Hemispheres) to represent the exertion of air pressure on both the internal and external surfaces of Magdeburg Hemispheres. Each event figure represented the exertion of air pressure on an area of the hemispheres, and collectively they represented the omnidirectional exertion of air pressure on an object.

The activity complex can also be achieved through the combination of symbolic attributive figures and action figures (see Figure 5.24).



(A8-BL-2)



(A9-RS-1)

Figure 5.24 Examples of activity complex realized by the combination of action figures and symbolic figures

In these two images, both narrative structures and conceptual structures were identified. While they differed in analytical figures (a balloon in a bottle versus rubber sucker on the wall), they were similar in symbolic attributive figures and non-transactional action figures. In both images, groups of non-transactional action figures formed activity complexes. Image A8-BL-2 included two activity complexes. The first activity complex represented the exertion of air pressure outside the bottle (Vectors: yellow large arrows + Goal: a schematic drawing of a balloon in a bottle) The second activity complex represented the exertion of air pressure inside the bottle (Vectors: small black arrows + Goal: a schematic drawing of a balloon in a bottle). Similarly, Image A9-RS-1 included two activity complexes, one representing the exertion of air pressure outside the rubber sucker (Vectors: yellow large arrows + Goal: a schematic drawing of a rubber sucker), and the other representing the exertion of air pressure inside the rubber sucker (Vectors: small black arrows + Goal: a schematic drawing of a rubber sucker).

In both images, symbolic attributive figures identified the meaning of yellow arrows and small black arrows to their names in language. The symbolic attributive figure (

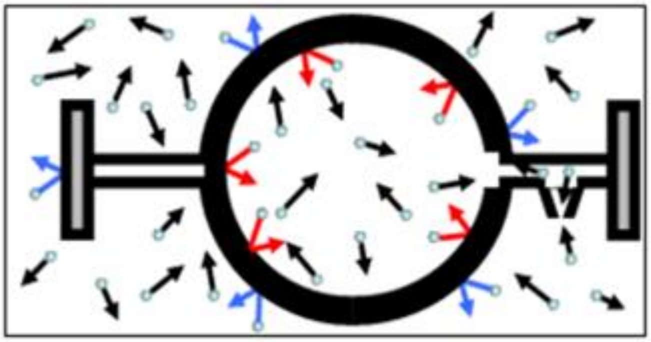
) was used in both images to establish the meaning of yellow arrows as atmospheric pressure (Carrier: the symbol of  + Attribute: the written text of "Atmospheric pressure"). By doing so, a synonymous relation was created between the text (i.e. atmospheric pressure) and the symbol (i.e. a yellow arrow). This helps recognizing all the yellow arrows in both images as representations of atmospheric pressure. The activity complex representing atmospheric pressure in Image A8-BL-2 was connected to the activity complex representing atmospheric pressure in Image A9-RS-1 through the elaboration linking of activity complex.

Similarly, through the synonymous relation established by the symbolic figures, Air pressure inside the bottle (→) and Air pressure inside the rubber sucker (←), the black arrows symbolized air pressure inside the container. This assists the interpretation of all the black arrows in one image as the representation of air pressure exerting on the internal surfaces of the container. Such an interpretation also transmits between one image to another, that air pressure acts upon the bottle and balloon and it also acts upon the rubber sucker.

5.3.2 Temporal linking

As its name suggests, the temporal linking concerns the sequential or simultaneous occurrence between visual structures. The type of temporal linking consists of two-subtypes: simultaneous event and sequential event. While the simultaneous event links narrative structures that occur simultaneously, the sequential event links narrative structures that occur subsequently. Both simultaneous event and sequential event were found in the data. This supports van Leeuwen's (2005) observation in films, where both simultaneous and sequential events are frequently used to help the narration of a story.

In what follows, the realizations of simultaneous event are introduced before moving to the realizations of sequential event. The temporal linking of simultaneous event can be realized by the co-presence of several narrative figures in an image, which emerge at the same time. Figure 5.25 presents examples of simultaneous event realized by the co-presence of narrative figures.



(A2-MH-2)

Figure 5.25 Examples of simultaneous event realized by the co-presence of narrative figures

As in Figure 5.25, Image A2-MH-2 contains an analytical figure (a schematic drawing of Magdeburg Hemispheres) and three groups of narrative figures. The first group of narrative figures showed that air molecules were moving at random directions (non-transactional action figures, Actor: grey dots + Vector: black arrows). The second group of narrative figures represented the collision between air molecules and the internal surface of Magdeburg Hemispheres (transactional action figures, Actor: grey dots + Vector: red bound arrows + Goal: inner layer of a schematic drawing of Magdeburg Hemispheres). The third group of narrative figures represented the collision between air molecules and the external surface of Magdeburg Hemispheres (transactional action figures, Actor: grey dots + Vector: blue bound arrows + Goal: outer shell of a schematic drawing of Magdeburg Hemispheres). When Image A2-MH-2 was displayed, all the visual structures appeared together. The simultaneous appearance of these narrative figures suggests that the temporal linking among them are simultaneous events.

Another sub-type of temporal linking is called sequential event. In van Leeuwen's (2005) study of films, the realization of the sub-type of sequential event is cut or other transition to the next action or event, which is very different from the ways of realizing sequential event in PowerPoint slideshows. The sub-type of sequential event in images presented on the slideshow can be realized in four ways. The first way to realize sequential event is to sequentially display one image after another, both of which have narrative figures. Figure 5.26 illustrates the realization of sequential event by sequentially displaying images.

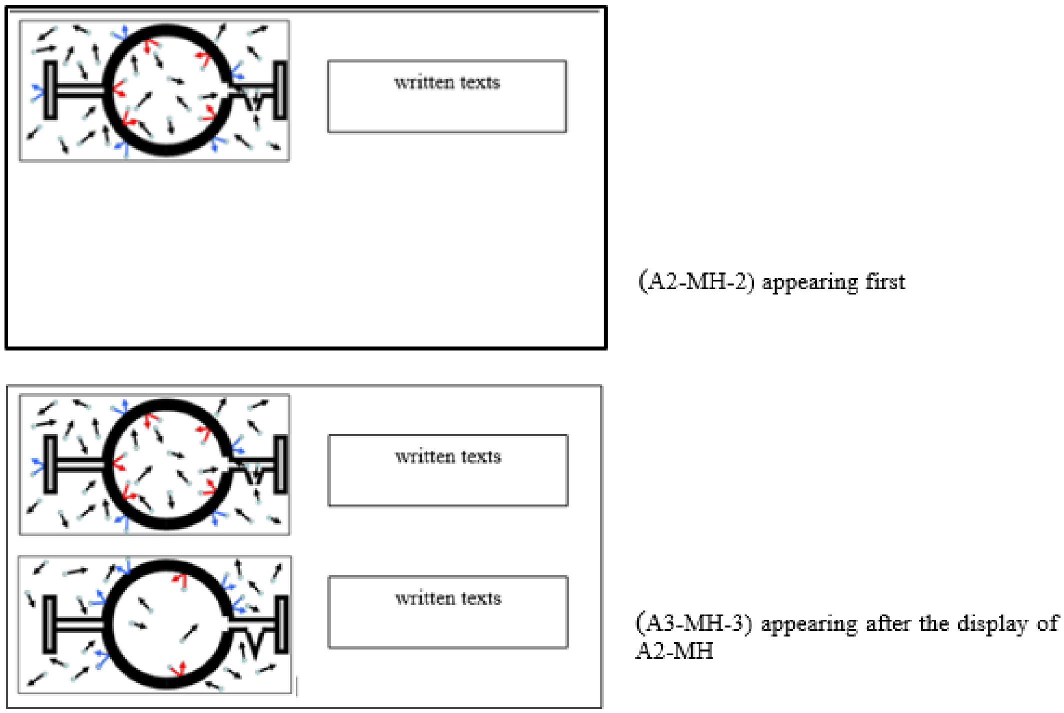


Figure 5.26 Examples of sequential event realized by sequential display of images

As illustrated in Figures 5.26, Image A2-MH-2 appears before Image A3-MH-3. The subsequent display of these two images created sequential links between narrative structures in Image A2-MH-2 and those in Image A3-MH-3. For instance, all non-transactional action figures in Image A2-MH-2 (Actors: grey dots + Vectors: black arrows) occurred prior to those in Image A3-MH-3 (Actors: grey dots + Vectors: black arrows).

The second way of showing sequential linking is to display the images including narrative structures in subsequent slideshows. Figure 5.27 presents two subsequent slideshows, each has an image with narrative structures.

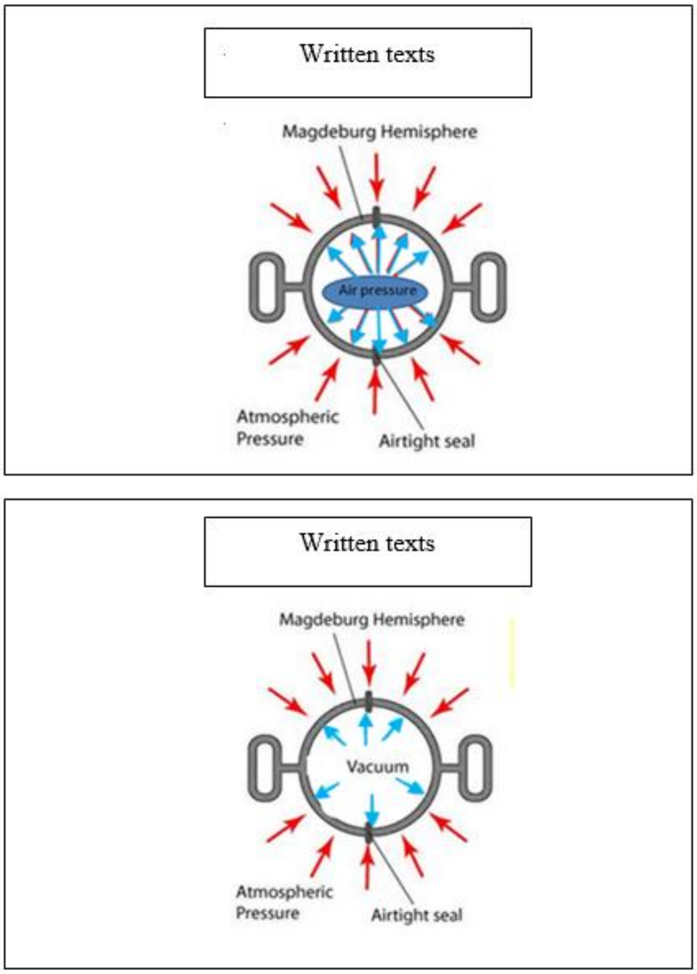
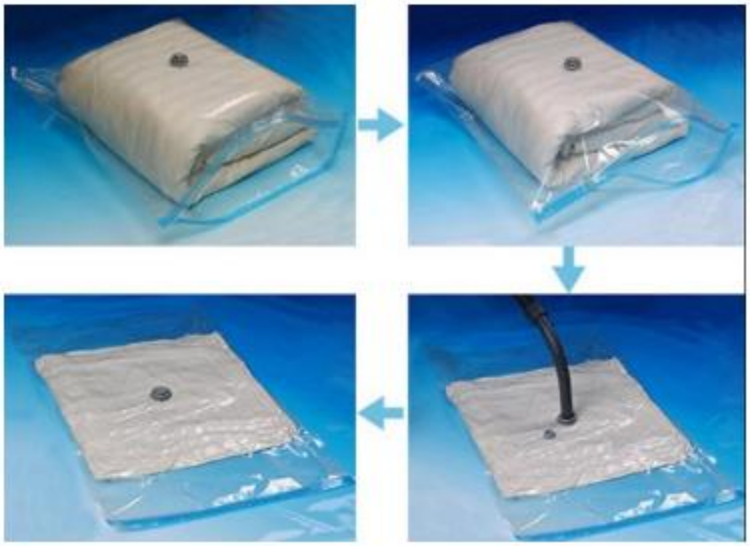


Figure 5.27 An example of sequential event realized by images on subsequent slideshows

The narrative structures in these two images were two groups of event figures, one group with the vectors of red arrows and the other group with the vectors of blue arrows. These event figures showed the exertion of air pressure on both the internal surface of hemispheres (Vector: blue arrows + Goal: inner layer of a schematic drawing of Magdeburg Hemispheres) and the external surface of hemispheres (Vector: red arrows + Goal: outer shell of a schematic drawing of Magdeburg Hemispheres). The subsequent display of these two slideshows created the sequential linking between all the narrative structures on the image that was shown previously and those shown on the subsequent image. Thus, the event figures in the first image occurred prior to those in the second image.

It is important to discuss the consequences of the first way and the second way of realizing sequential event. While both construct a sequential linking between narrative figures in one image and those in another image, their main difference lies in the presence of narrative figures in the prior image. The first way of realizing sequential event through sequential display of images on one slide enables the presence of both previous events and subsequent ones as all narrative figures are shown. Conversely, the second way of realizing sequential event only afford the presence of either previous events or subsequent events. This partial presentation results in difficulty in constructing the type of logical linking, where entities and their properties are compared (see Section 5.3.4 for detailed discussions on logical linking).

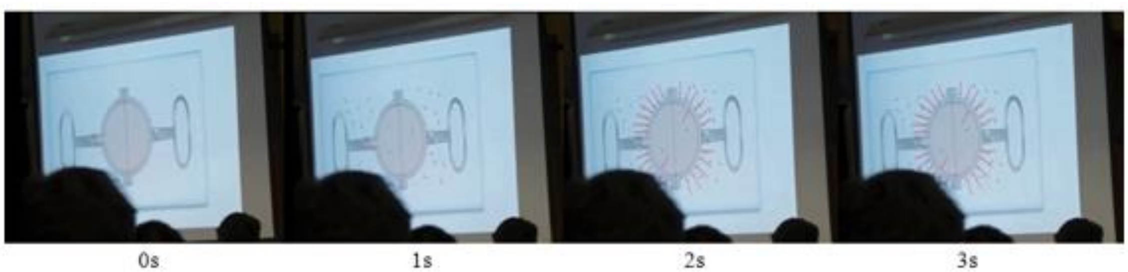
The third way of showing sequential linking is to use visual cues, such as arrows pointing one image to another (see Figure 5.28). Figure 5.28 presents four photographs with three blue arrows pointing from one photograph to another. Each photograph consists of an analytical figure, showing the attributes of a quilt inside a vacuum bag. A significant difference in these analytical figures is the volume of the quilt. Being the vectors of an activity sequence, these blue arrows in Image A10-VG-1 implied a sequential linking between these analytical figures (see Section 5.2.1.3 for details on activity sequences). This leads to the interpretation of these four images as a chain of transactional action figures that depict the decrease in the volume of a quilt inside a vacuum bag after being vacuumed.



(A10-VG-1)

Figure 5.28 Examples of sequential event realized by visual cues

The fourth way of showing sequential linking is to display several narrative structures sequentially in an animated image (see Figure 5.29).



(A6-MH-6)

Figure 5.29 An example of sequential event realized by an animated diagram

As Figure 5.29 illustrates, Image A6-MH-6 was an animated diagram, lasting for three seconds. When this animated diagram was displayed, an analytical figure, showing the shape and structure of Magdeburg Hemispheres appeared first. In the 1st second, a group of non-transactional action figures (Actors: grey dots + Vectors: black arrows) emerged, representing the random movement of air molecules. This was followed by the emergence of two groups of event figures (Vectors: red arrows + Goal: a schematic drawing of Magdeburg Hemispheres), showing the exertion of air pressure upon both the external and internal surfaces of hemispheres. The sequential emergence of the non-transactional action figures and the event figures established the sequential links between these two types of narrative figures. The sequential event in this animated force diagram led to the interpretation of the movement of air molecules (shown as grey dots with arrows in 1s) and the exertion of air pressures (shown as red arrows in 2s and 3s) as sequentially occurred events.

5.3.3 Spatial linking

Spatial linking concerns links between the visual structures based on locations. Spatial linking is divided into two sub-categories: spatial co-presence and spatial co-reference. A spatial co-presence link is created when visual structures (conceptual and narrative) are shown in the same location. Examples of spatial co-presence link are illustrated in Figure 5.30.

(B4-AP-4)

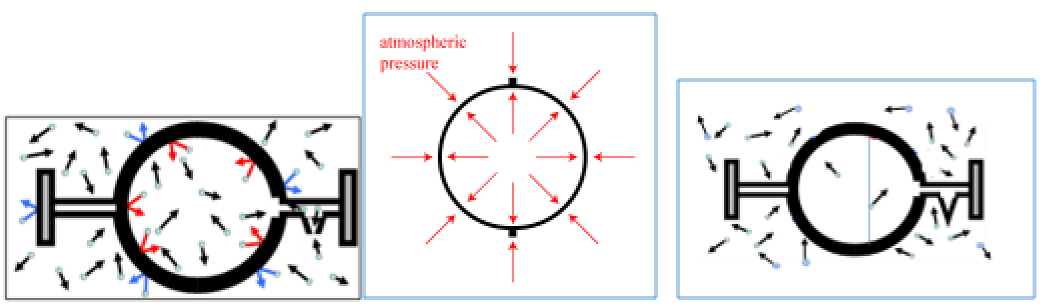
(B21-MH-15)

Figure 5.30 Examples of spatial co-presence realized between conceptual and narrative structures

Image B4-AP-4 showed two analytical figures, one being the elephant with a close shot and the other being the elephant with a long shot. These two analytical figures were linked through the spatial co-presence as suggested by the same depiction of location.

Spatial co-presence can also be realized between narrative structures. For instance, Image B21-MH-15 presented two visual structures: a transactional action figure (Actor: two groups of horses + Vector: red arrows and position of the horses + Goal: Madgeburg Hemispheres), and a transactional reactional figure (Reacter: a man + Phenomenon: the actions of these horses). The co-presence of these two narrative figures suggested that it was in the same venue that two groups of horses were pulling the Magdeburg Hemispheres and a man was watching this action.

As for spatial co-reference link, the location for these conceptual/narrative structures is abstracted from an actual place but the place for these structures is assumed to be the same based on the visual cues. While the type of spatial co-presence linking was observed in both iconic and schematic representations in one image, the type of spatial co-reference linking was typically associated with the schematic representations across images. Figure 5.31 illustrates one example of spatial co-reference in schematic representations.



(A2-MH-2) (B14-MH-8) (B19-MH-13)

Figure 5.31 An example of spatial co-reference in schematic representations across images

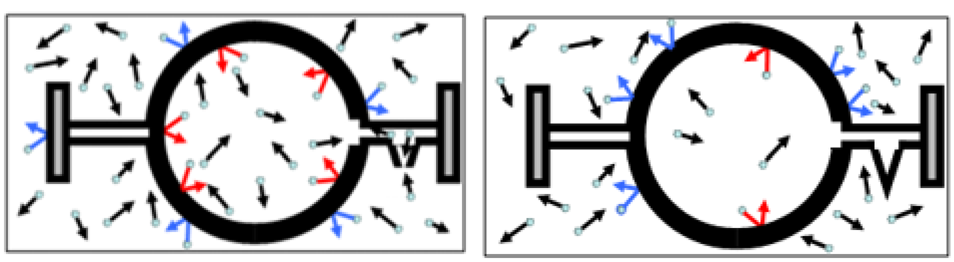
Figure 5.31 shows three images, each presenting one analytical figure (the schematic drawing of Magdeburg Hemispheres) and a number of action figures, suggested by the vectors of arrows. For instance, in Image A2-MH-2**,** the action figures consisted of transactional action figures (Actor: grey dots + Vector: red and blue arrows + Goal: the surfaces of Magdeburg Hemispheres) and non-transactional action figures (Actor: grey dots + Vector: black arrows). The analytical figure provided the circumstance of these action figures, that is, the surfaces of an instrument called Magdeburg Hemispheres.

Through the depiction link between these analytical figures (see Section 5.3.1 for details about depiction), all the action figures in these images were linked through spatial co-reference. The power of spatial co-reference lies in configuring a number of narrative visual structures across images in a decontextualized way so that the visual meanings are no longer constrained by the situation of "here and now".

5.3.4 Logical linking

The fourth type of linking, the logical linking concerns the comparison within an image or between images to extract the similarities and differences. The type of logical linking consists of two sub-categories: similarity and contrast. These two sub-categories are usually co-adopted to support the development of science reasoning (e.g. Ainsworth, 2006; Lemke, 2002; Liang, 2005). The similarity and contrast linking can be used to connect similar narrative structures or similar conceptual structures. Two ways of establishing the similarity linking were identified in the images displayed on PowerPoint slideshow: the use of color and visual symbols.

The first way of establishing similarity linking is using the same or similar color to construe visual structures. Figure 5.32 shows an example of creating similarity linking between narrative structures in two images.



(A2-MH-2) (A3-MH-3)

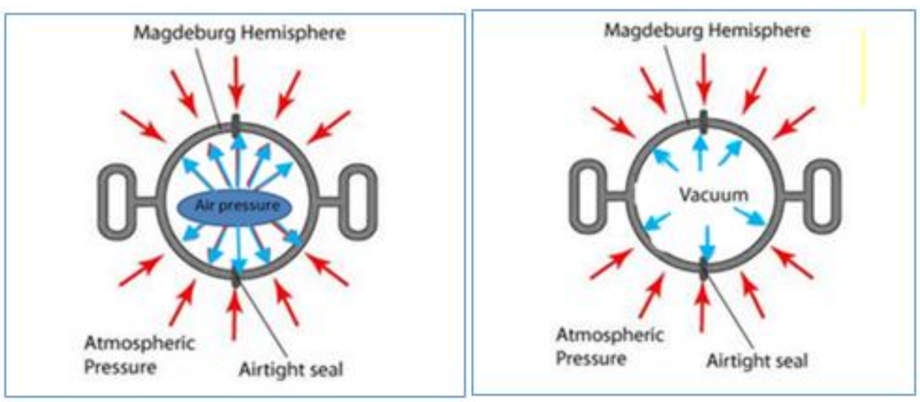
Figure 5.32 An example of similarity realized by the use of color and visual symbols

Consistent choice of color was observed in both Image A2-MH-2 and Image A3-MH-3. In both images, grey dots were used to represent the air molecules, which were the participants in several action figures. Similarly, black was used to show a schematic drawing of Magdeburg Hemispheres. Red arrows were used to represent the collision between air molecules and the internal surface of hemispheres whereas blue arrows were used to represent the collision between air molecules and the external surface of hemispheres. Apart from linking the participants and processes, the use of color can link the circumstances. For instance, in Figure 5.27, the color blue was used as the background for all four photographs, representing that the circumstance for the conceptual structures was the same (see Section 5.2.3.1 for discussions on the conceptual structures embedded in an activity sequence).

The second way of establishing similarity linking is using similar visual symbols, such as the bound arrows and straight arrows in Image A2-MH-2 and Image A3-MH-3 (see Figure 5.32). In both images, the bound arrows were consistently used as the vectors of transactional figures to represent the collision between air molecules and the surfaces of an instrument. The straight arrows were consistently used as the vectors of non-transactional figures to represent the random movement of air molecules without any collision (see Section 5.2.1 for detailed discussions on transactional and non-transactional figures). The consistent use of these two types of arrows led to an understanding of two types of activities by air molecules: the interpretation of transactional figures as the collision and of non-transactional figures as the random movements, which were presented in both images so that the link of similarity was established between the action figures in Image A2-MH-2 and those in Image A3-MH-3.

While similarity linking mainly concerned the links between participant, process and circumstance in several visual structures, the contrast linking contributed to the links between scalar and vector quantities attributed to the participants in these visual structures. Scalar quantities were typically shown through the amount of structures and variants of the arrow. For instance, in Image A2-MH-2 and Image A3-MH-3 (see Figure 5.32), the number of air molecules inside the hemispheres before and after vacuuming were represented as the number of grey dots. By comparing the number of grey dots in Image A2-MH-2 and that in Image A3-MH-3, the decrease in the number of air molecules after vacuuming was observed. Another example can be the number of transactional figures inside and outside the hemispheres in Image A3-MH-3. There were two transactional figures inside the hemispheres (using red bound arrows as vectors) and five transactional figures outside the hemispheres (using blue bound arrows as vectors). The difference in the number of transactional figures meant that the size of the air pressure inside the hemispheres differed from that outside the hemispheres.

Another way to link the scalar/vector quantities through contrast linking is using variants of visual symbols, such as variants of the arrow. Figure 5.33 presents an example of contrast linking in scalar/vector quantities realized by variants of the arrow.



(A4-MH-4) (A5-MH-5)

Figure 5.33 An example of contrast linking realized by variants of visual symbols

As Figure 5.33 illustrates, the scalar quantity of air pressure was related to the length and width of the arrows in Image A4-MH-4 and Image A5-MH-5. In both images, while the length of the red arrows and that of the blue arrows was the same in Image A4-MH-4, the length of the red arrows was longer than that of the blue arrows in Image A5-MH-5. This difference suggests that in Image A4-MH-4, the air pressure outside the hemispheres (represented as red arrows) equaled to that inside the hemispheres (represented as blue arrows) whereas in Image A5-MH-5, the air pressure outside the hemispheres was larger than that inside the hemispheres. This supports Kress and van Leeuwen's (2006) finding that variants of the arrow may affect the meaning in narrative diagrams. In addition to Kress and van Leeuwen's observation that the variants of the arrow impact the meaning of a process, this study has identified their influences on the meaning of a collection of narrative structures, which collectively function to construct quantitative reasoning.

The types of visual linking and their realizations in visual structures are summarized in Figure 5.34. The abbreviations are “analytical” for an analytical figure, “action” for an action figure, and “symbolic” for a symbolic attributive figure. For instance, the realization of depiction through a combination of analytical figures will be presented as Analytical + Analytical.

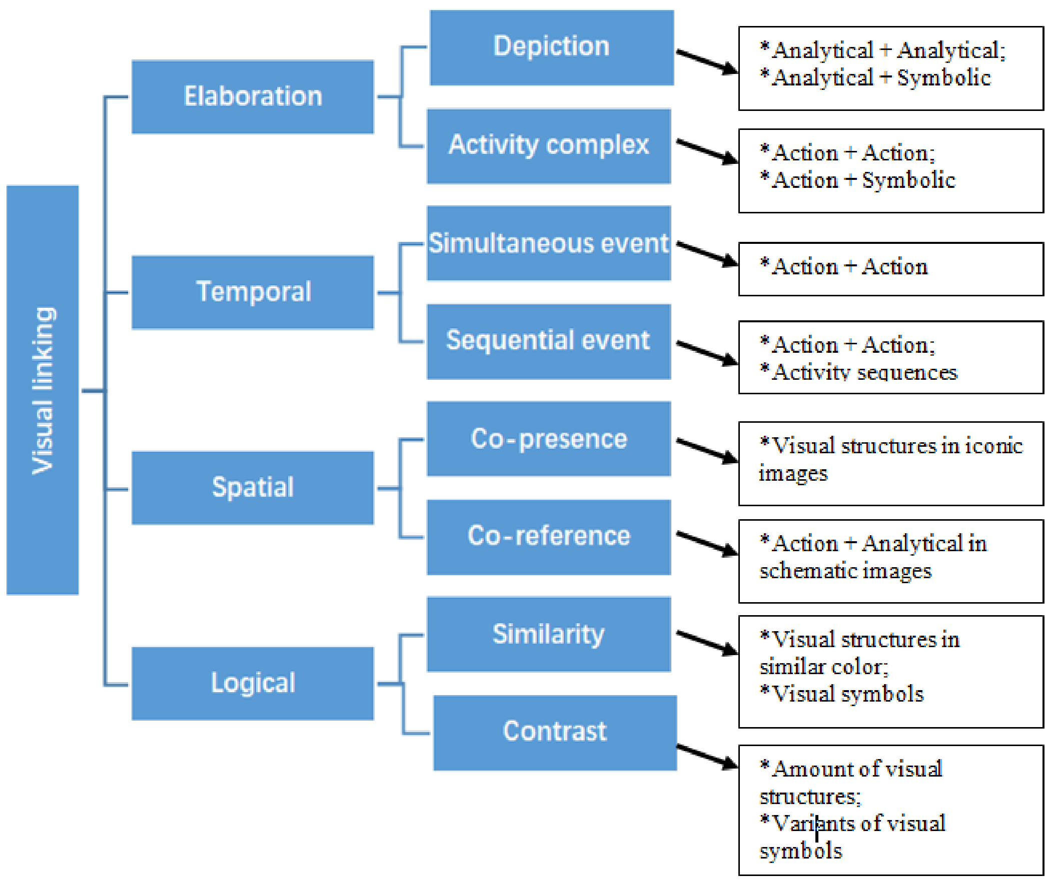


Figure 5.34 Types of visual linking and their realizations

Based on the number of visual structures to realize visual linking, the complexity of logical meaning can be evaluated. The next section, Section 5.3.5 will discuss how logical meanings can be evaluated and their contribution to the recontextualization of scientific knowledge related to air pressure.

5.3.5 Recontextualizing scientific knowledge through logical meanings in images

This section assembles four types of visual linking presented in previous sections, namely, elaboration linking (Section 5.3.1), temporal linking (Section 5.3.2), spatial linking (Section 5.3.3) and logical linking (Section 5.3.4), to discuss how they contribute to the recontextualization of air pressure-related concepts in two science classrooms. The distribution of each type of visual linking in two science classrooms will be presented, which is followed by an illustration of how logical meanings can be constructed through visual linking to recontextualize scientific knowledge.

The distributions of four main types of visual linking are presented in Figure 5.35.

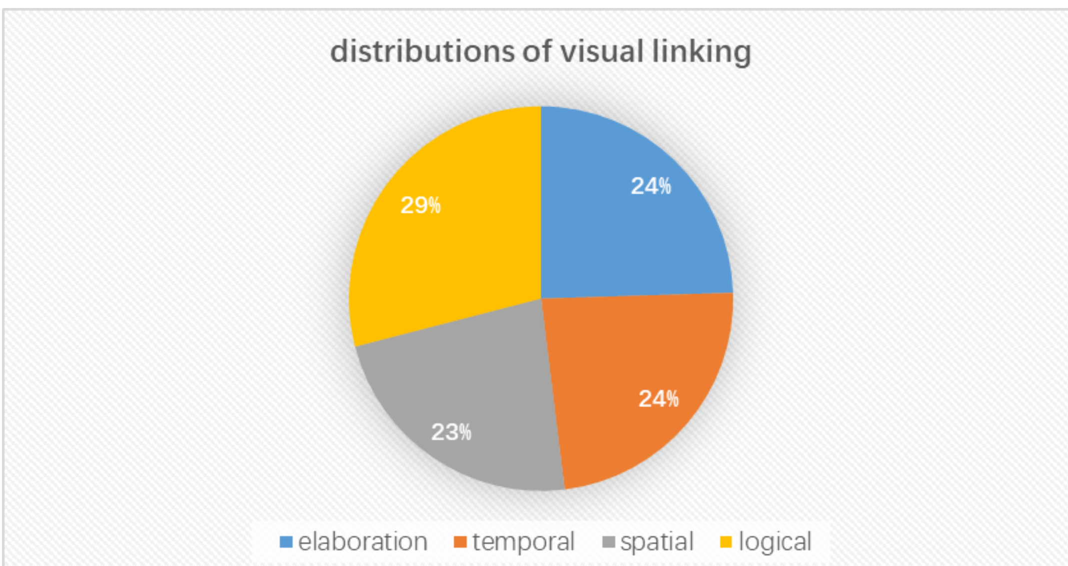


Figure 5.35 The distributions of visual linking

As Figure 5.35 shows, the distributions of elaboration, temporal, spatial and logical linking were even, with a slightly higher presence of logical linking (29%). This suggests that to fully appreciate the logical meanings in images, viewers are expected to have a comprehensive understanding of all types of visual linking. The slightly prominence of logical linking can be explained by the nature of knowledge under analysis, namely air pressure, which is a scalar quantity where comparing and contrasting is crucial.

The distributions of these four types of visual linking including their subcategories in Lesson A and Lesson B are presented in Table 5.3. Because the number of images in Lesson A differs significantly from that in Lesson B, the number of visual linking varies in both lessons. Therefore, the percentage of each subcategory based on the total number of visual linking in each class is compared between Lesson A and Lesson B (see Figure 5.36).

Table 5.3 Distributions of visual linking in Lesson A and Lesson B

Visual linking		**Lesson A**	**Lesson B**	**Occurrence**	**Percentage (%)**
Elaboration	Depiction	24	40	64	13%
	Activity complex	21	40	61	12%
Temporal	Simultaneous event	16	47	63	12%
	Sequential event	22	35	57	11%
Spatial	Co-presence	0	29	29	6%
	Co-reference	27	61	88	17%
Logical	Similarity	41	51	92	18%
	Contrast	20	36	56	11%
Total		171	339	510	100%

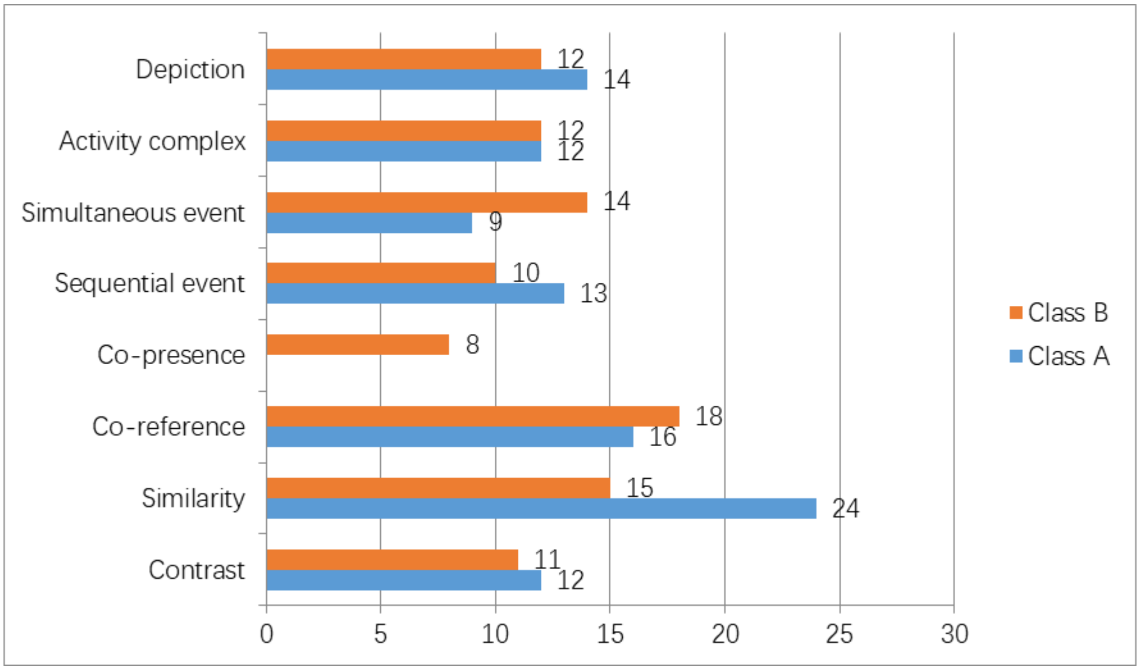


Figure 5.36 The percentage of each subcategories of visual linking in Lesson A and Lesson B

As **错误!未找到引用源。** shows, the most prominent subcategory of visual linking was similarity (18%), followed by co-reference (17%), depiction (13%), activity complex (12%), simultaneous event (12%), sequential event (11%), contrast (11%) and co-presence (6%). The prominence of similarity (18%) is not surprising as it is the typical feature that viewers tend to search for when viewing images. Although the overall proportion of contrast is not significant, this sub-type of visual linking is crucial for establishing quantitative reasoning, where scalar quantities, such as amount, volume and pressure are compared (through similarity linking) and contrasted (through contrast linking). The higher presence of co-reference (17%) compared with the scarce presence of co-presence is because more schematic images were used in these lessons about air pressure than iconic images, which in turn highlights the abstract nature of the visual representations of air pressure. A significant difference in similarity linking was observed between Lesson A and Lesson B. This can be explained by different types of visual representations used in images in Lesson A and those in Lesson B. While most images in Lesson A represented instruments for experiment and observational entities such as air molecules, those in Lesson B showed a greater variety of representations, ranging from instruments and observational entities, to people, animals and the earth.

Those representations that are distantly related to explaining air pressure-related phenomena, such as people, animals and the earth, require elaborations from language to explicit their connection to the knowledge of air pressure. For instance, when the representation of elephants was used in Lesson B, the teacher related this representation of animals to air pressure through a verbal analogue, that "At sea level the air pressure is about 100000 Pa, which is similar to the pressure exerted by the leg of an elephant on the ground.". How images and spoken language collectively contribute to the construction of an explanation will be discussed in detail in Section 5.4.

It is important to point out that logical meanings were constructed through the co-deployment of these visual linking. The development of logical meanings in images is illustrated through the case of Magdeburg Hemisphere experiment. Figure 5.37 shows six images that were used in the teaching stage of explaining Magdeburg Hemispheres. Image A1-MH-1 was a photograph of the instruments used for this experiment (i.e., Magdeburg Hemispheres and a tube), with the properties of these instruments visualized through analytical figures. The co-presence of three symbolic attribute figures assigned linguistic names to instruments or components of instruments (i.e., Magdeburg Hemispheres, tubing and valve). Both Image A2-MH-2 and Image A3-MH-3 were vector diagrams showing the instrument Magdeburg Hemispheres and the observational things, air molecules. The similar analytical figures about Magdeburg Hemispheres were presented in these two images as well as Image A1-MH-1, suggesting a depiction linking. The narrative figures in Image A2-MH-2 were linked through co-presence, suggesting that air molecules were moving randomly (through non-transactional figures) and some of them collided with the hemispheres (through transactional figures). The narrative figures in Image A3-MH-3 were also linked through co-presence. However, the sequential display of Image A2-MH-2 and Image A3-MH-3 inserted a sequential event linking between the narrative figures in Image A2-MH-2 and those in Image A3-MH-3. Also, the scalar quantities in Image A2-MH-2 and those in Image A3-MH-3 were linked through similarity and contrast linking. From the combination of the sequential event linking, similarity and contrast linking in Image A2-MH-2 and Image A3-MH-3, the viewers are able to infer at least that (1) the number of air molecules colliding with the internal surface of hemispheres equals that colliding with the external surface of hemispheres (in Image A2-MH-2); (2) the number of air molecules colliding with the internal surface of hemispheres is less than the that colliding with the external surface of hemispheres (in Image A3-MH-3); and (3) the number of air molecules inside the hemispheres in Image A2-MH-2 less than that shown in Image A3-MH-3 while the number of air molecules remain the same outside the hemispheres in both images.

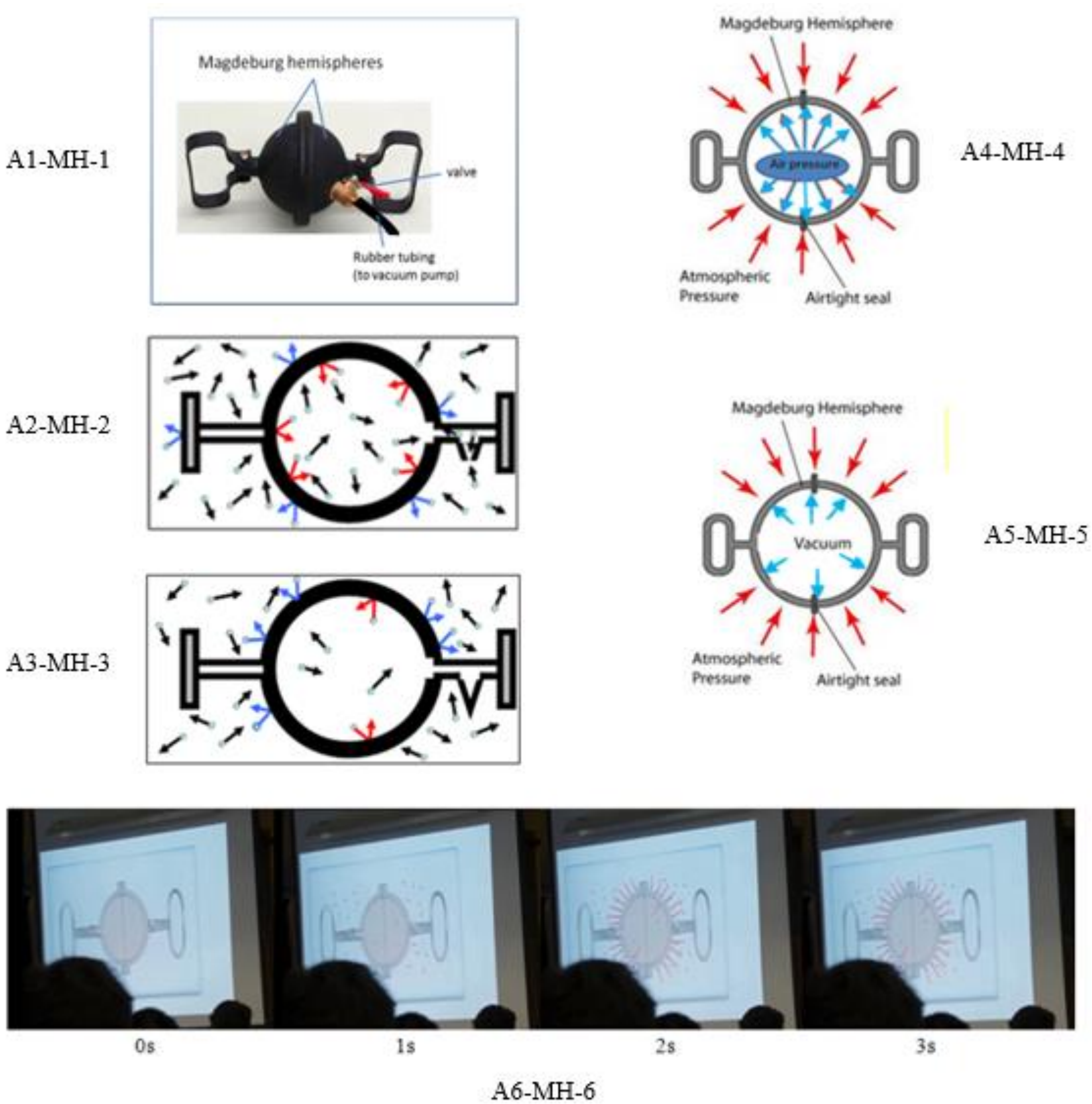


Figure 5.37 The images used to explain Magdeburg Experiment in Lesson A

As for the visual linking in Image A4-MH-4 and Image A5-MH-5, the combination of depiction, sequential event, co-presence/co-reference, similarity and contrast visual linking were used. The inference the viewers could draw include but are not limited to the following: (1) that the air pressure inside the hemispheres equals that outside the hemispheres (in Image A4-MH-4); (2) that the air pressure inside the hemispheres is less than that outside the hemispheres (in Image A5-MH-5); and (3) that the air pressure inside the hemispheres in Image A4-MH-4 is less than that in Image A5-MH-5 while the air pressure outside in both images is the same.

Image A6-MH-6 was an animated force diagram, which involved the visual linking: depiction, activity complex, sequential event, co-presence, similarity and contrast. The depiction linking was used to relate the schematic representation of hemispheres to those that are presented in the previous images. The activity complex linking in Image A6-MH-6 linked the narrative structures about the number of air molecules (in Image A2-MH-2 and Image A3-MH-3) to those about the size of air pressure (in Image A4-MH-4 and Image A5-MH-5). The sequential event linking was realized through the display of this animated force diagram: the narrative figures representing the movement of air molecules occurred prior to the narrative figures representing the exertion of air pressure. The co-presence linking was mainly used to present the scalar quantities of air molecules (i.e. amount and pressure). The similarity and contrast linking was mainly used to compare the scalar quantities of air molecules (i.e. amount and pressure).

In sum, four types of visual linking were identified in the images: elaboration, temporal, spatial and logical. While the temporal linking and spatial linking were used to connect the narrative meanings, the elaboration and logical linking were used to connect both the narrative meanings and conceptual meanings. The temporal linking organized the narrative figures into an activity sequence; the spatial linking bounded the narrative figures that occurred in the same location. The elaboration linking created synonymous relation between the depictions of the same object or activity complex. The depiction of object was realized through the combination of symbolic attributive figures and analytical figures. The activity complex was realized through the combination of symbolic attributive figures and narrative figures. Although the logical linking of similarity and contrast contributed to both narrative and conceptual meanings, they were mainly used for comparing the scalar quantities of the scientific entity, which were shown in narrative structures (e.g. the number of air molecules).

Like any other semiotic modes, images have potentials and constraints in affording meaning, which are shaped by the materiality and the social conventions (Kress, 2000; Lemke, 200). Images can simplify the phenomena under investigation, by deleting the unrelated details and visualizing the invisible scientific entities and thus making how and why the phenomena occur more accessible to the students. Images are also capable of modeling the relations between the actions and interactions that occur among scientific entities through multiple visual structures with logical links. However, the types of logical meanings in images are more restricted than those in language (e.g. van Leeuwen, 2005; Bateman, 2014). For instances, images cannot precisely assign the causal relations between activities, which is crucial for an explanation.

The types of visual linking identified in the images are shaped by the materiality and the context where it is produced. These images are presented in the PowerPoint slideshows, which enriches the juxtaposition of visual linking, such as the case of Image A6-MH-6. The juxtaposition gives rise to the multiple functions that the visual elements perform (Doran, 2016). For instances, the visual element of a hollow circle representing the hemispheres, form an analytical structure for the hemispheres, which creates elaboration linking to other depictions of hemispheres. It can also be viewed as the location where the activities of air molecules occur, which creates the spatial linking to the random movement of air molecules and the collision between air molecules and the hemispheres. These images are selected by the teacher and used for classroom teaching and learning, which means that some visual linking can be made more prominent than others through the cues from other semiotic resources, such as language. The next section, Section 5.4 shows how the explanations are constructed through the collective efforts of language and images.

5.4 Multiplying meanings between language and images

This section presents the findings related to the multiplication of meanings between language and images, specifically how relations between spoken language and images can contribute to the construction of scientific explanations. The multiplication of meanings between language and images were examined from two dimensions: status and logical semantic relations. This section starts with a description of displayed images and activated images (Section 5.4.1) before presenting an overview of findings on the relations between spoken language and activated images in terms of status and logical relations (Section 5.4.2). This is followed by detailing the three main categories of logical semantic relations in Section 5.4.2, namely, elaboration (Section 5.4.3.1), enhancement (Section 5.4.3.2), and extension (Section 5.4.3.3). Section 5.4.5 discusses how image-text relations can contribute to the recontextualization of air pressure-related concepts and explanations.

5.4.1 Displayed images and activated images

This section presents the findings related to the status between language and images in constructing explanations, that is, how semiotic labor is distributed in the modes of language and images. Before discussing the status of language and images, it is important to distinguish two ways of using images: to display or to activate. When an image is showed on the slideshow for a period, without being referred to by the teacher verbally, it is considered as an image being displayed. The meanings in the displayed images are still accessible to the students, if they are noticed by the students. When an image is not only displayed but also referred to by the teacher, it is considered as an image being activated. The cue for the activation of an image can be either verbal or gestural, such as the use of demonstrative pronoun “this” in “this image” (verbal cue) and a pointing gesture (gestural cue). In this case, the students’ attentions are directed towards the image. Such distinction enables us to evaluate the prominence of each image. Figure 5.38 illustrates the number and proportion of images being displayed and those being activated.

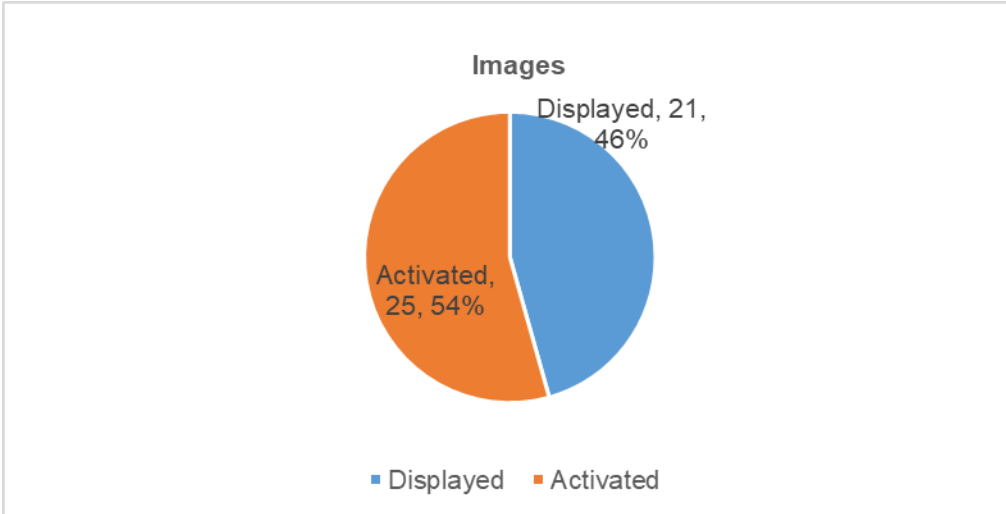


Figure 5.38 The proportion of images being displayed and those being activated

As Figure 5.38 shows, more than half of the images (54%) were activated through either gestural or verbal cues while simply displayed, with 46 % of images being simply displayed. This suggests that students are assumed to be able to interpret half of these images autonomously. However, both representative meanings (see Section 5.2 for details) and logical meanings (see Section 5.3 for details) in these images can be complex enough to present considerable challenges for both teachers and students. Figure 5.39 illustrates two examples of the images with complex representative and logical meanings but were only displayed.

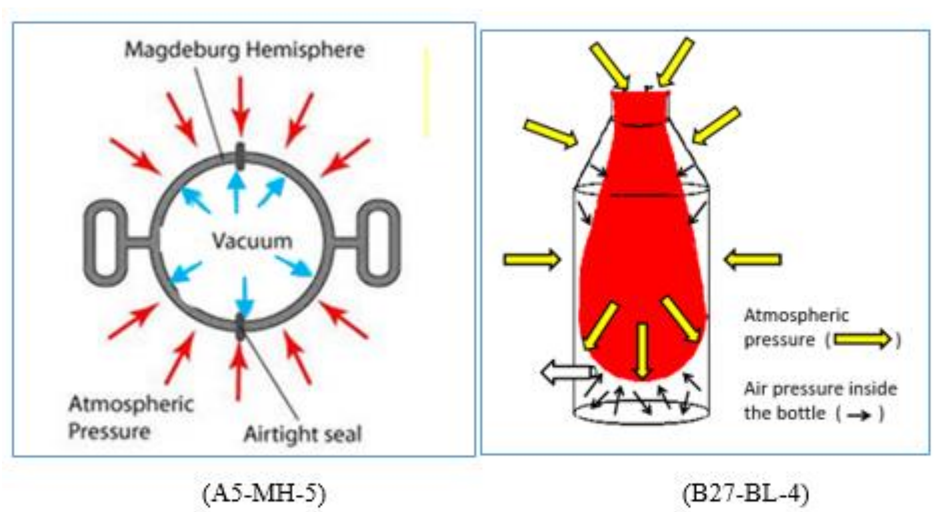


Figure 5.39 Examples of images being displayed with complex visual meanings

In Image A5-MH-5, three types of representational meanings were presented: analytical figures, action figures and symbolic attributive figures. While the analytical figure depicted a schematic drawing of Magdeburg Hemispheres, the symbolic attributive figures labeled the visual elements in their linguistic names. Two groups of action figures represented the exertion of air pressure on both internal and external surfaces of the instrument (see Section 5.2 for detailed discussions on representational meanings in images). Also presented in this image were the logical linking of depiction, activity complex, simultaneous event, sequential event, co-reference, similarity and contrast. For instance, the logical linking of depiction related the analytical figure of Magdeburg Hemispheres in Image A5-MH-5 to other visual depictions of this instrument. The logical linking of activity complex of these action figures illustrated the omni-directional behavior of air pressure, which existed in all directions equally. The logical linking of similarity and contrast established the quantitative reasoning by comparing the number of action figures within this image and that between this image and another one (see Section 5.3 for detailed discussions on logical meanings in images).

Image B27-BL-4 was similar to Image A8-BL-2 (see Figure 5.24) in terms of both representational and logical meanings. However, while Image A8-BL-2 was activated in Lesson A, Image B27-BL-4 was simply displayed in Lesson B. Detailed discussions on the comparison between the interactive meanings in images between Lesson A and Lesson B will be presented in Section 5.3.

Representationally, this image consisted of analytical figures, action figures and symbolic attributive figures. For instance, the action figures demonstrated two types of activities, that is, the exertion of air pressure and the action of vacuum. Logically, this image incorporated the logical linking of depiction, activity complex, sequential event, simultaneous event, co-presence, similarity and contrast. The visual meanings in those images were densely packed and interweaved, which required advanced level of visual literacy. Therefore, it is suggested that a detailed demonstration of how to interpret a type of image can be presented in the beginning of the lesson, followed by several trials of interpreting the similar type of image by students with corrections and feedbacks, before requiring students to interpret this type of image independently.

In what follows, how visual meanings in images can be activated to interact with the spoken texts is reported in terms of status and logical relations.

5.4.2 Status and logical relations between language and images

The multiplication of meanings between activated images and spoken texts is considered in terms of status and logico-semantic relations. While the status concerns the relative dependence between image and text, the logico-semantic relations specify the semantic relations that link image and text. The number of the clauses in the spoken texts and their interaction with the images are summarized in Table 5.4.

Table 5.4 The status and logico-semantic relations between image and spoken texts

status	**Logico-semantic relation**			**Total**
	elaboration	enhancement	extension	
unequal	13	16	19	48 (91%)
equal	1	0	4	5 (9%)
Total	14 (27%)	16 (30%)	23 (43%)	53 (100%)

The status between the activated images and the spoken texts was predominantly unequal (91%). While the unequal states can be [verbal sub. to image] or [image sub. to verbal], only the former type was found, suggesting that the interpretation of the spoken texts was dependent on the images. This was indicated by the multiple use of referential words, such as *this special instrument, this picture,* and *the middle part*. The exceptional instances of equal status co-occurred with the logico-semantic relation of extension and elaboration, where the spoken texts added information to the images in terms of scalar quantity and attribution. The other exceptional instance of equal status co-occurred with the logico-semantic relation of elaboration, to state a fact that the size of air pressure at sea level is 100,000 Pa. Although the equal status was observed, the dominating status of [verbal sub. to image] suggests that when images were activated, they were usually foregrounded to convey meanings, which could be further extended, elaborated or enhanced through spoken language.

Among the three main logico-semantic relations, the most prominent type was extension (43%), followed by enhancement (30%) and elaboration (27%). This suggests that when images were activated, spoken texts were mainly used to expand the meanings in images in terms of adding new but related information. How these meanings were expanded through the logical semantic relation of elaboration, enhancement and extension are detailed in Section 5.4.3.

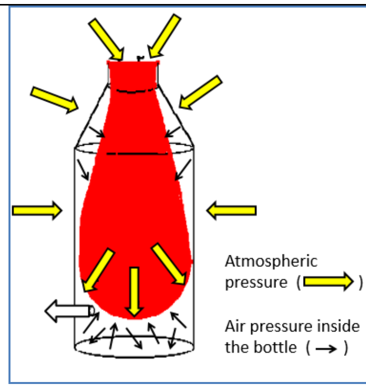
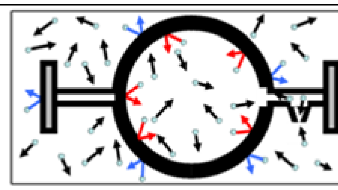
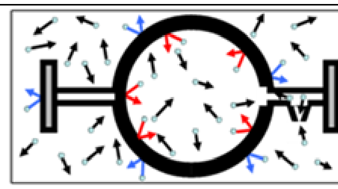
5.4.3 Logical semantic relations between language and images

5.4.3.1 The logical semantic relation of elaboration

The first main category of logico-semantic relation in the system of expansion is elaboration, where the same figure (i.e. processes, participants and circumstances) is depicted visually and verbally. Under the main category of elaboration are two sub-categories: exposition and exemplification depending on the level of abstraction of the visual and verbal depictions. The image-text relation is exposition if the level of abstraction is the same while the image-text relation is exemplification if one mode is more abstract than the other. Both exposition and exemplification were identified in the relation between the images and the spoken texts. The 20 instances of exposition between the image and the spoken texts served two functions. One function was to symbolize scientific entities or their properties while the other function was to identify the visual elements in the images in terms of location and state. The examples of exposition relation are illustrated in

Table 5.5.

Table 5.5 Examples of the logico-semantic relation of exposition elaboration

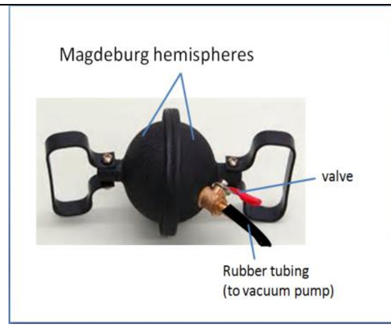
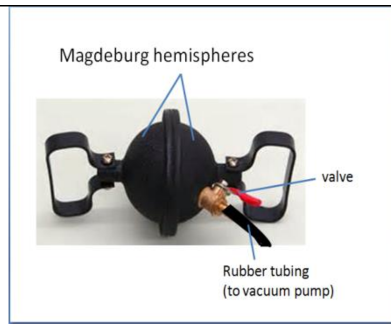
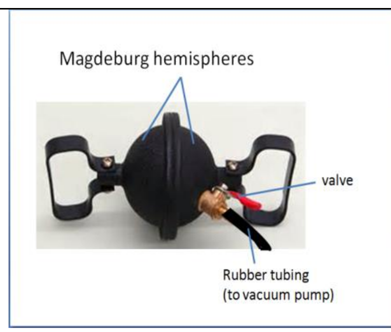
Resource for coordination	Visual unit	Verbal unit
Pointing gesture & speech	 (A8-BL-2) Visual structure: event Visual structure: symbolic	*We have atmospheric pressure here, the yellow arrow.* Verbal structure: relational
Pointing gesture & speech	 (A2-MH-2) Visual structure: analytical	*Can you find the valve in this picture?* Verbal structure: material
speech	 (A2-MH-2) Visual structure: analytical	*It is now open.* Verbal structure: relational

In the first example of exposition, the exertion of air atmospheric pressure was depicted through the visual events shown as yellow arrows pointing to the bottle, which was restated through the relation figure verbally *We have atmospheric pressure here, the yellow arrow,* accompanying a pointing gesture to one of the yellow arrows. Both the image and the spoken text suggested that the yellow arrows symbolized the atmospheric pressure, and thus the image-text were related through exposition. Both gestural (a pointing gesture to the yellow arrow) and verbal (the referential phrase *here*) cues were drawn on to suggest the link. The second example of exposition related the visual analytical structure of Magdeburg Hemispheres in the image to the spoken text *Can you find the valve in this picture?*, where the teacher invited the students to identify the location of valve in the image. Both gestural cue and verbal cue (i.e. the definite articles *this* and *the*) were provided for the coordination. In the third example, the analytical structure of Magdeburg Hemispheres in the image was related to the relation process verbally *It is now open*, suggesting the state of the valve. The verbal cue to suggest the coordination was the use of pronoun *it*, which referred to the visual representation of valve in the image.

Another sub-category of elaboration is exemplification, where the image and the spoken text demonstrate a discrepant level of abstractness. The level of abstractness between the image and the spoken texts are considered unequal when the photograph is used to show an object whereas the speech refers to this type of the object. In this case, the object represented in the photograph is regarded as an example for this type of object in general whereas the use of language refers to the general type of this object. There were four instances of exemplification between the image and the spoken texts, which were used for two purposes. The first purpose was to represent instrument or a part of an instrument through a visual example. The second purpose was to locate one part of an instrument in the visual example. The examples of exemplification relation are presented in

Table 5.6.

Table 5.6 Examples of the logico-semantic relation of exemplification elaboration

Resource to activate	Visual unit	Verbal unit
Pointing gesture & speech	 A1-MH-1 Visual structure: analytical Visual structure: symbolic	*We have this special instrument Magdeburg Hemispheres.* Verbal structure: relational
Speech & pointing gesture	 A1-MH-1 Visual structure: analytical	*Before we start, I want to show you one part of the M.H., here.* Verbal structure: mental
Speech	 A1-MH-1 Visual structure: analytical	*We call it a valve, V-A-L-V-E, valve of the M.H.* Verbal structure: verbal

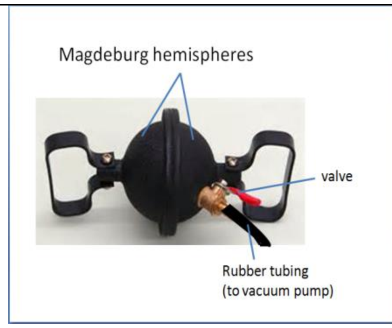
In the first example of exemplification, the instrument Magdeburg Hemispheres was represented through an example in photograph, showing the composing parts of this instrument (two hemispheres, two handles, a valve etc.) its textual (metal) and color (black). The name of this instrument was given in the photograph with a symbolic attributive figure, which was then restated in the spoken text *We have this special* *instrument Magdeburg Hemispheres*. Although the pronoun *this* was used, it should be considered as a general reference to the type of instrument called Magdeburg Hemispheres. The image-text relation here was exemplification. In other words, the visual representation of Magdeburg Hemispheres in the photograph was a specific instance, whereas *Magdeburg Hemispheres* in the spoken texts was a generic reference to this type of instrument. In the second and third example, the location of valve in Magdeburg Hemispheres was identified through the adverb *here* and a pointing gesture at the location of valve in the visual example. The part-whole relation between valve and Magdeburg Hemispheres was established visually and verbally. Visually, the analytical structures in the photograph presented a specific case that this M.H. has a valve; Verbally, the phrases in the spoken texts *one part of the M.H.* and *valve of the M.H.* extended this part-whole relation to a convention, that every M.H. has a valve.

5.4.3.2 The logical semantic relation of enhancement

The second main category of logico-semantic relation in the system of expansion is enhancement, where one mode qualifies the other in terms of circumstance, such as time, place, and purpose. The logico-semantic relation of enhancement consists of five sub-categories: purpose, time, condition, result and manner. These sub-types are discussed in detail with examples.

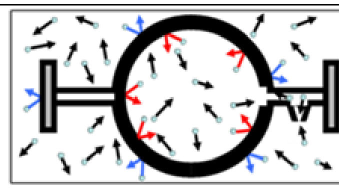
As its name suggests, the sub-category of purpose was used to expand the meaning in terms of the function of an object or the intention of an action. Three instances of purpose relation were identified, two of which were used to assign the function of the instrument Magdeburg Hemispheres, that is, to demonstrate air pressure. The other instance of purpose relation was used to suggest the intention of representing the narrative structures in the image, that is, to explain the activities of air molecules inside the instrument. The activation between the visual unit and the verbal unit was achieved by using the determiners *the* and *this* in the spoken text. The examples of purpose relation are illustrated in Table 5.7.

Table 5.7 Examples of the logico-sematic relation of purpose

<table>
<tr><th>Resource to activate</th><th>Visual unit</th><th>Verbal unit</th></tr>
<tr><td>speech</td><td>

A1-MH-1

Visual structure: analytical
Visual structure: symbolic</td><td>This is a special instrument to demonstrate the power of air pressure.

Verbal structure: relational</td></tr>
<tr><td>speech</td><td>
A2-MH-2

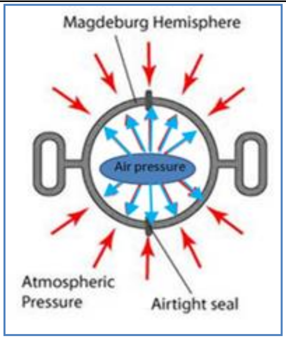
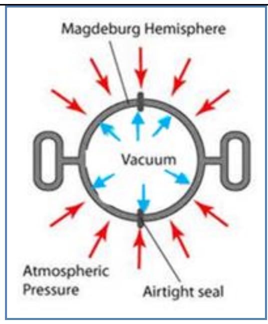
Visual structure: non-transactional (vector: black arrows)
Visual structure: transactional (vector: red arrows & blue arrows)
Visual structure: analytical</td><td>Try to explain what is happening inside the hemispheres.

Verbal structure: verbal</td></tr>
</table>

In Image A1-MH-1, a photograph of Magdeburg Hemispheres, there were an analytical figure and three symbolic figures. While the analytical figure showed the attributes of this instrument, such as shape, color and constituting parts, three symbolic figures assigned the linguistic names to three constituting parts of this instrument. When this image was displayed, the spoken text of a relational clause cooccurred (i.e. *This is a special instrument to demonstrate the power of air pressure.*). The verbal structure enhanced the visual depiction of the instrument by providing its function, that is, to demonstrate the power of air pressure. Image A2-MH-2 showed a schematic drawing of Magdeburg Hemispheres. The visual structures in this image were an analytical figure of Magdeburg Hemispheres, and two groups of narrative figures, formed by the vectors of black arrows and the vectors of red and blue arrows. When this image was displayed, the spoken text (i.e. *Try to explain what is happening inside the hemispheres*) activated the narrative figures inside the hemispheres, which were five transactional figures (red bound arrows as vectors) and eight non-transactional figures (black arrows as vectors). The students were requested to explain the activities of air molecules inside the instrument based on the visual structures presented in the image. The spoken text thus enhanced the narrative meanings in the images in terms of purpose.

The second sub-category is time, where the element of time is expanded to the presented information. There were three instances of the logical semantic relation of time between visual structures and verbal structures, two of which are shown in Table 5.8 as examples.

Table 5.8 The logico-semantic relation of time

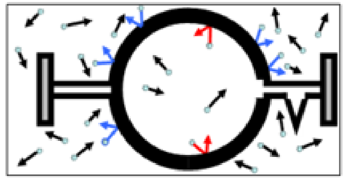
Resource to activate	Visual unit	Verbal unit
Speech & pointing	 B22-MH-16 Visual structure: analytical Visual structure: event (vectors: red arrows) Visual structure: event (vectors: blue arrows)	*So before we suck out the air inside,…..* Verbal structure: material
Speech & pointing	 B22-MH-17 Visual structure: analytical Visual structure: event (vectors: red arrows) Visual structure: event (vectors: blue arrows)	*And then after we suck out the air inside,…* Verbal structure: material

As shown in Table 5.8, Image B21-MH-16 included an analytical figure, showing the attributes of Magdeburg Hemispheres, and two groups of event figures. One group of the event figures were formed by the vectors of red arrows, representing that atmospheric pressure were exerting on the external surface of the instrument. The other group of the event figures were formed by the vectors of blue arrows, representing the exertion of air pressure on the internal surface of the instrument. The verbal statement, *so before we suck out the air inside*, enriched the condition of the visual structures. Integrating the meanings from the verbal structure and the visual structures, we know that before the action of suction, the exertions of air pressures on the internal and external surfaces of the instrument are the same. The visual structures in Image B21-MH-16 are thus enhanced by the verbal structure in terms of condition. Similarly, the visual structures in Image B22-MH-17 were enhanced by the verbal structure in terms of condition. But this time, the circumstance of time enhanced by the verbal structure changed to after vacuuming the instrument (i.e. *And then after we suck out the air inside*,). Synergizing the visual structures in the image and the verbal structure in the spoken text, we know that after being vacuumed, the air pressure inside the hemispheres was smaller than that outside the hemispheres, which was demonstrated through the smaller number of event figures with blue arrows as vectors than those with red arrows.

The third sub-category is condition, where the element of condition is expanded to the presented information. There were three instances of the logical semantic relation of condition between visual structures and verbal structures, marked by the conjunction *when*.

Table 5.9 presents an example of using the conjunction *when* to establish the logical semantic relation of [enhancement: condition].

Table 5.9 The logical semantic relation of condition

Resource to activate	Visual unit	Verbal unit
pointing	 B13-MH-7 Visual structure: analytical Visual structure: non-transactional (vector: black arrows) Visual structure: transactional (vector: red arrows & blue arrows)	*And now when I turn on the vacuum pump,…* Verbal structure: material

As shown in

Table 5.9, Image B13-MH-7 included an analytical figure, showing the attributes of Magdeburg Hemispheres, and three groups of action figures. The first group of the action figures were formed by the vectors of red arrows, representing the collision between air molecules and the internal surface of the instrument. The second group of action figures were formed by the vectors of blue arrows, representing collision of air molecules on the external surface of the instrument. The third group of action figures were shaped by the vectors of black arrows, representing the movement of air molecules without any collision. When this image was displayed, the teacher said *And now when I turn on the vacuum pump*, with a pointing gesture to the image. Through the activation of a pointing gesture, the visual structures were enhanced in terms of condition because this information was not presented in the visual structures but was expanded by the spoken text.

The fourth sub-category is result, where the element of result is provided in the spoken text to expand the information in the images. Only one instance of the logical semantic relation of result was identified, which is presented in

Table 5.10.

Table 5.10 The logical semantic relation of result enhancement

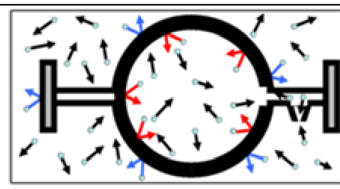
Resource to activate	Visual unit	Verbal unit
pointing	 B21-MH-15 Visual structure: transactional (vector: arrow pointing to the left) Visual structure: transactional (vector: arrow pointing to the right)	*They can't be pulled apart even by sixteen horses.* Verbal structure: material

This only instance of the logical semantic relation of result was activated by a pointing gesture. While Image B21-MH-15 was displayed on the slideshow, the teacher pointed to the image and said that *they can't be pulled apart even by sixteen horses*. The pointing gesture activated the visual units of two transactional action figures, representing the pulling action by two groups of horses to the opposite directions, and the verbal unit (i.e. *They can't be pulled apart*). While the pulling action was represented in the images, the result of this action was expanded by the verbal unit and thus the logical semantic relation of result was established between the visual and verbal units.

The fifth sub-category of the logical semantic relation of enhancement is manner, where the element of manner is provided in the spoken text to expand the information in the images. Only one instance of the relation of manner was identified between Image A2-MH-2 and the corresponding spoken text, which are presented in Table 5.11. Image A2-MH-2 included two main types of visual structures. The first type was an analytical structure, representing the schematic drawing of Magdeburg Hemispheres. The second type was the groups of action figures, formed by the vectors of black, red and blue arrows. These visual structures demonstrated the movement of air molecules inside and outside the hemispheres. When Image A2-MH-2 was displayed, the verbal unit enhanced the visual unit showing the movement of air molecules with the adverb *freely*.

To a certain extent, this suggests the random nature of air molecules' movement. When the valve was open, it was possible for air molecules to move inside or outside the instrument.

Table 5.11 The logical semantic relation of manner enhancement

Resource to activate	**Visual unit**	**Verbal unit**
speech	 A2-MH-2 Visual structure: analytical Visual structure: non-transactional (vector: black arrows) Visual structure: transactional (vector: red arrows & blue arrows)	*Yes that means the air molecules can go inside and outside freely.* Verbal structure: relational

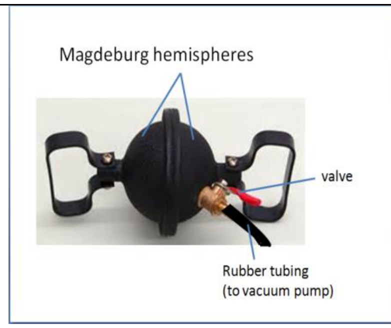
5.4.3.3 The logical semantic relation of extension

The third main category of logico-semantic relation in the system of expansion is extension, where new but related figures are described verbally, adding new but related meaning to the visual depictions. The type of extension adds meanings from four aspects: (1) attribution, (2) analogy, (3) action, and (4) scalar/vector quantity. The first three aspects were associated with the instrument while the fourth aspect was related to the scientific entities. While the extension associated with the instrument was perception-centered, the extension associated with scientific entities focused on the development of quantitative reasoning between the scalar/vector quantities of air molecules.

The first sub-type of extension is attribution, with two instances identified from the data. These two instances of extension attribution were used for assigning quality (i.e. special) to the instrument (i.e. Magdeburg Hemispheres). An example of the logico-semantic relation of attribution is shown in

Table 5.12.

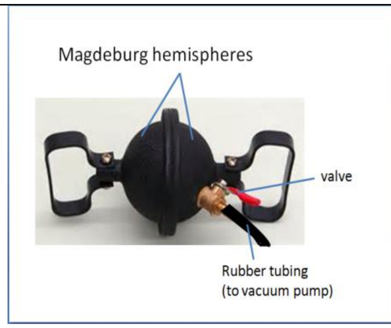
Table 5.12 The logical semantic relation of attribution extension

Resource to activate	Visual unit	Verbal unit
speech	 A1-MH-1 Visual structure: analytical	*This is not a common instrument.* Verbal structure: relational

In Image A1-MH-1, while the attributions, such as shape, color and texture, were presented through the analytical figure of a photograph of Magdeburg Hemispheres, the attribution of quality was not found. The pronoun *this* in the spoken text clearly referred to the instrument shown in Image A1-MH-1 and provided the cue of visual-verbal units to multiply meanings. The spoken text assigned the quality (i.e. special) to the instrument through describing Magdeburg Hemispheres as *not a common instrument*. The logical semantic relation of extension attribution was thus established between the visual unit and the verbal unit.

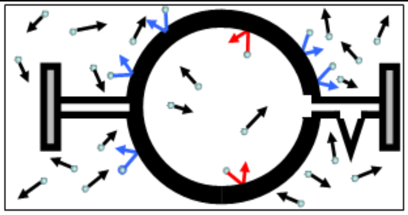
The second subtype of extension is analogy, inferring the meaning of technical domain from the commonsense one. There was only one instance of the logical semantic relation of analogy. This only instance of analogy of a valve to a door was used to explain the working mechanism of a valve, which was similar to that of a door. Table 5.13 presents the instance of the logical semantic relation of analogy between the visual and verbal units. The display of Image A1-MH-1 accompanied the verbal statement that *It is just like a door, which closes or connects to the vacuum pump*. The pronoun *it* in the verbal statement marked the multiplication of meanings between the verbal unit, that is, this particular clause, and the visual unit, that is, the relevant visual structures in Image A1-MH-1. The relevant visual structures included an analytical figure, showing the attribute of a valve and a symbolic figure, labelling the visual representation of valve as *valve*. The verbal unit extended the meaning in the visual structures by providing additional information about the working mechanism of valve through an analogy (i.e. *It is just like a door*). Analogy is considered an effective device for science teachers to connect new concepts (in this case, the function of a valve) to familiar ones (in this case, the function of a door) based on the similarities (in this case, the function of controlling access) (e.g. Lemke, 1990; Jornet & Roth, 2015). The identification of this new subtype of extension enriches the ways to multiply visual and verbal meanings.

Table 5.13 The logical semantic relation of analogy extension

Resource to activate	Visual unit	Verbal unit
speech	 A1-MH-1 Visual structure: analytical Visual structure: symbolic	*It is just like a door, which closes or connects to the vacuum pump.* Verbal structure: relational

The third sub-type of extension is action extension, where an action that is relevant to the presented information is added through another mode. There were three instances of action extension in the data, which were used to describe the manipulation of the instrument in the experiment. Table 5.14 presents one of these instances as an example. Image A3-MH-3 included two types of visual structures. The first type was an analytical figure of an instrument called Magdeburg Hemispheres. This schematic representation showed the shape, and the components of this instrument: two hemispheres, two handles and a valve. The activation of visual and verbal units was achieved through a pointing gesture and an article *the*. The visual units being activated were the analytical figure, which showed the location of valve in the instrument, and the action figures, which demonstrated the movements of air molecules. The verbal unit extended the visual meaning by adding the action of closing the valve, which corresponded to the enclosed shape of the instrument.

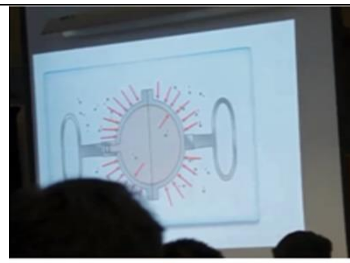
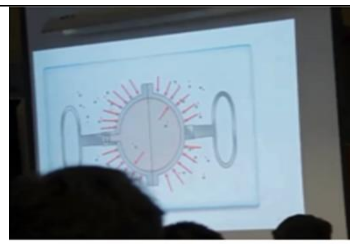
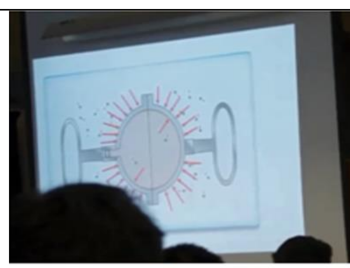
Table 5.14 The logical semantic relation of action extension

Resource to activate	**Visual unit**	**Verbal unit**
Pointing & speech	 A3-MH-3 Visual structure: analytical Visual structure: non-transactional (vector: black arrows) Visual structure: transactional (vector: red arrows & blue arrows)	*And then we close the valve.* Verbal structure: material

The fourth sub-type of extension is scalar/vector quantity extension, which extend the information about scalar or vector quantities, such as amount, pressure and force. There were five instances of the sub-type of scalar/vector quantity extension.

Table 5.15 presents the examples of this sub-type. Image A6-MH-6 was an animated diagram, which included an analytical figure to show the schematic representation of the instrument, two groups of non-transactional action figures to represent the movement of air molecules and two groups of event figures to represent the exertion of air pressure. The scalar/vector quantities extended by the verbal units were the connection between the size of pressure, the amount of air molecules and net force. The amount of air molecules and the size of air pressure were represented in the images through the number of grey dots and the number of large red arrows. The spoken texts compared the amount of air molecules inside the hemispheres and that outside the hemispheres, suggesting that fewer air molecules inside the hemispheres led to an inward force. This demonstrated a quantitative reasoning from the scalar quantity of amount, to the size of pressure, and finally to the size of net force.

Table 5.15 The logical semantic relation of scalar/vector quantity extension

Resource to activate	Visual unit	Verbal unit
Speech	 3s A6-MH-6 Visual structure: analytical Visual structure: non-transactional (vector: small red arrows) Visual structure: event (vector: large red arrows)	*There are fewer air molecules inside,* Verbal structure: existential
	 3s A6-MH-6 Visual structure: analytical Visual structure: non-transactional (vector: small red arrows) Visual structure: event (vector: large red arrows)	*and there are more air molecules outside.* Verbal structure: existential
	 3s A6-MH-6 Visual structure: analytical Visual structure: non-transactional (vector: small red arrows) Visual structure: event (vector: large red arrows)	*And the force will be inward.* Verbal structure: relational

To sum up, the multiplication of meanings between language and images were found in the construction of instruments and scientific entities. The status for visual and verbal units were predominantly [verbal sub. to images]. Similar logico-semantic relations of elaboration were used, to identify or to name instruments and scientific entities. The logico-semantic relation of enhancement was used to state the function of the instrument whereas for scientific entities, it was used to qualify the activities of air molecules in terms purpose and manner. The logico-semantic relation of extension was the main difference in the construction of instruments and that of scientific entities. The extension between visual and verbal units to construct instruments was perception-centered whereas the extension to construct scientific entities contributed to quantitative reasoning. This orchestrates with Duschl and his colleagues' observation that the shift from perception-centered thinking to model-mediated quantitative reasoning are important to develop more sophisticated understanding of science (Duschl, Maeng, & Sezen, 2011).

While the crucial role of images and language in producing varied types of meanings has been recognized in the fields of multimodal studies and science education (e.g. Ainsworth, 2005; Lemke, 2002a; Yeo & Gilbert, 2017), it is important to specify the visual and verbal units that are combined before examining the image-text relations (Bateman, 2014). The findings from this section demonstrate the usefulness of the analyzing framework proposed in Section 3.4.5 in specifying the visual and verbal units being activated and the specific logical semantic relations holding between them. Based on Martinec and Salway's (2005) original model, the framework proposed in this study provides the fine-grained sub-categories of extension and enhancement, which help clarify the ways of expanding the message. Another theoretical contribution is the further development of the sub-categories of enhancement. While in Martinec and Salway's (2005) original framework, the logico-semantic relation of enhancement consists of three sub-types of time, place, reason/purpose, the framework in this study identifies the subtypes of condition, result and manner, which are typically related to scientific reasoning.

5.4.4 Recontextualizing scientific knowledge through the multiplication of meanings between language and images

This section focuses on the realization of interactive meanings between language and images in two classes. The realizations of image-text relations in two classes will be compared in terms of status and logical semantic relations. This section starts by presenting the number of displayed images and activated images, followed by comparing the distribution of status and logical semantic relations between language and images in Lesson A and that in Lesson B.

The number of images being displayed or being activated in Lesson A and Lesson B are presented in Table 5.16 and Table 5.17 respectively. The experiments related to the images are also presented following the unfolding of the lesson. This enables us to trace the pattern in the use of images along the scale of time.

Table 5.16 The number of images being displayed or being activated (Lesson A)

Related experiment	**Displayed**	**Activated**	**Total**
M.H.	1	5	6
Balloon	1	1	2
Rubber sucker	1	0	1
Vacuum bag	4	0	4
Total	7 (54%)	6 (46%)	13 (100%)

Table 5.17 The number of images being displayed or being activated (Lesson B)

Related experiment	**Displayed**	**Activated**	**Total**
Atmospheric pressure	0	4	4
Air pressure gun	0	2	2
M.H.	5	12	17
Balloon	3	1	4
Beverage can	5	0	5
Vacuum bag	1	0	1
Total	14 (42%)	19 (58%)	33 (100%)

The overall distribution between displayed images and activated images in both lessons is relatively balance. While a slightly higher presence of displayed images (54%) was observed in Lesson A, a slightly prominence of activated images was found in Lesson B. This suggests that compared with Lesson A, Lesson B witness greater efforts to enhance students' multisemiotic literacy development. It is important to notice that the development of multisemiotic literacy lies not in simply displaying an array images but rather the activation and circulation of images that can contribute to the understanding of scientific concepts. Does this mean that the more images being activated, the better multisemiotic literacy skill obtained? The answer is no because like any other teaching practices, time is another vital factor to consider. To activate more images means greater devotion of time, which may be constrained by the design of curriculum and lesson plans. Therefore, it is ideal to activate just enough images for students to comprehend the ways of interpreting visual meanings.

Another pattern observed is that the activated images occurred mostly in the experiments in earlier stage of the lessons. Among all the experiments, Magdeburg Hemispheres (M.H) experiment involved the largest number of images being activated, five images in Lesson A and seven images in Lesson B. This prominence on the images used in this experiment compared with those used in other experiments suggests that both teachers intend to foster the visual literacy in the beginning of the lesson. However, the scarce distribution of activated images in the following experiments suggests a lack in scaffolding students to master the multisemiotic literacy skills of interpreting images related to other experiments. One possible explanation is that the primary focus of the lesson was to construct written explanations for air pressure-related experiments rather than to represent air pressure through images. However, the development of writing skills and visual literacy are not mutually exclusive. An alternative way to also develop the visual literacy is to add a task of producing a force diagram showing the exertion of air pressure for each experiment.

The distributions of logical semantic relations in image-language interactions in Lesson A and Lesson B are shown in Figure 5.40. As shown in the figure, while the distribution of extension was similar in both classrooms, the distributions of enhancement and elaboration varied significantly in Lesson A and Lesson B. The logical semantic relation of extension was the primary contribution to quantitative reasoning based on the scalar quantities in images. The prominence of extension in both lessons suggest its crucial role in establishing quantitative reasoning. The different distribution of enhancement and elaborate implies different focus on what meanings to be multiplied in Lesson A and Lesson B. In Lesson A, spoken texts elaborated the visual meanings in images, such as to specify the location of a valve in the schematic drawing of Magdeburg Hemispheres and to repeat the symbolic attributive figures in images. This enables the establishment of depiction linking between different representations of the same object. In Lesson B, spoken texts enhanced the visual meanings in the images by specifying the time, condition and result of an action or event. This helps capture the sequential linking between events in the images that are used to demonstrate the air pressure-related phenomena.

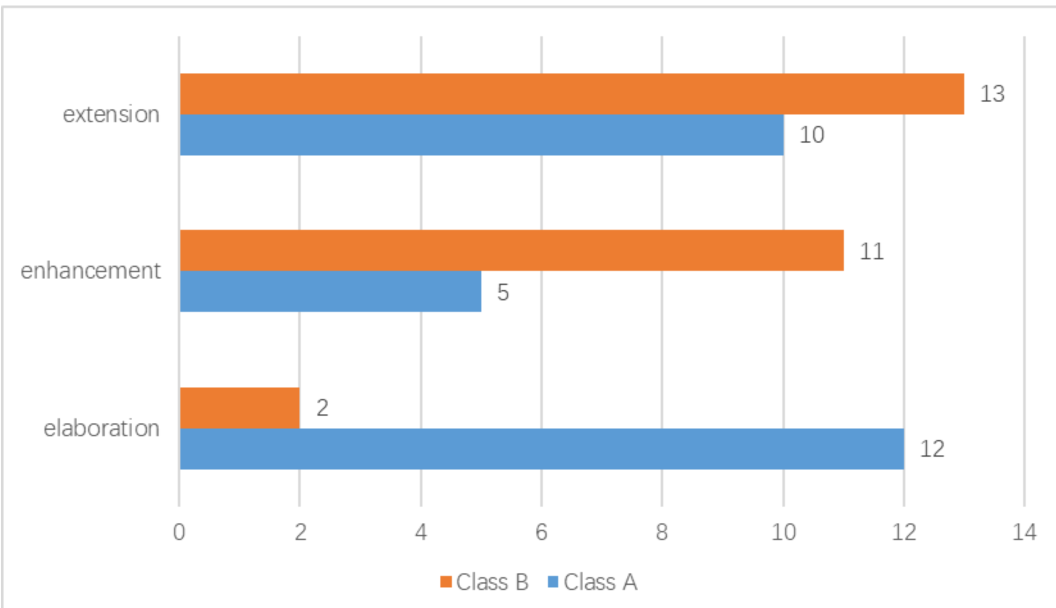


Figure 5.40 Logical semantic relations in image-language interactions in Lesson A and Lesson B

5.5 Summary of Chapter 5

This chapter presents the findings of multimodal analyses of 46 images that were used in two science classrooms. The multimodal analyses examined representational meanings in the images (Section 5.2), logical meanings in the images (Section 5.3) and interactive meanings between language and images (Section 5.4). Representational meanings in the images consist of both narrative and conceptual meanings. While narrative meanings are conveyed through three main categories of narrative visual structures namely, action figures, reactional figures and activity sequences, conceptual meanings were realized through three types of conceptual visual structures, namely, analytical figures, symbolic figures and classificational figures. As for logical meanings, four types of visual linking were identified in the images: elaboration, temporal, spatial and logical. While temporal and spatial linking mainly served to connect narrative meanings, elaboration and logical linking were used to connect both narrative and conceptual meanings. The multiplication of meanings between language and images were examined in terms of status and logical semantic relations. The status for visual and verbal units was predominantly [verbal sub. to images], suggesting that images are foregrounded as the primary mode to convey meaning when they were activated. Three main categories of logical semantic relations were identified: elaboration, extension and enhancement, among which extension was the most salient one. How representational, logical and interactive meanings in images can contribute to the recontextualization of scientific knowledge are also discussed via the case study of two science classrooms.

This chapter has explored the meanings in images in terms of design (i.e., representational meanings), organization (i.e., logical meanings) and activation (i.e., the multiplication of meanings between language and images). The representational analysis of images reveals both the extent and the complexity of visual meanings in the images. A new type of narrative visual structure was identified in this study, that is, elliptical event figures. The logical analysis of images explicit the connections between visual structures in one image and those across images. Two new types of visual linking were identified in this study: activity complex, and spatial co-reference. The interactive analysis shows that the status between spoken language and activated images was dominantly unequal. The visual meanings in these activated images were extended, elaborated and enhanced through spoken language. Under the logical semantic relation of enhancement, the sub-categories of condition, result and manner are new sub-categories emerging from this study. Also emerging from this study are the sub-categories of extension, consisting of attribution, analogy, action, and scalar/vector quantity.

The analyzing tools used in the chapter provide science educators and teaching practitioners with a comprehensive package to conduct multimodal analysis of images. Findings from this chapter contribute to the development of multisemiotic literacy and the critical evaluation of multisemiotic teaching and learning practices. The practical implications of these results will be discussed in Chapter 6.

Chapter 6 Conclusion

6.1 Overview

This study is both a semiotic investigation into the modes of communication and a pedagogical inquiry into the recontextualization of scientific knowledge. First, it has aimed to investigate how different modes of communication (i.e., spoken language, written language and images) may contribute to the construction of scientific explanations. Second, since this study has focused specifically on modes of communication in educational contexts (i.e., spoken language, written language and images in science classrooms), it has also been pedagogically motivated to examine how scientific knowledge (i.e., air pressure) can be recontextualized similarly or differently in two science classrooms. Findings from the present study can thus inform teaching and learning practices and material design from a multisemiotic perspective. In order to achieve these two aims, the present study has adopted textual analyses informed by SFG and image analyses informed by Systemic Functional Multimodal Discourse Analysis (SF-MDA). This chapter concludes the study by reflecting on the extent to which these two research aims have been achieved.

The chapter recapitulates the principal findings of this study to highlight the original contributions of this study in terms of theory and pedagogy before pointing out directions for future research. Section 6.1 summarizes the key findings of this study, based on which final conclusions are drawn. Section 6.2 highlights the theoretical and pedagogical contributions of this study. Section 6.3 considers the limitations of this study and proposes suggestions for future research.

6.2 Key findings and discussion

To assess whether this study has achieved its objectives, it is useful to consider what answers the study has given in relation to the research questions formulated it set out to address. For ease of reference, the questions are reproduced here.

The research questions and the sub-questions are:

(1) How is language used to organize relevant scientific knowledge to construct explanations in the classroom?

(1a) What thematic patterns can be identified in the written explanations?

(1b) What thematic patterns can be used in the spoken discourse to construct these written explanations?

(2) How do images represent and link relevant scientific knowledge to construct explanations in the classroom?

(2a) What representational meanings can be identified in the images to construct explanations?

(2b) How are these representational meanings linked in the images to construct explanations?

(3) How do language and images interact in the construction of explanations in the classroom?

6.2.1 Responding to RQ1

The first research question (RQ1) was addressed in Chapter 4, where the construction of scientific knowledge in the explanations was examined through thematic patterns in the written texts (RQ1a) and the spoken ones (RQ1b). For both the written and spoken texts, the examination of thematic patterns was conducted at the clausal and discoursal levels, integrating the parameters of Theme provided in Halliday and Matthiessen (2014), Martin and Rose (2003), and Taboada and Lavid (2003). At the level of a clause, the choice of Themes was investigated in terms of three parameters: metafunctional types (i.e. textual Themes, interpersonal Themes and topical Themes), semantic categories of topical Themes and Theme markedness (see Section 4.2.1 and Section 4.3.1 for findings on written and spoken texts respectively). Moving up to the discourse level, the thematic structures were examined through tracing the thematic progression (TP) patterns (Section 4.2.2.1) and the presence of hyperThemes and macroThemes (see Section 4.2.2 and Section 4.3.2 for findings on written and spoken texts respectively).

The first sub-question of RQ1 concerning written texts was addressed in Section 4.2. Thematic selections at the clausal level were dominantly topical and textual Themes. This differs from the thematic selections in workplace texts, where not only topical and textual Themes, but also interpersonal Themes were identified (Forey, 2004). The dominance of topical and textual Themes in the written explanations reflects to some extent the ideational nature of the text, which concerns more about field knowledge, rather than interpersonal relations. The topical Themes identified in this study consist of three semantic categories: People, Things and Syntactic items, where Things were further categorized into instrumental Things and observational Things. The distribution of the semantic types of topical Themes tend to be indicative of the genre under study: the high frequency of observational Things foregrounds the scientific entities under investigation, and the presence of People and instrumental Things reflects the involvement of experimenter and equipment in the identification of a phenomenon.

The textual Themes identified in this study served to construct the relations of cause, condition and addition. The distribution of these textual Themes reveals the relation between processes of observational Things (causal relation), and those in the identification of a phenomenon (condition). The identification of these sematic types of topical Themes and the relations constructed by textual Themes help reveal the semantic nature of the texts, focusing on the processes related to a scientific entity that are causally linked, which can be identified in a phenomenon. Compared with the 14 semantic types of topical Themes identified in Banks's (2008) study of journal articles, the semantic types found in this study restrict to three types: the scientific entity under investigation, experimenter, and equipment. This can be explained by the need for recontextualization of complex scientific knowledge from its field of production to science classrooms (Bernstein, 2000). With limited types of semantic meanings constructed by topical and textual Themes, students can focus on how causal mechanism is established between abstract processes related to abstract entity, such as air molecules.

As for Theme markedness, 99% of topical Themes were unmarked, and 71% of textual Themes were inherently and characteristically unmarked. The predominance of these unmarked choices of Themes suggests that the texts are intended to be read as a coherent flow of information (Halliday & Matthiessen, 2014). The marked choices of textual Themes, either inherently or/and characteristically marked, were motivated by the need to establish causal relations, which is crucial for an explanation. While a range of strategies can be used to construct causality in written explanations (e.g., Hao, 2018), the construction of causal relations in this study mainly adopt the strategy of using causal conjunctions or/and conjunctive adjuncts between clause complexes (e.g., *so* in clause complexes, *There are fewer air particles inside to hit the wall of the M.H.,* ***so*** *the air pressure inside the M.H. decreases*). One possible reason for such a choice is that students' understanding of the phenomenon was developed from constructing individual processes, to adding causal relations between these processes. This can be considered as an appropriate starting point for constructing causality as the students under study were new to constructing scientific causalities. As Hao (2018) suggests, when students progress their study at tertiary level, they are expected to construct causality with a combination of nominal group, verbal group and nominal group in one clause, which is identified as the most preferred way of constructing scientific causality by Halliday (1998). One example of this typical ways of establishing causality can be: A decrease in the number of air particles inside the M.H. leads to a decrease in air pressure inside the M.H. In this example, the process that the number of air particles decreases is packed into a nominal group (a decrease in the number of air particles), enabling it function as the cause of another process (air pressure decreases) that is also packed into a nominal group (a decrease in air pressure). While this typical way of constructing scientific causality through nominalization might be too challenging for the students at secondary level, it is suggested that nominalization should be introduced to students at tertiary level. Nominalization can be practiced after introducing the construction of individual processes, followed by adding causal links between these processes, and explicitly instructing on how processes can be packed into nominal groups.

As for the thematic structures at the discourse level, the most prominent TP path was constant progression (49%), followed by linear (31%) and derived (20%) progression patterns. The genre (to explain) and the mode (written) are accountable for those TP paths. The writers shift between constant and linear TP paths to develop the topical Themes from People (e.g. *we*), to observational Things (e.g., *air particles*) and then to the attribution of scalar quantities to the observational Things (e.g., *number*, *pressure*), suggesting an increasing abstractness from what is observable (e.g., *we* as the experimenter conducting the investigation) to what is abstract (e.g., *air particles, the number of air particles, air pressure*). The inclusion of abstract entities and relationships in the causal reasoning, as observed in the present study, reflect a high level of complexity in a scientific explanation (Wu & Hsieh, 2006). It is suggested that the development of topical Themes of abstract entities and relationships in a mix of constant and linear TP paths can be used as an index for a well-articulated scientific explanation with high complexity. Within the constant and linear TP paths, simple Themes were more salient than multiple Themes, and contiguous progression had a greater incidence than gapped progression. This reflects the characteristics of a text in written mode, where the structure of a text is neatly organized, so that a topical Theme originates from one of the previous Themes or Rhemes, and progresses contiguously in the following text (Halliday, 1993). Apart from the dominating constant and linear TP paths, derived TP path was also observed in these written texts, typically realized by syntactic items, such as existential *there* in *There are fewer air particles*. When syntactic items, such as existential there, occupy the Theme position, it is difficult to maintain thematic progression from previous Themes or Rhemes. Therefore, it is suggested that derived TP path should be used with caution. For instance, an alternative way to express a similar meaning as the clause *There are fewer air particles*, can be the number of air particles decreases. In this alternative statement, the topical Theme is the number of air particles, which can be related to previous Themes/Rhemes and to following Themes/Rhemes.

While the important roles of hyperThemes and macroThemes have been identified in previous research (e.g., Forey, 2002; Hood, 2009; Martin & Rose, 2008), neither hyperThemes nor macroThemes were observed in the written texts, which may be due to the short length of these written texts, with an average of 68 words in one text. With such a short length, topical and textual Themes are sufficient for the organization of a text without further aid from hyperThemes and macroThemes.

Based on these thematic patterns, a schematic structure of explanations was identified in these written texts: Experiment Condition ^ Explanation Sequences ^ Phenomenon Perception. These thematic patterns illuminate the role of Themes in organizing the ideational meanings to construct an explanation, specifically how actions of experimenters (Experiment Condition) lead to changes in the properties of scientific entities (Explanation Sequences) that can be observed in experiments (Phenomenon Perception). The schematic structure of written explanations identified in this study differs from the typical schematic structure of causal explanations identified by Veel (1997) and Martin and Rose (2014), that is, Phenomena ^ Explanation Sequences. While both schematic structures include a stage of Explanation Sequences, their main difference lies in the stage related to phenomena identification. In the schematic structure identified by Veel (1997) and Martin and Rose (2008), the phenomenon to be explained is identified before articulating the causal mechanism operating behind this phenomenon. However, in the schematic structure identified in the present study, the phenomenon to be explained is separated into two components: Experiment Condition and Phenomenon Perception. While the stage of Experiment Condition occurs prior to the stage of Explanation Sequences, setting up the condition for the phenomenon to be identified, the stage of Phenomenon Perception is presented after the stage of Explanation Sequences, identifying what phenomenon can be observed. This schematic structure can be considered as a derived version of the typical schematic structure of causal explanations, which can be taught and learned by science teachers and students.

The second sub-question of RQ1 regarding spoken text was addressed in Section 4.3. The Themes in the spoken texts that were identified at the clausal level were predominantly topical and textual Themes, although instances of interpersonal Themes were also present. The dominance of topical and textual Themes in spoken texts reflects the ideational motivation of the text, that is, to construct written explanations. The presence of interpersonal Themes suggests that these spoken texts were also interpersonally motivated where teachers and students provided their viewpoints and negotiated how a phenomenon should be interpreted. The selection of textual Themes tended to be sensitive to each teacher's rhetorical style, as evidenced by the higher frequency of textual Themes in Lesson B than that in Lesson A. This reveals a more complex picture of the functions performed by textual Themes in spoken texts than those in written texts. While textual Themes in the written texts mainly contribute to the construction of scientific causality, textual Themes in the spoken texts could function to establish scientific causality and to motivate the development of spoken discourse, such as signalling the transition from one task (e.g., addressing the first guided question about the number of air particles), to another (e.g., addressing the second guided question about the gas pressure inside the instrument). Therefore, it is important for both teachers and students be fully aware of which function a textual Theme intends to serve in spoken texts.

Topical Themes in the spoken texts fell into six main semantic categories: people, things, semiotic, circumstances, actions, semiotic and syntactic items. The topical Themes of Things and People were the most prominent semantic types in spoken texts although the exact distribution tended to vary depending on the field of knowledge (see Section 4.3.1.2 for details). To some extent, the wide range of semantic categories, and the prominence of Things and People as topical Themes in the spoken texts reflects the characteristics of semi-planned spoken discourse. While the prominence of Things and People points to a preference of topical Themes corresponding to those in the written texts, the distribution of other semantic categories suggests an on-going construction and negotiation of meaning in the classroom, which cannot be planned. The high frequency of People realized as pronouns reflects the interactivity of the texts in spoken mode, which is also observed in Taboada and Lavid's (2003) study on scheduling dialogues.

As for Theme markedness, more than half of the Themes were unmarked topically, inherently or characteristically. The distribution of topical Theme markedness pointed to a preference for maintaining the coherence of information flow in the spoken texts, which accords with Taboada and Lavid's (2003) study of scheduling dialogues. As for the distribution of inherent and characteristical Themes, a slightly higher presence of unmarked choices was observed than the marked ones. The inherently or characteristically marked Themes played an important role in organizing classroom activities (i.e., establishing temporal relations between activities) and constructing explanations (i.e., establishing sequential relations between events in explanations) (see Section 4.3.1.3).

At the discourse level, the prominent TP paths were constant, linear and derived progression patterns, with a few instances of complex progression. While constant and linear TP path maintain the discussion on topical Themes of People and Things, which contribute to the construction of scientific causality, the derived path played an important role in introducing new information from the sources of context, prior knowledge and cross-modal reference, which help shape students' scientific understandings of the phenomena under investigation. The predominance of simple Theme sources in the present study is consistent with Taboada and Lavid's (2003) observation that simple Theme sources tend to occur more frequently than multiple Theme sources in spoken texts. The slightly higher presence of contiguous progression than gapped progression reflects the tradeoff between the intention of maintaining the topic about scientific concepts and the needs for unpacking scientific knowledge so that students are able to understand it. This tradeoff is evident in the short span of each contiguous progression, from two to three clauses on average.

The distribution of hyperThemes and macroThemes tended to vary according to the functions of the spoken texts. While neither hyperThemes nor macroThemes were found in the spoken texts related to experiment demonstrations, both types of Themes were identified in the spoken texts related to explanation construction. The distribution of hyperThemes and macroThemes tends to be field-oriented in this study: the hyperThemes and macroThemes organized the spoken texts around several guiding questions, each question corresponding to the construction of one explanation sequence in an explanation. Findings from this study contends that hyperThemes and macroThemes in spoken texts perform the function of packaging information within phases of a text as how they organize written texts (Martin & Rose, 2007).

Based on these thematic patterns found in the spoken texts, two schematic structures were identified, respectively, in the experiment demonstrations and in the construction of explanations. The schematic structure for the experiment demonstrations consisted of two obligatory stages: Experiment Introduction ^ Experiment Demonstration, where the background of the experiment, such as instruments and procedures, was introduced (Experiment Introduction) before this experiment was performed by students with the teacher's instruction (Experiment Demonstration) (see Table 4.35 for typical thematic patterns related to this schematic structure). The schematic structure for explanation construction was composed of three obligatory stages: Phenomenon Identification ^ Explanation Sequences Construction ^ Coda. This thematic structure started with the identification of experiment conditions and perceivable phenomenon (Phenomenon Identification), followed by the construction of explanation sequences to account for the phenomenon (Explanation Sequence Construction), and a final stage to present the written text of the explanation (Coda) (see

Table 4.36 for a summary of the typical thematic patterns in relation to this schematic structure). These schematic structures identified in the spoken texts reveal a more comprehensive picture of how scientific investigations are conducted, compared with those in written texts. While the schematic structure in the written texts focuses on the construction of causality to explain a phenomenon, those in the spoken texts highlight other aspects in a scientific investigation, such as conducting experiments, observing the phenomenon to be explained, identifying scientific entities to be studied, and identifying causal relations between properties of these scientific entities accounting for the occurrence of this phenomenon.

6.2.2 Responding to RQ2

RQ2 and RQ3 were addressed in Chapter 5, where the findings of the multimodal analysis of 46 images were presented. Specifically, RQ2 was addressed in Section 5.2 (representational meanings) and Section 5.3 (logical meanings). The ideational meanings in the images were examined via representational analysis using Kress and van Leeuwen's (2006) framework and visual linking analysis adapted from van Leeuwen (2005).

In relation to the first sub-question of RQ2, this study found that representational meanings in the examined images consisted of both narrative and conceptual meanings. Three main categories of narrative visual structures were identified: action figures, reactional figures and activity sequences. Of these categories, action figures were the predominant, mainly concerned with the construction of actions by air molecules and the exertion of air pressure (see Section 5.2.1). Action figures are mainly used to explain the exertion of air pressure as multiple activities. Air molecules move omnidirectionally, some of which collide to the surface of an object. Air pressure is produced on the surface where air molecules collide. However, these multiple activities are presented sequentially, without specifying whether they are linked through a temporal relation or through a causal relation. The viewers need to infer that it should be a causal relation between these activities, which requires an adequate level of multisemiotic literacy.

Findings from this study support Doran’s (2016) argument that image afford the construction of multiple visual structures in one go, which results in multiple functions performed by one visual element. This study observed two additional consequences of this multiple presentation of visual structures. The first consequence is the possibility for embedding one visual structure in a larger visual structure, such as the case of an activity sequence. As Kress and van Leeuwen (2006) points out, an activity sequence is constituted by a chain of transactional action figures, which involves embedding several transactional action figures in a large narrative visual structure. The second consequence is the establishment of multiple visual links from one visual structure to another, which will be discussed in detail in the response to the second sub-question of RQ2. Both the embedding of visual structures and the establishment of multiple visual linking to one visual structure complicate how visual meanings can be interpreted, and thus are in high demand for advanced visual literacy skills. It is therefore suggested to explicitly stating which visual meaning has been activated. For instance, when using an embedded visual structure to make meaning, teachers should be clear about whether students should consider the entire embedded visual structure or just part of it. If it is the latter case, teachers are expected to be specific on which part of this embedded structure that students should refer to. When linking one visual structure to another, explicit instructions should be given as to which visual structure is linked to another one in what way.

Three categories of conceptual visual structures were found: analytical figures, symbolic figures and classificational figures, among which analytical and symbolic figures were dominant (see Section 5.2.2). Symbolic figures provide linguistic names to visual elements in analytical figures. The present study found the distinction of naturalistic analytical figures between schematic analytical figures points to the different levels of abstractness in images. While the presence of naturalistic analytical figures in photographs suggests a low level of abstractness, the presence of schematic analytical figures in schematic drawings reflects a high level of abstractness. In addition, the conventional use of schematic analytical figures in schematic drawings orchestrates with Kress and van Leeuwen's (2006) urge that visual meaning should be interpreted in a specific context.

In relation to the second sub-question of RQ2, four main types of visual linking were identified in the images: elaboration, temporal, spatial and logical (see Section 5.3). While temporal and spatial linking connected narrative meanings, elaboration and logical linking connected both narrative and conceptual meanings in the images (see Figure 5.33 for types of visual linking and their realizations). The visual linking identified in images in this study vary, to some extent, from those identified by van Leeuwen (2005) in his study of films. This reflects how media, such as film and PowerPoint slide shape the affordance of visual meaning, as observed in the case of visual linking. Another important finding from this study is that both representational and logical meanings in images could be densely packed and highly complex, which poses literacy challenges for both teachers and students. For instance, findings from this study substantiate Doran's (2016) claim that images cannot distinguish between temporal and causal relations, which are both presented as multiple activities that are related temporally. To infer whether it is temporal or causal relation that is established between these multiple activities requires high level of scientific literacy in its fundamental sense and in its derived sense. Therefore, it is suggested to specify the relation in images using language, such as a written text of "causal relations" showing besides the image and a verbal statement that "They are causally related.".

6.2.3 Responding to RQ3

RQ3 was addressed in Section 5.4, which elucidates the activation and multiplication of meanings through language-image interactions. The activation of meanings in the images was examined by distinguishing images that were simply displayed (i.e., displayed images) and those that were activated by the teacher (i.e., activated images) (Section 5.4.1). Findings from this study suggest a discrepancy in the number of images being activated and those being displayed. The distinction between displayed and activated images allows for a comparison between what visual meanings are available and what visual meanings are activated, which is an area underexplored in previous research. The interactions between spoken language and activated images were investigated in terms of status and logical relations (Section 5.4.2). The status was predominantly [verbal sub. to images], suggesting that when activated, images were the primary mode to convey meanings, with spoken language serving to refine the focus of meaning. This finding is similar to Taboada and Habel's (2013) observation of image-text relations in figures, where language elaborates visual meaning in images. However, the logical semantic relations between language and image in the present study are more complex than those in Taboada and Habel (2013).

Three categories of logical semantic relations were identified for the multiplication of meanings between language and images: elaboration, extension and enhancement. Among these logical semantic relations, extension had a higher incidence than the other two (see Section 5.4.3). This suggests the importance of being literate in both language and images (i.e., multisemiotic literacy) for understanding scientific knowledge because both modes were found to contribute to the construction of meaning. A representative example from this study is the establishment of analogy between visual and verbal units to infer the causal mechanism of a valve from non-technical observations in daily life, that is, how a door works. Another example is the construction of quantitative reasoning with multiple visual structures representing the changes in scalar quantity in images and verbal language extending on how these scalar quantities are causally related. This study, among others (e.g., Lemke, 1998; Danielsson, 2016; Tang, Delgado, & Moje, 2014), have illustrated that the construction of scientific knowledge involves the mobilization of linguistic, visual, gestural and actional resources. While the logical semantic relations between written texts and images have been extensively explored (see Bateman, 2014 for a comprehensive review of studies on (written) text-image relations), those between spoken texts and images are underexplored. This study enriches the existing literature on specifying types of logical semantic relations that can be established between images and spoken language with the co-adoption of multimodal semiotic resources. Findings from this study point to the need of recognizing multisemiotic literacy as a vital component of scientific literacy, that should be fostered simultaneously with the development of scientific knowledge. How multisemiotic literacy can be developed will be discussed in detail in Section 6.3, after the discussion of theoretical contributions.

6.3 Contributions of the present study

6.3.1 Theoretical contributions

Theoretically, the present study contributes to the research fields of science education, linguistics and multimodality.

Its theoretical contribution to the field of science education lies in an integrated account of scientific literacy that has drawn on Norris and Phillips's (2003, 2009) two senses of scientific literacy, Bernstein's (1999, 2000, 2001) sociological view of knowledge, and a systemic functional view of language as social semiotics (Halliday, 1978). Norris and Phillips (2003, 2009) distinguish a derived sense of scientific literacy (knowledge of science) and a fundamental sense of scientific literacy (language of science). The derived sense of scientific literacy is conceptualized by this study within Bernstein's sociological view of knowledge (Bernstein, 1999, 2000, 2001), which regards scientific knowledge as possessing a hierarchical knowledge structure and being coded in a vertical discourse that can be recontextualized in school. The present study shows possible ways of investigating the recontextualization of scientific knowledge by comparing the realizations of scientific knowledge in language and images in two science classrooms. The fundamental sense of scientific literacy is conceptualized by this study within an SFL-based view of language as a semiotic system, which exists on three principal dimensions: instantiation, stratification and metafunction (Halliday, 1975; Halliday & Matthiessen, 2014). In the present study, the fundamental sense of scientific literacy has been extended beyond language to include other semiotic resources, such as images. The present study demonstrates how the fundamental sense of scientific literacy can be examined through a linguistic analysis of Themes (see Chapter 4) and a multimodal analysis of images (see Chapter 5).

The theoretical contribution of this study to the field of linguistics is a further development of the scale of Theme markedness. Supplementing Halliday and Matthiessen's (2014) scale of Theme markedness, which is mainly illustrated in declaratives, the present study has proposed frameworks to examine this thematic feature in declaratives, interrogatives and imperatives (see Section 3.4.2 for analytical frameworks and Chapter 4 for findings). In addition, the present study has extended the examination of Themes as a linguistic feature to include a multimodal perspective: how Themes can be marked through visual resources, such as font size, colors and animations. The frameworks for analyzing Theme markedness, along with other Theme-relevant parameters, allow for an in-depth investigation into the role of Themes in organizing both ideational and interpersonal meanings.

The present study's contribution to the field of multimodality lies in the identification of new subcategories of visual structures, visual linking and logical semantic relations. In addition to the narrative visual structures presented in Kress and van Leeuwen (2006), a new type was identified in this study: elliptical event figures (see Figure 5.5 for an example and Section 5.2.1.1 for details). Building on van Leeuwen's (2005) framework of visual linking in images, this study has identified two new types of visual linking: activity complex (see Figure 5.22 for an example and Section 5.3.1 for details) and spatial co-reference (see Figure 5.30 for an example and Section 5.3.3 for details). Supplementing to the types of logical semantic relations between language and images proposed by Martinec and Salway (2005), three new subcategories of enhancement emerged from this study: condition, result and manner (see Section 5.4.3.2 for details). Four subcategories of addition also emerged from this study: attribution, analogy, action, and scalar/vector quantities (see Section 5.4.3.3 for details). These new categories provide future research in multimodality with powerful tools to examine the visual meaning in images.

6.3.2 Pedagogical implications

Pedagogically, this study has explored the construction of scientific explanations through multisemiotic systems (i.e., language and images) in classrooms. The analyses of written explanations, spoken texts and images conducted in this study have revealed that the construction of a scientific explanation in the classroom is a complex social activity requiring multisemiotic literacy. The present study has demonstrated how scientific knowledge that explains air pressure-related phenomena can be linguistically developed (e.g., via Themes in language), represented (e.g., through visual structures and visual linking in images), and multiplied (e.g., by language-image interactions) with the use of language and images.

Specifically, this study has found that written explanations and the spoken texts produced to construct these explanations deployed different thematic patterns to develop meanings. While both the written and spoken texts predominantly selected unmarked Themes to facilitate the discourse flow, they differed in the semantic categories of topical Themes and thematic patterns at the discourse level. First, the spoken texts showed a greater variety of semantic types of topical Themes than the written texts. The semantic types of topical Themes in the written texts were People, things, and syntactic items, whereas those in the spoken texts ranged from people, things, syntactic items to semiotic, actions and circumstances. This suggests that the spoken mode is more complex in terms of topical Theme categories compared with the written mode. It is suggested that teacher education programs need to foster teachers' awareness of how topical Themes differ in spoken and written texts. For instance, written texts from this study can be used as modeling texts for students to practice identifying topical Themes in each clause, reporting the semantic types of topical Themes, and evaluating the choices of topical Themes. When students are able to identify and evaluate topical Themes in written texts, they can be provided with excerpts of spoken texts from this study to work on topical Themes in spoken texts. Then students can work in groups to compare the similarities and differences in the choices of topical Themes between written and spoken texts, and select topical Themes for their written explanations. After these activities, students are expected to construct their own written explanations, with verbal justifications of the choices of topical Themes. Another suggestion for the construction of explanations is to start from the construction of individual processes, to add causal relations to these processes, and to construct scientific causality realized through nominalizations. The stage of nominalization may present challenges to students, and therefore calls for explicit instructions on how processes can be packed into nominal groups.

Second, the thematic structures at the discourse level in the written texts also differed from those in the spoken texts. In the written texts, the contiguous progression of simple Themes through a mix of constant and linear TP paths was the dominant thematic progression pattern, whereas in the spoken texts, this dominant thematic pattern was occasionally interrupted by derived new information or syntactic items, with frequent gapped progressions from previous clauses. This suggests that the spoken mode deployed more complex TP patterns than the written mode, where listeners needed to constantly refer to local segments of a text to connect the information that were fragmented or derived. It is suggested that the development of topical Themes of abstract entities and relationships in a mix of constant and linear TP paths can be used as an index for a good written explanation. In the construction of such a written explanation, teachers should weigh carefully what to introduce as new information, as it can disrupt the information flow in the spoken texts. Classroom activities can be organized to identify TP paths in two written texts, one adopting the typical pattern identified in the present study (i.e., simple Themes progressing contiguously through a mix of linear, and constant TP paths), and the other with random TP pattern. Students are then asked to compare these two texts in terms of TP pattern, and decide which one they prefer for their own texts. Students can then practice writing explanations with the typical TP pattern by revising written texts with random TP patterns.

Another difference was the absence of hyper-/macro-Themes in the written texts and the presence of both hyperThemes and macroThemes in the spoken texts. The presence of hyperThemes and macroThemes in the spoken texts signaled how the rest of a text would unfold without indicating any evaluative stances (Martin & Rose, 2003). These macroThemes and hyperThemes organized the spoken texts related to explanation sequences construction into a hierarchical structure, within which scientific knowledge was decomposed into several manageable components for the effective teaching and learning of science to occur. Therefore, it is suggested to use both hyperThemes and macroThemes in classroom talks, with a macroTheme to overview the structure of following spoken texts, and several hyperThemes to organize the spoken texts around several topics.

These findings illuminate distinct thematic features of both written and spoken modes in educational contexts, such as one schematic structure consistently employed in the written explanations (i.e., written texts) and two schematic structures underlying classroom talks (i.e., experiment demonstrations and explanation constructions). A conscious awareness of these linguistic features provides science teachers with keys to uncover the "hidden curriculum of language" in science education (Bratkovich, 2018, p. 780). It also contributes to an appreciation of an integrative view of scientific literacy in both its derived and fundamental senses and points out possible ways to investigate the connections between language and knowledge, such as thematic features in relation to scientific explanations as demonstrated in this study. Explication of these connections between language and knowledge is important for stakeholders in educational contexts, such as curriculum designers, textbook publishers, teachers and students, as it helps reveal the hidden curriculum of language in school education.

With the understanding that science communication is highly multimodal (e.g., Danielsson, 2016; He & Forey, 2018; Kress et al., 2001; Lemke, 1998), the notion of scientific literacy in its fundamental sense has been extended beyond linguistic literacy to include visual literacy. Visual literacy in this case means both the ability to distinguish one visual structure from another one (representational meanings) and the ability to relate the visual meanings in these visual structures (logical meanings). Findings from the present study illuminate at least five visual strategies for demonstrating and explaining abstract phenomenon such as air pressure. These visual strategies are visualizing abstract entities, representing scientific concepts involving collective actions with multiple narrative visual structures, representing instruments in both naturalistic and schematized ways, using analogy in accompany with naturalistic analytical figures, and using visual linkings to understand relational causality. These visual strategies will be elaborated with an example of explaining air pressure-related phenomena in the present study.

The first visual strategy is visualizing abstract scientific entities under investigation. One of the difficulties in explaining abstract phenomenon such as air pressure is the involvement of non-obvious variables such as air molecules, which is not perceivable with human eyes (Basca & Grotzer, 2003). Air molecules were visualized as grey dots in images, enabling model the non-obvious behavior of air molecules as something one can physically manipulate and perceive.

The second visual strategy is representing scientific concepts involving collective actions via multiple action structures. Findings from this study show that the behaviors of air molecules were represented by multiple action figures (Section 5.2.1.1). These action figures represented three types of actions: the omnidirectional movement of air molecules (non-transactional action figures), the collision between air molecules and an object (transactional action figures), and the exertion of air pressure (event figures). To explain air pressure-related phenomena requires understanding the exertion of air pressure (event figures) as the collective result of air molecules that move randomly (non-transactional action figures) and exert forces against the surface with which they have contact (transactional action figures). Reasoning about the exertion of air pressure can be challenging for students as it involves both the recognition of actions at the molecular level (i.e., the omnidirectional movement of air molecules and the collision between air molecules to an object) and the appreciation of outcomes at the collective level (i.e., air pressure as a collective outcome). Therefore, it is suggested that how visual structures collectively represent one behavior of an abstract entity (e.g., the omnidirectional movement of air molecules, the collision between air molecules and an object and the exertion of air pressure) should be explicated. For instance, when showing an image with multiple action figures representing both the movement of air molecules and the exertion of air pressure (as in the case of Image A6-MH-6 in Figure 5.22), teachers can explicitly state that "The small arrows pointing to random directions represent how air molecules move around in the air. Some air molecules collide to the surface of an object and produce air pressure. The big arrows represent the exertion of air pressure on this object.". This verbal clarification can be accompanied by pointing gestures to the corresponding action figures in the image.

The third visual strategy concerns the representation of instruments. The instruments for demonstrating air pressure-related phenomena were presented by naturalistic analytical figures (e.g., a photograph of Magdeburg Hemispheres) and by schematic analytical figures (e.g., a schematic drawing of Magdeburg Hemispheres). It is suggested that both naturalistic and schematic representations of an instrument should be included. It is ideal for a naturalistic representation of an instrument to be presented before its schematic counterpart. In addition, the connection between the naturalistic representation and the schematic representation of the same instrument (i.e., analytical structures with Depiction linking) should be made explicit, such as using a verbal statement "This is another way of showing Magdeburg Hemispheres.".

The fourth visual strategy is to use analogy in accompany with naturalistic analytical figures. Findings from the present study suggest the combination of verbal analogy and naturalistic representations is an effective device to connect abstract scientific knowledge to concrete everyday knowledge. For instance, when introducing atmospheric pressure, teachers can use a photograph of an elephant with a verbal analogy "The size of atmospheric pressure equals to the pressure applied by one leg of an elephant." In this way, students are able to connect the size of atmospheric pressure to the size of pressure that they are familiar with.

The fifth visual strategy is related to the understanding of relational causality. One difficulty in explaining phenomena such as air pressure, lies in what Basca and Grotzer (2003) call relational causality, where an outcome is due to the result of the relationship between two variables. This study found that a relational understanding of air pressure-related phenomena was achieved through quantitative reasoning based on visual linking in images (Section 5.3). Based on findings from this study, it is suggested that the difficulty in understanding relational causality can be overcame with the aid from visual linking in images. Findings from this study show even distributions of elaboration, temporal, spatial and logical linking, which suggests that it is necessary to include all these four types in the development of visual literacy for teachers, students and other stakeholders.

Among these four types of visual linking, logical linking played a crucial role in establishing quantitative reasoning that contribute to the construction of relational causality. Therefore, it is suggested that when teachers and students are engaged with relational causality, they should pay special attention to logical linking in images. It is also important to be explicit on what visual structures are activated for logical linking. For instance, in the present study, the equilibrium or differential relationship (i.e., relational causality) between air pressure exerted on different areas of an object were visually realized through a number of visual structures and variants of visual symbols. Although other three types of visual linking were presented, it is the presence of logical linking (similarity and contrast), that directly related to relational causality. When the air pressure inside an object and that outside the object were in equilibrium, the same number of event figures were presented inside and outside the object with similar representations of arrows as vectors (logical linking of similarity). When there was a pressure differential between a lower pressure inside an object and a higher pressure outside this object, a greater number of event figures were presented outside the object than that inside, with different depictions of arrows to emphasize the size of pressure (logical linking of contrast). In this case, it is the amount of narrative visual structures as well as the size and length of variants of arrows that are involved in logical linking (both similarity and contrast), and therefore should be made explicit. Teachers can explicitly state that “We are going to compare the amount of narrative structures in these two images”, so that other visual meanings in these two images, such as conceptual structures, will not distract viewers’ attentions. Teachers can then connect the comparison between visual structures to the comparison between air pressure inside an object and air pressure outside this object. Through such quantitative reasoning with the aid of visual linking, an understanding of relational causality can be developed.

The present study has demonstrated the possibility to enhance visual literacy through understanding language-image relations. To develop visual literacy in students, teachers need to move beyond displaying an array of images in the classroom to activating visual meanings in images through spoken language and gestures (Section 5.4.1). The findings of this study suggest that visual meanings in images that are essential for the understanding of scientific concepts (e.g., event figures to represent air pressure) should be activated and explicated in the earlier stage of a lesson. For instance, teachers can use a pointing gesture orienting students' attention to event figures in an image, accompanying verbal statements "These arrows pointing to the surface of an object represent how air pressure acts upon an object.". This statement can be further developed to introduce the omnidirectionality of air pressure as suggested by the directions of these arrows. Teacher can then activate the logical linking of similarity and contrast in these event figures by asking questions about the number of arrows, such as "How many arrows are there inside the object?", and "How many arrows are there outside the object?". The visual meaning of these arrows can be connected to the comparison of air pressure inside the object and air pressure outside the object.

In the following stages of a lesson, these crucial visual meanings should be revisited several times to scaffold students' development of visual literacy. For instance, after the demonstration and explication of event figures to represent air pressure on the Magdeburg Hemispheres in one image, teachers can provide students with other images related to air pressure, each involving event figures to represent air pressure. In the final stage of a lesson, the level of students' development of visual literacy should be evaluated through tasks involving student-generated visual representations (e.g., Tang, Delgado, & Moje, 2014). For instance, an evaluative task can be to produce a diagram that represents the exertion of air pressure on a balloon, which can be assigned as an individual task. After this task, students can discuss their diagrams within a small group.

Within the discussion, students may find their diagrams differ from others and therefore provides opportunities for comparing different visual representations and argue for their choices in visual representations.

6.4 Limitations and recommendations for future research

Despite the important findings of the present study and its pedagogical implications, several of its limitations need to be recognized. One limitation is the amount and composition of the data collected and analyzed, which have implications for the generalizability of the findings. The dataset collected for this study was not large, consisting of 159 minutes of video recording of two science lessons, where four spoken texts (2515 words, lasting for 35 minutes), 13 written texts (879 words) and 46 images were selected for the various analyses. While the qualitative approach adopted in this study enabled an in-depth investigation into the modes of communication in the classrooms and their contributions to the recontextualization of scientific knowledge, it must be acknowledged that without data from more classrooms, it is not clear whether the findings of this study are generalizable beyond the two classrooms studied. To be sure, access to classrooms was greatly limited by the need to videotape classroom teaching and learning, which many teachers found intrusive and uncomfortable. In future research, it is important to consider how teachers' concerns can be alleviated so that more teachers can volunteer to participate. This will allow quantitative analyses of a large corpus of classroom data to complement more in-depth qualitative analyses, such as those adopted in the present study, to investigate multimodal meaning-making in science and other school subjects.

Apart from the modes of communication examined in this study (i.e., spoken texts, written texts and images), other meaning-making resources in the classroom, such as models, gestures and body movements, can be examined to provide a comprehensive picture of the multimodal meaning-making in the classroom. For instance, Lim's (2009) study on secondary English language classrooms provides ways of investigating the meaning-making between language, gestures and body movement. The use of models can be investigated by identifying types of models characterizing quantitative reasoning, and reporting on how students actively engage with these models to develop their scientific understandings. Since the present study has examined multimodal meaning-making in teacher-student interactions more from the perspective of teachers than from the perspective of students, there is a need to take the student perspective into full account in future work. Studies focusing on students could producing findings that are complementary to the perspective focusing on teachers in the present study, such as Tang, Delgado and Moje (2014). Interesting areas to explore from the perspective of students include, but are not limited to, students' spoken texts and self-generated representations during group discussions in the classroom and out-of-school activities that potentially shape their scientific understandings. A recent study by DeJarnette and González (2016) demonstrates how students connect disciplinary knowledge with out-of-school knowledge in their discussion of mathematical knowledge after school. In another study of school visits to museums, Shaby, Assaraf, and Tal (2019) investigate into the mediational role played by museums in constructing technical knowledge and engaging students during their visits to museums.

Furthermore, it is important to note a limitation of the linguistic analyses conducted in this study. The analyses have mainly focused on Themes in terms of the textual metafunction to investigate the organization patterns of ideational meanings in both spoken and written texts at the clausal (i.e., metafunctional types of Themes, semantic types of topical Themes and Theme markedness) and discoursal level (i.e., thematic progression, hyperThemes and macroThemes). Although such analyses are crucial to understanding the relation between language and knowledge and to cultivating scientific literacy in its fundamental and derived sense, several studies (e.g., Danielsson, 2016; Tang, 2014; Yeo & Gilbert, 2014) have also demonstrated that an investigation into the ways of developing scientific literacy can also include other systems in ideational and interpersonal metafunctions, such as the transitivity system (in the ideational metafunction) and mood and modality system (in the interpersonal metafunction). Based on the findings from this study, it is recommended that further research investigate patterns of ideational meanings related to the representation of knowledge in syllabus, textbooks and school curricula, to uncover the role played by government, publishers and institutions in recontextualizing knowledge.

With regard to the multimodal analyses conducted in this study, the focus has been mainly on representational and logical meanings in images as well as the multiplication of meanings between spoken language and images. This focus has enabled the examination of ideational meanings available in images (i.e., representational meanings realized in visual structures and logical meanings realized in visual linking) and those being activated and multiplied (i.e., status and logical semantic relations between spoken language and activated images), and highlighted the need to attend consciously to the selection and use of images to communicate science. It is important to note that findings from this study only reveal one perspective of meaning-making in images, that is, the construction of representative and logical meanings. In order to obtain a more holistic understanding of meaning-making in images, other perspectives on meaning-making in images should also be investigated in future research, such as interactive meanings (i.e., the enactment of the relation between producers and viewers of images), and compositional meanings (i.e., the organization of representative and interpersonal meanings in images). Based on these perspectives on meaning-making in images, we can move one step further to explore the recurrent combination(s) of meanings, which is referred to as coupling by Martin (2008). Research on the patterns of coupling has been conducted on written texts (e.g., Akashi, 2017), which makes the investigation into the patterns of coupling in other semiotic systems, such as images, an interesting area to explore in future research. For instance, further investigations can be conducted on the patterns of coupling of representative meanings and interactive meanings in images.

This study mainly focused on the multiplication of meanings between images and spoken texts. However, it is important to note that the multiplication of meanings also occurs between images and written texts on PowerPoint slides. While considerable efforts have been paid to the interaction between written texts and images in printed documents (e.g., Bateman, 2008; Liu & O'Halloran, 2009; Martinec & Salway, 2005), the investigation of the interaction between written texts and images on the media of

PowerPoint slides is lacking (with the exception of Zhao & van Leeuwen, 2014). Future research on the multiplication of meanings between images and written texts on PowerPoint slides is crucial for understanding how PowerPoint makes meaning with an integration of semiotic resources enabled by its software's design. Findings from these research can expand the scope of multisemiotic literacy in this study.

The present study yields valuable insights into how modes of communication (i.e., images, spoken and written language) contribute to the construction of scientific knowledge (i.e., scientific explanations of air pressure-related phenomena). Its findings point to the need to explicitly articulate language and images as key components of scientific literacy. It is hoped that this study can generate further research interest in how the teaching and learning of science as a multisemiotic practice can be reflected, refined and improved.

Appendix I consent forms

Consent Form

To whom it may concern:

LETTER OF CONSENT

I,________________________(NAME OF PARTICIPANT), DO HEREBY GIVE MY CONSENT for my written work, audio and video data recorded during internal sharing session to be used by Ares HE (HE Qiuping), Department of English, The Hong Kong Polytechnic University for the proposed PhD project:

Towards multisemiotic literacy:
Constructing explanations in secondary science classrooms

I understand the nature of the research, and have had the opportunity to ask any questions related to this study, and received satisfactory answers to my questions with additional details.

I also understand that my name or any other personal identifying information will not appear in the research. The data, after removal of personal identifying information, can be accessed only by the course instructor, the researcher, and her supervisor(s).

I am also aware that excerpts from my written work, audio and video data recorded during class observation my be included in the research-related publications.

I was informed that I may withdraw my consent at any time by advising the research team.

With full knowledge, I agree to participate in this study.

Participant Name: ______________________

Participant Signature: ______________________

Date: ______________________

Appendix II The written explanations from Lesson A and Lesson B

Text A1

When we use the vacuum pump to suck away the air particles inside the Magdeburg hemispheres (M. H.), the number of air particles inside the hemispheres decreases. There are fewer air particles inside to hit the wall of the M. H., so the air pressure inside the M. H. decreases. Air pressure inside the M. H. becomes lower than the air pressure outside the M. H. We cannot pull the hemispheres apart.

Text A2

We suck out the air inside the bottle. The number of air particles inside the bottle decreases. The air pressure outside the bottle is higher than that inside. Some air enters the balloon and it inflates.

Text A3

We force out the air inside the rubber sucker by pressing it down. The number of air particles inside the rubber sucker decreases. The air pressure inside the sucker decreases. The air pressure outside the rubber sucker is higher than that inside. The rubber sucker sticks firmly on the wall.

Text A4

We suck out the air inside the bag by a vacuum pump. The number of air particles inside the plastic bag is decreases. The air pressure inside the plastic bag decreases. The air pressure outside the plastic bag is higher than that outside. Some air leaves the plastic bag and it inflates.

Text A5

When we force out the air inside the rubber sucker by pressing it down, the number of air particles inside the rubber sucker decreases. So the air pressure inside the sucker decreases. So/And thus the air pressure outside the rubber sucker is higher than that inside. As a result, the rubber sucker sticks firmly on the wall.

Text A6

When the air inside the plastic bag is sucked out by a vacuum pump, the number of air particles inside the plastic bag decreases. So the air pressure inside the plastic bag decreases. And thus the air pressure outside the plastic bag is higher than that inside. As a result, the space occupied by the blanket is reduced.

Text B1

When we use the vacuum pump to suck away the air particles inside the Magdeburg Hemispheres (M.H.), the number of air particles inside the hemispheres decreases. The smaller number of air particles inside to hit the wall of the M.H. decreases the air pressure inside the M.H. The air pressure inside the M.H. decreases, so the air pressure inside the M.H. becomes lower than the air pressure outside. There is a difference in air pressure, so it is difficult to pull the hemispheres apart.

Text B2

When we use the vacuum pump to suck away the air particles inside the Magdeburg Hemispheres (M.H.), the number of air particles inside the hemispheres decreases. The smaller number of air particles to hit the wall of the hemispheres decrease the air pressure inside the M.H. The air pressure inside becomes lower than the gas pressure outside. There is a difference in air pressure, so it is difficult to pull the hemispheres apart.

Text B3

When we suck out the air inside the plastic bottle from a hole, the number of air particles inside the bottle decreases. There are fewer air particles inside to hit the wall of the bottle, so the air pressure inside the bottle decreases. The air pressure inside the bottle decreases, therefore the air pressure outside the bottle becomes higher than that inside. There is a difference in air pressure, so air enters the balloon and the balloon inflates.

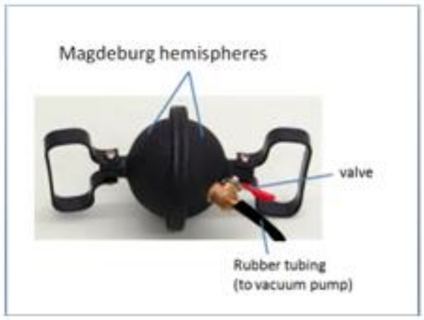
Text B4

When we use the vacuum pump to suck away the air particles inside the soft drink can, the number of air particles inside the soft drink can decreases. There are fewer air particles inside to hit the wall of the soft drink can. Air pressure inside the soft drink can decreases. The air pressure inside the soft drink can decreases. Air pressure inside the soft drink can becomes lower than that outside. There is a difference in air pressure. The soft drink can collapses.

Text B5

When we use the vacuum pump to suck away the air particles inside the soft drink can, the number of air particles inside the soft drink can decreases. There are fewer air particles inside to hit the wall of the soft drink can, so the air pressure inside the soft drink can decreases. The air pressure inside the soft drink can becomes lower than that outside. There is a difference in air pressure. As a result, the soft drink can collapses.

Appendix III The images used in Lesson A and Lesson B



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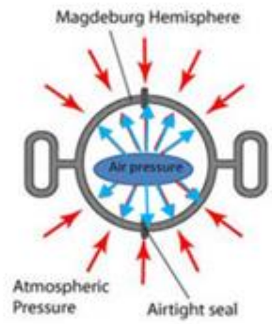
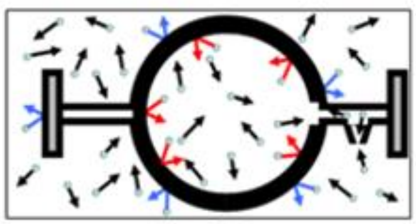


A4-MH-4



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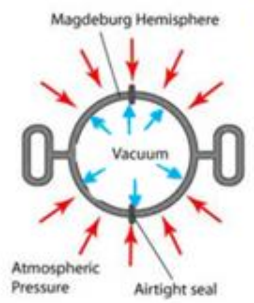
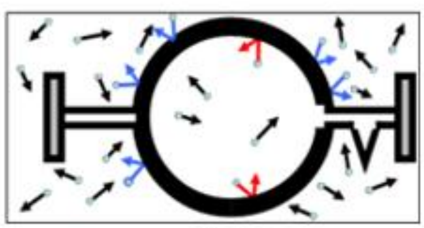


A5-MH-5



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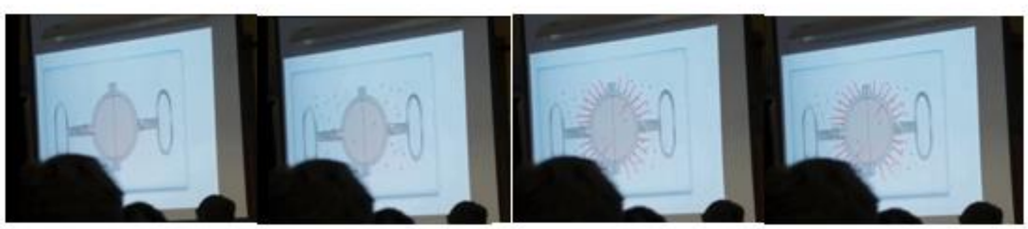
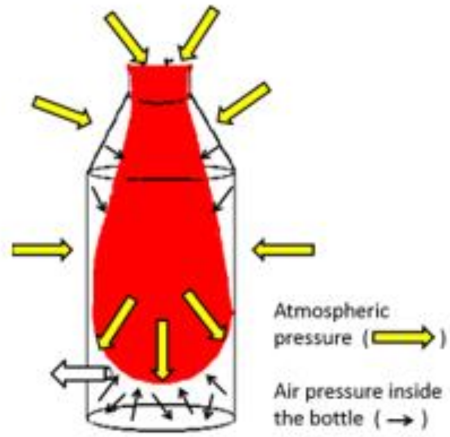
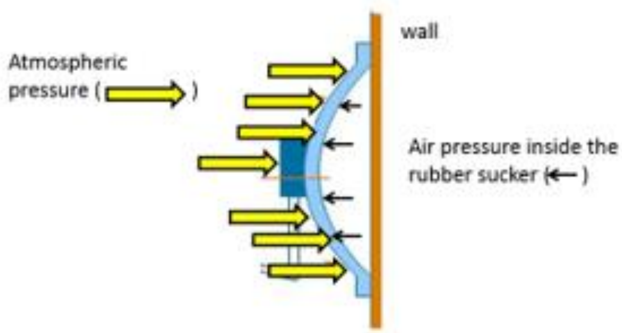


A6-MH-6

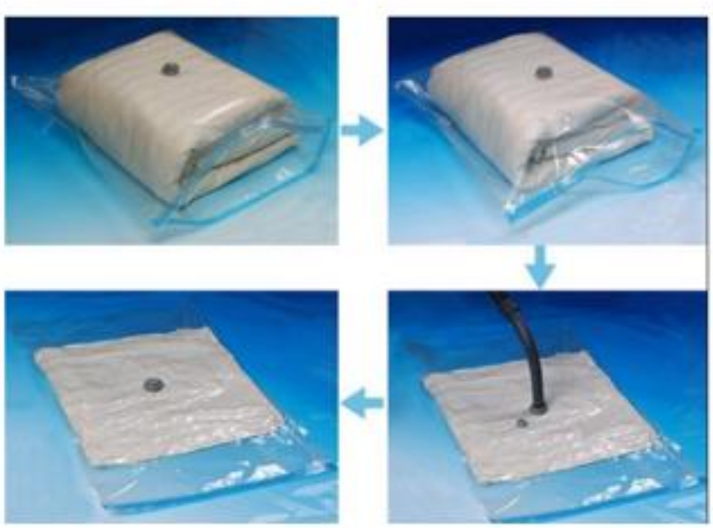
A7-BL-1



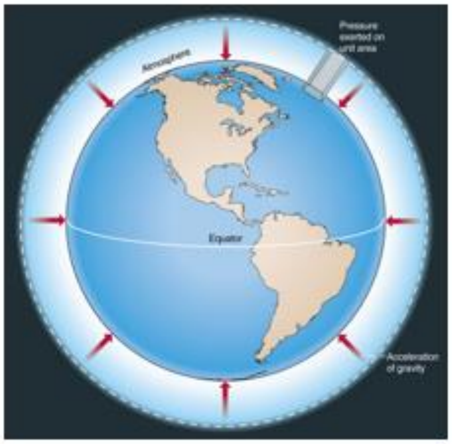
A8-BL-2



A9-RS-1

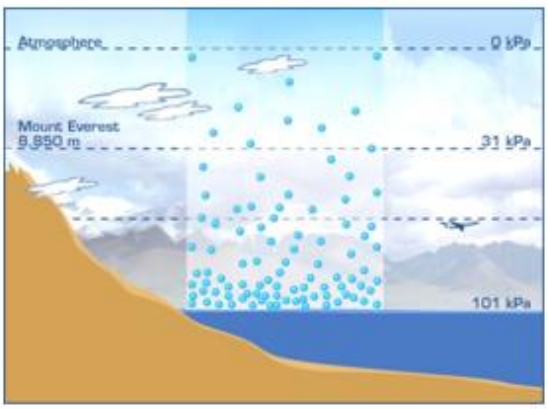


A10-VG-1



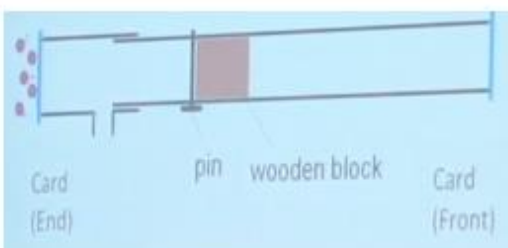
B1-AP-1

B2-AP-2



B3-AP-3

B4-AP-4



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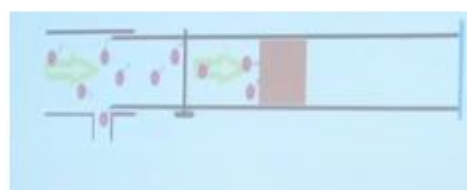

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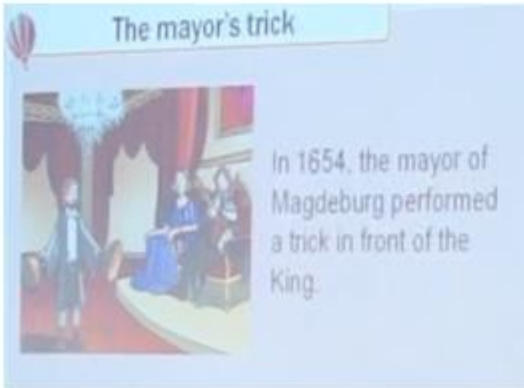

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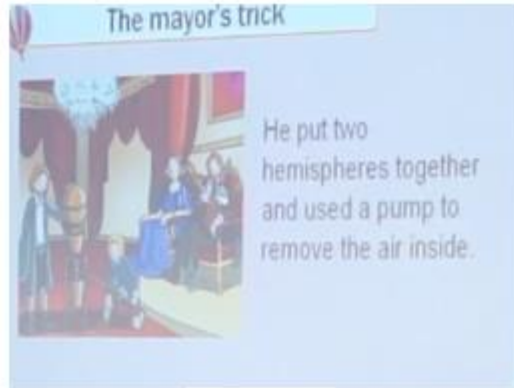

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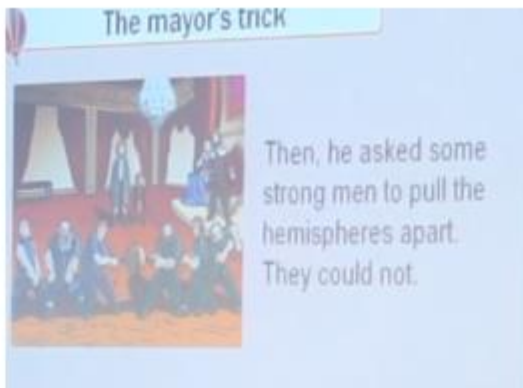
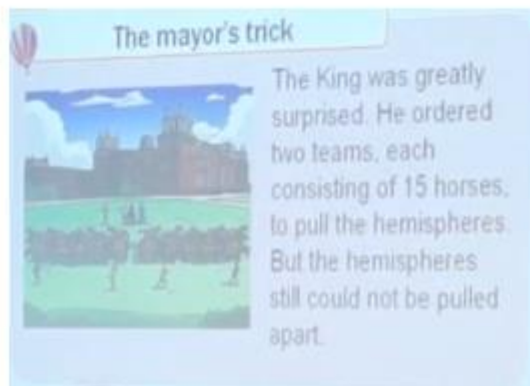


B9-MH-3



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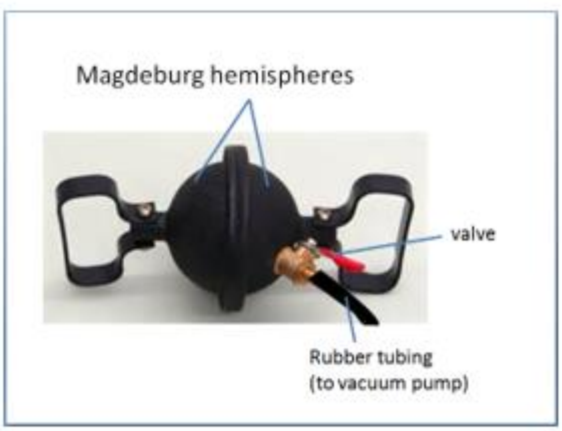

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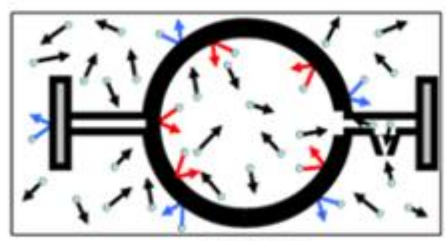

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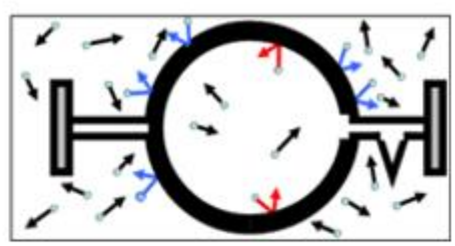

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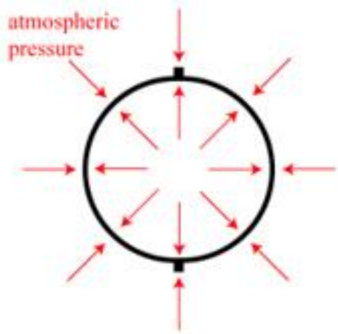

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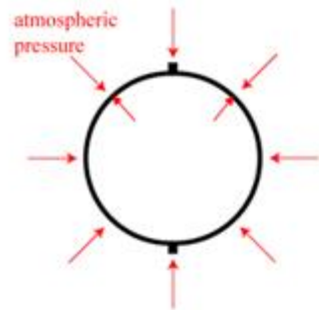
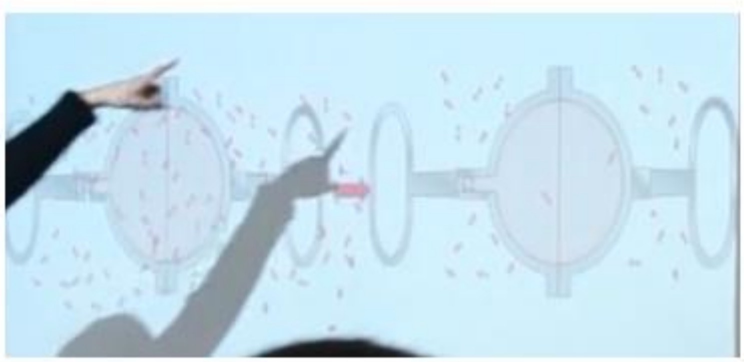


B15-MH-9

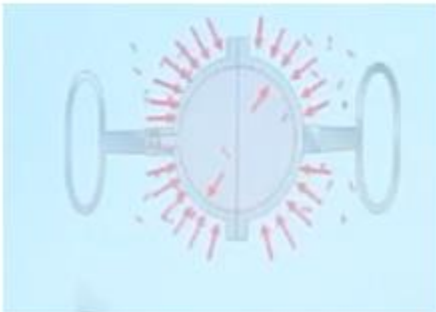
B16-MH-10

B17-MH-11



B18-MH-12

B19-MH-13



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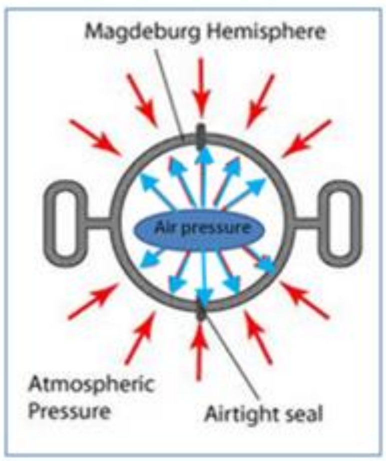

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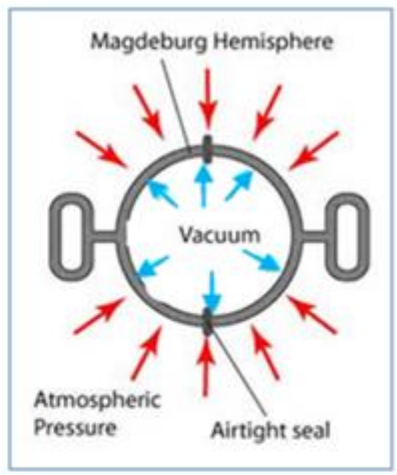
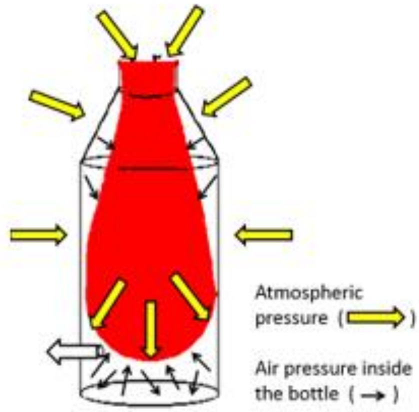


B23-MH-17

B24-MH-18

B25-MH-19

B26-BL-1



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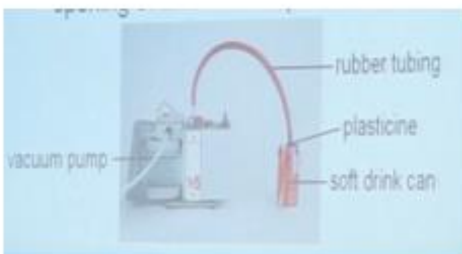

B28-BC-1

B33-BC-6

B29-BC-2

B30-BC-3

B31-BC-4

B32-BC-5

References

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction*, *16*(3), 183–198.

Airey, J. (2009). *Science, language and literacy: Case studies of learning in Swedish university physics*. Uppsala University.

Airey, J., & Linder, C. (2009). A disciplinary discourse perspective on university science learning: Achieving fluency in a critical constellation of modes. *Journal of Research in Science Teaching*, *46*(1), 27–49.

Akashi, T. (2017). *A social semiotic investigation of historical narratives in history textbooks from Hong Kong and Japan*. The Hong Kong Polytechnic University.

Australian Curriculum Assessment and Reporting Authority. (2014). *Foundation to Year 10 curriculum, science*. Retrieved on November19, 2013, from http://www.australiancurriculum.edu.au/science/curriculum/f-10?layout=1

Baldry, A. P. (2000). *Multimodality and multimediality in the distance learning age*. Campobasso, Italy: Palladino Editore.

Baldry, A., & Thibault, P. (2006). *Multimodal transcription and text analysis: A multimedia toolkit and coursebook*. London: Equinox.

Banks, D. (2008). The significance of thematic structure in the scientific journal article , 1700-1980. In *Systemic functional linguistics in use: Odense working papers in language and communications* (Vol. 29, pp. 1–29).

Banks, D. (2012). Thematic structure in eighteenth century astronomical texts: A study of a small sample of articles from the corpus of English texts on Astrtonomy. In I.Moskowich & B.Crespo (Eds.), *Astronomy "playne and simple": The writing of science between 1700 and 1900* (pp. 221–238). Amsterdam: John Benjamins.

Barthes, R. (1977). *Image, music, text (Fontana communication series)*. London: Fontana.

Basca, B., & Grotzer, T. (2003). *Causal patterns in air pressure phenomena: Lessons to infuse into pressure units to enable deeper understanding*. Cambridge, MA: Harvard Graduate School of Education. Retrieved on 11 November, 2018 from https://www.cfa.harvard.edu/smg/Website/UCP/pdfs/AirPressureModule.pdf

Bassey, M. (1999). *Case study research in educational settings*. Buckingham: Open University Press.

Bateman, J. (2008). *Multimodality and genre: A foundation for the systematic analysis of multimodal documents*. Hampshire: Palgrave Macmillan.

Bateman, J. (2014). *Text and image: A critical introduction to the visual/verbal divide*. Abingdon: Routledge.

Bateman, J. (2017). Triangulating transmediality: A multimodal semiotic framework relating media, modes and genres. *Discourse, Context and Media*, *20*, 160–174.

Berland, L. K., Schwarz, C.V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*, *53*(7), 1082–1112.

Bernstein, B. (1999). Vertical and horizontal discourse: An essay. *British Journal of Sociology of Education*, *20*(2), 157–173.

Bernstein, B. (2000). *Pedagogy, symbolic control, and identity: Theory, research, critique (revised edition)*. New York: Rowman & Littlefield.

Bernstein, B. (2001). From pedagogies to knowledges. In A. Morais, I. Neves, B. Davies, & H. Daniels (Eds.), *Towards a sociology of pedagogy: The contribution of Basil Bernstein to research* (pp. 363–368). New York: Peter Lang.

Berry, M. (1995). Thematic options and success in writing. In M.Ghadessy (Ed.),*Thematic development in English texts* (pp. 55–84). London: Pinter.

Botzer, G., &Reiner, M. (2005). Imagery in physics learning—from physicists' practice to naïve students' understanding. In J. K.Gilbert (Ed.), *Visualization in science education* (pp. 147–168). Dordrecht: Springer.

Braaten, M., & Windschitl, M. (2011). Working toward a stronger conceptualization of scientific explanation for science education. *Science Education*, *95*(4), 639–669.

Bratkovich, M. O. (2018). Shining light on language for, in, and as science content. *Science & Education*, *27*, 769–782.

Bucher, H.-J., & Niemann, P. (2012). Visualizing science: The reception of powerpoint presentations. *Visual Communication*, *11*(3), 283–306.

Carvalho, L., Dong, A., & Maton, K. (2009). Legitimating design: A sociology of knowledge account of the field. *Des Stud*, *30*(5), 483–502.

Chan, J. Y. H. (2016). The fine-tuning medium-of-instruction policy in Hong Kong: A case study of the changing school-based test papers in science subjects. *Education Journal*, *44*(1), 159–193.

Christie, F. (1999). The pedagogic device and the teaching of English. In F.Christie (Ed.), *Pedagogy and the shaping of consciousness: Linguistic and social processes* (pp. 156–184). London: Cassell.

Christie, F. (2002). *Classroom discourse analysis: A functional perspective*. London: Continuum.

Christie, F., & Derewianka, B. (2008). *School discourse: Learning to write across the years of schooling*. London: Continuum.

Christie, F., & Martin, J. R. (Eds.). (1997). *Genre and institutions: Social processes in the workplace and school*. London: Continuum.

Christie, F., & Martin, J. R. (2005). *Genre and institutions: Social processes in the workplace and school*. London: Continuum.

Christie, F., & Martin, J. R. (Eds.). (2007). *Language, knowledge and pedagogy: Functional linguistic and sociological perspective*. London: Continuum.

Christie, F., & Soosai, A. (2001). *Language and meaning 2*. Melbourne: Macmillan Education.

Coffin, C. (2004). Learning to write history: The role of causality. *Written Communication*, *21*(3), 261–289.

Coffin, C. (2006). *Historical discourse: The language of time, cause and evaluation*. London: Continuum.

Coffin, C., Donohue, J., & North, S. (2013). *Exploring English grammar: From formal to functional*. London, New York: Routledge.

Cope, B., & Kalantzis, M. (Eds.). (2000). *Multiliteracies : Literacy learning and the design of social futures*. London: Routledge.

Corbin, J. M., & Strauss, J. M. (2007). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (3rd ed.). Thousand Oaks, CA: SAGE.

Creswell, J., & Creswell, J. D. (2018). *Research design : Qualitative, quantitative, and mixed methods approaches* (5th ed.). Thousand Oaks: SAGE.

Creswell, J. D. (2013). *Qualitative inquiry research design: Choosing among five* *approaches*. London: SAGE.

Cromley, J. G., Weisberg, S. M., Dai, T., Newcombe, N. S., Schunn, C. D., Massey, C., & Merlino, F. J. (2016). Improving middle school science learning using diagrammatic reasoning. *Science Education*, *100*(6), 1184-1213.

Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process*. London: SAGE.

Curriculum Development Council. (2015). *Promotion of STEM education – Unleashing potential in innovation*. Retrieved on January 24, 2019, from https://www.edb.gov.hk/attachment/en/curriculum-development/renewal/Brief on STEM (Overview)_eng_20151105.pdf

Curriculum Development Council. (2017). *Science education: Key learning area curriculum guide (Primary 1 – Secondary 6)*. Hong Kong: Author. Retrieved on January 24, 2019, from https://www.edb.gov.hk/attachment/en/curriculum-development/renewal/SE/SE_KLACG_P1-S6_Eng_2017.pdf

Curriculum Planning and Development Division Singapore. (2012). *Science syllabus, lower secondary express course normal (academic) course*. Retrieved on January 24, 2019, from https://www.moe.gov.sg/docs/default-source/document/education/syllabuses/sciences/files/science-lower-secondary-2013.pdf

Daneš, F. (1974). Functional sentence perspective and the organisation of the text. In F.Daneš (Ed.), *Papers on functional sentence perspective* (pp. 106–128). The hague: Mouton.

Danielsson, K. (2016). Modes and meaning in the classroom — The role of different semiotic resources to convey meaning in science classrooms. *Linguistics and Education*, *35*, 88–99.

deAndrade, V., Freire, S., & Baptista, M. (2019). Constructing scientific explanations: A system of analysis for students' explanations. *Research in Science Education 49*(3), 787-807.

Denzin, N. K., & Lincoln, Y. S. (2011). *The Sage handbook of qualitative research* (4th ed.). Thousand Oaks, CA: SAGA.

Derewianka, B., & Coffin, C. (2008). Visual representations of time in history textbooks. In L.Unsworth (Ed.), *Multimodal semiotics* (pp. 187–200). London: Continuum.

Doran, Y. J. (2016). *Knowledge in physics through mathematics, image and language*. The University of Sydney.

Dubois, B. (1987). (1987). A reformulation of thematic progression typology. *Text*, *7*(2), 89–116.

Duschl, R., Maeng, S., & Sezen, A. (2011). Learning progressions and teaching sequences: a review and analysis. *Studies in Science Education*, *47*(2), 123–182.

Forey, G. (2002). *Aspects of theme and their role in workplace texts*. University of Glasgow.

Forey, G. (2004). Workplace texts: Do they mean the same for teachers and business people? *English for Specific Purposes*, *23*(4), 447–469.

Forey, G., & Polias, J. (2017). Multi-semiotic resources providing maximal input in teaching science through English. In A. Llinares & T. Moton (Eds.), *Applied Linguistics Perspectives on CLIL* (pp. 145–166). Amsterdam: John Benjamins.

Fries, P. H. (1995). Themes, methods of development, and texts. In R. Hasan & P. H.Fries (Eds.),*On Subject and Theme: A Discourse Functional Perspective* (pp. 317–359). Amsterdam: John Benjamins.

Fries, P. H. (2009). The textual metafunction as a site for discussion of the goals of linguistics and techniques of linguistic analysis. In G. Forey & G. Thompson (Eds.), *Text Type and Texture: In Honour of Flo Davies* (pp. 8–44). London: Equinox.

Gaines, P. (2011). The multifunctionality of discourse operator okay: Evidence from a police interview. *Journal of Pragmatics*, *43*(14), 3291–3315.

Gee, J. (2007). *What video games have to teach us about learning and literacy (Rev. and updated ed.)*. New York: Palgrave Macmillan.

Gentner, D., & Stevens, A. L. (1983). *Mental models*. Hillsdale, NJ: Erlbaum.

Gibbons, P. (2002). *Scaffolding language, scaffolding learning : Teaching second language learners in the mainstream classroom*. Portsmouth, NH: Heinemann.

Gilbert, J. K. (2005). *Visualization in science education*. Amsterdam: Springer.

Gilbert, J. K., Boulter, C. J., & Rutherford, M. (2000). Explanations with models in science education. In J. K. Gilbert & J. Boulter (Eds.), *Developing models in science education* (pp. 193–208). Dordrecht: Kluwer.

Gilbert, J. K., Reiner, M., & Nakhleh, M. (Eds.). (2008). *Visualization: Theory and practice in science education*. Amsterdam: Springer.

Glassner, A., Weinstock, M., & Neuman, Y. (2005). Pupils' evaluation and generation of evidence and explanation in argumentation. *British Journal of Educational Psychology, 75*, 105–118.

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Technology Research and Development*, *29*(2), 75–91.

Guba, E. G. (1990). The alternative paradigm dialog. In E. G. Guba (Ed.), *The paradigm dialog* (pp. 17–30). Newbury Park, CA: SAGE.

Guba, E. G., & Lincoln, Y. S. (2005). Paradigmatic controversies, contradictions, and emerging confluences. In N. K. Denzin & Y. S. Lincoln (Eds.), *The Sage handbook of qualitative research* (3rd ed., pp. 191–215). Thousand Oaks, CA: SAGE.

Guo, L. (2004). Multimodality in Biology textbooks. In K. L. O'Halloran (Ed.), *Multimodal discourse analysis: Systemic-functional perspectives* (pp. 196–219). London: Continuum.

Hakkarainen, K. (2004). Pursuit of explanation within a computer-supported classroom. *International Journal of Science Education*, *26*(8), 979–996.

Halford, G. S. (1993). *Children's understanding: The development of mental models*. Hillsdale, NJ: Erlbaum.

Halliday, M. A. K. (2007). Language and Education. In J. Webster (Ed.), *The collected works of M.A.K. Halliday* (Vol.10). London: Continuum.

Halliday, M. A. K. (1978). *Language as social semiotic: The social interpretation of language and meaning*. London: Arnold.

Halliday, M. A. K. (1985). *An introduction to functional grammar*. London: Arnold.

Halliday, M. A. K. (1993). Some grammatical problems in scientific English. In M. A. K. Halliday, & J. R. Martin (Eds.), *Writing science: Literacy and discursive power* (pp. 69–85). London: Routledge.

Halliday, M. A. K. (1998). Things and relations: Regrammaticing experience as technical knowledge. In J. R. Martin & R. Veel (Eds.), *Reading science: Critical and functional perspectives on discourses of science* (pp. 185–235). London: Routledge.

Halliday, M. A. K., & Greaves, W. S. (2008). *Intonation in the grammar of English*. London: Equinox.

Halliday, M. A. K., & Hasan, R. (1985). *Language, context, and text: Aspects of language in a social-semiotic perspective*. Oxford: Oxford University Press.

Halliday, M. A. K., & Martin, J. R. (1993). *Writing science: Literacy and discursive power (critical perspectives on literacy and education)*. London: Falmer Press.

Halliday, M. A. K., & Matthiessen, C. M. I. M. (1999). *Construing experience through meaning: A language-based apporach to cognition*. London: Cassell.

Halliday, M. A. K., & Matthiessen, C. M. I. M. (2014). *Halliday's introduction to functional grammar* (4th ed.). Abingdon: Routledge.

Hao, J. (2018). Reconsidering cause inside the clause in scientific discourse-from a discourse semantic perspective in systemic functional linguistics. *Text and Talk*, *38*(5), 525-550.

Hartshorne, C. (1974). Perception and the 'concrete abstractness' of science. *Philosophy and Phenomenological Research*, *34*(4), 465–476.

Hasan, R. (1999). Speaking with reference to context. In M. Ghadessy (Ed.), *Text and context in functional linguistics* (pp. 219–328). Amsterdam: Benjamins.

He, Q., & Forey, G. (2018). Meaning-making in a secondary science classroom: A systemic functional multimodal discourse analysis. In K.-S.Tang & K. Danielsson (Eds.), *Global developments in literacy research for science education* (pp. 183–202). Cham: Springer.

He, Q., & Yang, B. (2018). A corpus-based study of the correlation between text technicality and ideational metaphor in English. *Lingua*, *203*, 51–65.

Heckler, A. F. (2010). Some Consequences of Prompting Novice Physics Students to Construct Force Diagrams. *International Journal of Science Education*, *32*(14), 1829–1851.

Hjelmslev, L. (1961). *Prolegomena to a theory of language*. Madison, WI.: University of Wisconsin Press.

Holbrook, J., & Rannikäe, M. (2007). The nature of science education for enhancing scientific literacy. *Journal of Science Education*, *29*(11), 1347–1362.

Hood, S. (2009). Texturing interpersonal meanings in academic argument: Pulses and prosodies of value. In G. Forey & G. Thompson (Eds.), *Text Type and Texture: In Honour of Flo Davies* (pp. 216–233). London: Equinox.

Hood, S. (2010). *Appraising research: Evaluation in academic writing*. London: Palgrave Macmillan.

Hood, S. (2011). Body language in face-to-face teaching: A focus on textual and interpersonal meaning. In S. Dreyfus, S. Hood, & M. Stenglin (Eds.), *Semiotic margins: Meaning in multimodalities* (pp. 31–52). London: Continuum.

Hood, S., & Forey, G. (2005). Introducing a conference paper: Getting interpersonal with your audience. *Journal of English for Academic Purposes*, *4*, 291–306.

Hood, S., & Forey, G. (2008). The interpersonal dynamics of call-centre interactions: Co-constructing the rise and fall of emotion. *Discourse & Communication*, *2*(4), 389–409.

House, J. (2013). Developing pragmatic competence in English as a lingua franca: Using discourse markers to express (inter)subjectivity and connectivity. *Journal of Pragmatics*, *59*, 57–67.

Hubber, P., Tytler, R., & Haslam, F. (2010). Teaching and learning about force with a representational focus: Pedagogy and teacher change. *Research in Science Education*, *40*(1), 5–28.

Hurd, P. D. (1958). Scientific literacy: Its meaning for American schools. *Educational Leadership*, *37*, 13–16.

Jaipal, K. (2010). Meaning making through multiple modalities in a biology classroom: A multimodal semiotics discourse analysis. *Science Education*, *94*(1), 48–72.

Jewitt, C. (2007). Multimodality and literacy in school classroom. *AERA Reviw of Research in Education*, *32*(1), 241–267.

Jewitt, C. (2008). Multimodality and literacy in school classrooms. *Review of Research in Education*, *32*(1), 241–267.

Jewitt, C. (2009). Different approaches to multimodality. In C. Jewitt (Ed.), *The Routledge handbook of multimodal analysis* (pp. 28–39). London: Routledge.

Jewitt, C. (Ed.). (2014). *The Routledge handbook of multimodal analysis* (2nd ed., Vol. 22). London: Routledge.

Johnstone, A. H. (1993). The development of chemistry teaching: A changing response to a changing demand. *Journal of Chemical Education*, *70*(9), 701–705.

Jong, J.-P., Chiu, M.-H., & Chung, S.-L. (2015). The use of modeling-based text to improve students' modeling competencies. *Science Education*, *99*(5), 986–1018.

Kapon, S., Faniel, U., Eylon, B. S., Kapon, S., Ganiel, U., & Eylon, B. S. (2010). Explaining the unexplainable: Translated scientific explanations (TSE) in public physics lectures. *International Journal of Science Education*, *32(2)*(15), 245–264.

Klein, P., & Rose, M. (2010). Teaching argument and explanation to prepare junior students for writing to learn. *Reading Research Quarterly*, *45*(4), 433–461.

Klein, P., & Unsworth, L. (2014). The logogenesis of writing to learn: A systemic functional perspective. *Linguistics and Education*, *26*, 1–17.

Kong, K. (2004). Marked themes and thematic patterns in abstracts, advertisements and administrative documents. *Word*, *55*(3), 343–362.

Kress, G. (2003). *Literacy in the new media age*. London: Routledge.

Kress, G. (2007). Meaning, learning and representation in a social semiotic approach to multimodal communication. In A. McCabe, M. O'Donnell, & R. Whittaker (Eds.), *Advances in language and education* (pp. 15–39). London: Continuum.

Kress, G. (2010). *Multimodality: A social semiotic approach to contemporary communication*. London: Routledge.

Kress, G. (2014). The rhetorical work of shaping the semiotic world. In A. Archer, & D. Newfield (Eds.), *Multimodal approaches to research and pedagogy: Recognition, resources, and access* (pp. 131–152). New York: Routledge.

Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning: The rhetorics of the science classroom*. London: Continuum.

Kress, G., & van Leeuwen, T. (1996/2006). *Reading images: The grammar of visual design* (2nd ed.). London: Routledge. (1st ed. 1996).

Kress, G., &VanLeeuwen, T. (2002). Colour as a semiotic mode: Notes for a grammar of colour. *Visual Communication*, *1*(3), 343–368.

Lemke, J. (1990). *Talking science: Language, learning, and values*. New Jersey: Ablex.

Lemke, J. (2004). The literacies of science. In E. W. Saul (Ed.), *Crossing borders in literacy and science instruction: Perspectives on theory and practice* (pp. 33–47). Newark DE: International Reading Association and National Science Teachers Association.

Lemke, J. (1984). *Semiotics and education*. Toronto: Toronto Semiotic Circle Monograph.

Lemke, J. (1998). Multiplying meaning: Visual and verbal semiotics in scientific text. In J. R. Martin & R. Veel (Eds.), *Reading science: Critical and functional perspectives on discourses of science* (pp. 87–113). London: Routledge.

Lemke, J. (2002). Multimedia semiotics: Genres for science education and scientific literacy. In M. Schleppegrell & M. C. Colombi (Eds.), *Developing advanced literacy in first and second languages: Meaning with power* (pp. 21–44). Mahwah, NJ: Erlbaum.

Lemke, J. (2002). Travels in hypermodality. *Visual Communication*, *1*(3), 299–325.

Leu, D. J., Kinzer, C. K., Coiro, J., Castek, J., & Henry, L. A. (2017). New literacies: A dual-level theory of the changing nature of literacy, instruction, and assessment. *Journal of Education*, *197*(2), 1–18.

Lim, F. V. (2011). *A systemic functional multimodal discourse analysis approach to pedaghogic discourse*. National University of Singapore.

Lin, A. M. Y., & Lo, Y. Y. (2017). Trans/languaging and the triadic dialogue in content and language integrated learning (CLIL) classrooms. *Language and Education*, *31*(1), 26–45.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, CA: SAGE.

Lincoln, Y. S., Lynham, S. A., & Guba, E. G. (2011). Paradigmatic controversies, contradictions, and emerging confluences, revisted. In N. K. Denzin & Y. S. Lincoln (Eds.), *The Sage handbook of sociolinguistics handbook of qualitative research* (4th ed., pp. 97–128). Thousand Oaks, CA: SAGE.

Lindholm-Leary, K. J. (2001). *Dual language education*. Clevedon, England: Multilinngual Matters.

Liu, Y., & O'Halloran, K. L. (2009). Intersemiotic texture: Analyzing cohesive devices between language and images. *Social Semiotics*, *19*(4), 367–388.

Lo, Y. Y., & Macaro, E. (2012). The medium of instruction and classroom interaction: evidence from Hong Kong secondary schools. *International Journal of Bilingual Education and Bilingualism*, *15*(1), 29–52.

Love, K. (2009). Literacy pedagogical content knowledge in secondary teacher education: Reflecting on oral language and learning across the disciplines. *Language and Education*, *23*(6), 541–560.

Lukin, A., Moore, A., Herke, M., Wegener, R., & Wu, C. (2011). Halliday's model of register revisited and explored. *Linguistics and the Human Sciences*, *4*(2), 187–214.

Macken-Horarik, M., Sandiford, C., Love, K., & Unsworth, L. (2015). New ways of working 'with grammar in mind' in school English: Insights from systemic functional grammatics. *Linguistics and Education*, *31*, 145–158.

Martin, J. R. (1986). Grammaticalising ecology: The politics of baby seals and kangaroos. In T.Threadgold, E. A. Grosz, G. Kress, & M. A. K.Halliday (Eds.), *Semiotics, ideology, language* (pp. 225–268). Sydney: Sydney Association for Studies in Society and Culture.

Martin, J. R. (1992). *English text: System and structure*. Amsterdam: Benjamins.

Martin, J. R. (1999). Modelling context: A crooked path of progress in contextual linguistics. In M.Ghadessy (Ed.), *Text and context in functional linguistics* (pp. 25–62). Amsterdam: John Benjamins.

Martin, J. R. (2007). Construing knowledge: A functional linguistic perspective. In F. Christie & J. R. Martin (Eds.), *Language, knowledge and pedagogy: Functional linguistic and sociological perspectives* (pp. 34–64). London: Continuum.

Martin, J. R. (2009). Genre and language learning: A social semiotic perspective. *Linguistics and Education*, *20*, 10–21.

Martin, J. R. (2010). Semantic variation — modelling realisation, instantiation and individuation in social semiosis. M. Bednarek, & J. R. Martin (Eds.), *New discourse on language: Functional perspectives on multimodality, identity, and affiliation* (pp. 1–33). London: Continuum.

Martin, J. R. (2011). Bridging troubled waters: Interdisciplinarity and what makes it stick. In F. Christie & K. Maton (Eds.), *Disciplinarity: Functional linguistic and sociological perspectives* (pp. 35–61). London: Continuum.

Martin, J. R., & Rose, D. (2007). *Working with discourse: Meanign beyond the clause* (2nd ed.). London: Bloomsbury Academic.

Martin, J. R., & Rose, D. (2008). Genre relations mapping culture. London,: Equinox.

Martin, J. R., & White, P. (2005). *The language of evaluation*. New York: Palgrave Macmillan.

Martinec, R. (2000). Types of process in action. *Semiotica*, *130*(3–4), 243–268.

Martinec, R. (2004). Gestures that co-occur with speech as a systematic resource: The realization of experiential meanings in indexes. *Social Semiotics*, *14*(2), 193–213.

Martinec, R. (2013). Nascent and mature uses of a semiotic system: the case of image-text relations. *Visual Communication*, *12*(2), 147-172.

Martinec, R., & Salway, A. (2005). A system for image-text relations in new (and old) media. *Visual Communication*, *4*(3), 337–371.

Maton, K. (2013). Making semantic waves: A key to cumulative knowledge-building. *Linguistics and Education*, *24*, 8–22.

Matthiessen, C. M. I. M. (2007). The "architecture" of language according to systemic functional theory: Developments since the 1970s. In R. Hasan, C. M. I. M. Matthiessen, & J. Webster (Eds.), *Continuing discourse on language: A functional perspective* (pp. 505–561). London: Equinox.

Matthiessen, C., Teruya, K., & Lam, M. (2010). *Key terms in systemic functional linguistics*. London: Continuum.

Maxwell-Reid, C. (2015). The role of clausal embedding in the argumentative writing of adolescent learners of English. *System*, *49*, 28–38.

Maxwell-Reid, C., & Lau, K. (2016). Genre and technicality in analogical explanations: Hong Kong's English language textbooks for junior secondary science. *Journal of English for Academic Purposes*, *23*, 31–46.

Mayer, R. E., & Jackson, J. (2005). The case for coherence in scientific explanations: quantitative details can hurt qualitative understanding. *Journal of Experimental Psychology. Applied*, *11*(1), 13–8.

McNeil, K. L., & Krajcik, J. (2008). Scientific explanations: Characterizing and evaluating the effects of teachers' instructional practices on student learning. *Journal of Research in Science Teaching*, *45*(1), 53–78.

McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *Journal of the Learning Sciences, 15*(2), 153–191.

Mehisto, P., Marsh, D., & Frigols, M. (2008). *Uncovering CLIL : Content and language integrated learning in bilingual and multilingual education (Macmillan books for teachers)*. Oxford: Macmillan Education.

Merriam, S. B. (1998). *Qualitative research and case study applications in education*. San Francisco: Jossey-Bass.

Mertens, D. M. (2010). *Research and evaluation in education and psychology: Integrating diversity with quantitative, qualitative, and mixed methods* (3rd ed.). Thousand Oaks, CA: SAGE.

Moje, E. B. (2007). Developing socially just subject-matter instruction: A review of the literature on disciplinary literacy teaching. *Review of Research in Education, 31*(1), 1-44.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academy Press.

Neuman, M. L. (2009). *Social research methods: Qualitative and quantitative approaches* (7th ed.). Boston: Allyn & Bacon.

Ngo, T., & Unsworth, L. (2015). Reworking the appraisal framework in ESL research: refining attitude resources. *Functional Linguistics*, *2*(1), 1.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, *87*(2), 224–240.

Norris, S., & Phillips, L. (2009). Scientific literacy. In D. R. Olson & N.Torrance (Eds.), *The Cambridge handbook of literacy* (pp. 271–285). New York: Cambridge University Press.

O'Halloran, K. L. (1998). Classroom discourse in Mathematics: A multisemiotic analysis. *Linguistics and Education*, *10*(3), 359–388.

O'Halloran, K. L. (2004). *Multimodall discourse analysis: Systemic functional perspectives*. London: Continuum.

O'Halloran, K. L. (2005). *Mathematical discourse: Language, symbolism and visual* *images*. London: Continuum.

O'Halloran, K. L. (2007). Mathematical and scientific forms of knowledge: A systemic functional multimodal grammartical approach. In F. Christie & J. R. Martin (Eds.), *Language, knowledge and pedagogy: Functional linguistic and sociological perspectives* (pp. 205–236). London: Continuum.

O'Halloran, K. L. (2007). Systemic functional multimodal discourse analysis (SF-MDA) approach to Mathematics, grammar and literacy. In M. McCabe, M.O'Donnell, & R.Whittaker (Eds.), *Advances in language and education* (pp. 75–100). London: Continuum.

O'Halloran, K. L. (2008). Systemic functional-multimodal discourse analysis (SF-MDA): constructing ideational meaning using language and visual imagery. *Visual Communication, 7*(4), 443–475.

O'Halloran, K. L. (2009). Historical changes in the semiotic landscape: From calculation to computation. In C.Jewitt (Ed.), *The Routledge handbook of multimodal analysis* (pp. 98–113). London: Routledge.

O'Halloran, K. L. (2011a). Multimodal discourse analysis. In K. Hyland & B. Paltridge (Eds.), *Companion to Discourse* (pp. 120–137). London: Continuum.

O'Halloran, K. L. (2011b). The semantic hyperspace: Accumulating mathematical knowledge across semiotic resources and modalities. In F. Christie & K. Maton (Eds.), *Disciplinarity: Functional linguistic and sociological perspectives* (pp. 217–236). London: Continuum.

O'Halloran, K. L., & Smith, B. A. (2012a). Multimodal text analysis. In C. A. Chapelle (Ed.), *Encyclopaedia of applied linguistics*. New Jersey: Wiley-Blackwell.

O'Halloran, K. L., & Smith, B. A. (2012b). Multimodality and technology. In C. A. Chapelle (Ed.), *Encyclopaedia of applied linguistics*. New Jersey: Wiley-Blackwell.

O'Toole, M. (1994/2000). *The language of displayed art* (2nd ed.). London: Routledge.(1st ed. 1994).

O'Toole, M. (2011). Art vs computer animation: Integrity and technology in "South Park." In K. L.O'Halloran & B. A.Smith (Eds.), *Multimodal studies: Exploring issues and domains* (pp. 239–252). London: Routledge.

Osborne, J. (2002). Science without literacy: A ship without a sail? *Cambridge Journal* *of Education*, *32*(2), 203–218.

Ozdemir, G., & Clark, D. (2009). Knowledge structure coherence in turkish students ' understanding of force. *Journal of Research in Science Teaching*, *46*(5), 570–596.

Painter, C. (1999). *Learning through language in early childhood*. London: Cassell.

Painter, C. (2003). Developing attitude: An ontogenetic perspective on APPRAISAL. *TEXT*, *23*(2), 183–209.

Painter, C., Martin, J. R., & Unsworth, L. (2013). *Reading visual narratives*. Sheffield: Equinox.

Patton, M. (1990). *Qualitative evaluation and research methods*. Beverly Hills, CA: SAGE.

Peirce, C. S. (1955). Logic as semiotic: The theory of signs. In J. Buchler (Ed.), *Philosopical writings of Peirce*. New York: Dover.

Perkins, D. N., & Grotzer, T. A. (2005). Dimensions of causal understanding: The role of complex causal models in students' understanding of science. *Studies in Science Education*, *41*(1), 117–165.

Polias, J. (2016). *Apprenticing students into science: Doing, talking & writing scientifically*. Melbourne: Lexis Education.

Poon, A. Y. K. (2013). Will the new fine-tuning medium-of-instruction policy alleviate the threats of dominance of English-medium instruction in Hong Kong? *Current Issues in Language Planning*, *14*(1), 34–51.

Pozzer-Ardenghi, L., & Roth, W.-M. (2005). Photographs in lectures: Gestures as meaning-making resources. *Linguistics and Education*, *15*(3), 275–293.

Pozzer-Ardenghi, L., & Roth, W.-M. (2009). How do we know he is not talking about himself? Demonstrations in science classroom. *Journal of Pragmatics*, *41*(4), 684–698.

Reiner, M. (2009). Sensory cues, visualization and physics learning. *International Journal of Science Education*, *31*(3), 343–364.

Rose, D., & Martin, J. R. (2012). *Learning to write, reading to learn : Genre, knowledge and pedagogy in the Sydney school*. Bristol: Equinox.

Royce, T. D. (2002). Multimodality in the TESOL classroom: Exploring visual-verbal synergy. *TESOL Quarterly*, *36*(2), 191.

Salmon, W. C. (2006). *Four decades of scientific explanation*. Pittsburgh: Univeristy of Pittsburgh Press.

Schiffrin, D. (1987). *Discourse matters*. Cambridge: Cambridge University Press.

Schleppegrell, M. (2004). *The language of schooling: A functional linguistics perspective*. Mahwah, N.J: Lawrence Erlbaum Associates.

Schwarz, C. V, Reiser, B. J., Davis, E. A., Kenyon, L., Acher, A., & Fortus, D. (2009). Designing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal for Research in Science Teaching*, *46*(6), 632–654.

Silverman, D. (2006). *Interpreting qualitative data: Methods for analyzing talk, text, and interaction* (3rd ed.). London: SAGE.

Spradley, J. P. (1980). *Participant observation*. New York: Holt, Rinehart & Winston.

Stake, R. (1995). *The art of case study research*. Thousand Oaks, CA: Sage.

Stake, R. (2006). *Multiple case study analysis*. New York: Guilford Press.

Swales, J. M. (1990). *Genre analysis: English in academic and research settings*. Cambridge: Cambridge University Press.

Taboada, M., & Habel, C. (2013). Rhetorical relations in multimodal documents. *Discourse Studies*, *15*(1), 65–89.

Taboada, M., & Lavid, J. (2003). Rhetorical and thematic patterns in scheduling dialogues: A generic characterization. *Functions of Language*, *10*(2), 147–179.

Tam, A. C. F. (2013). Pre-service teachers' beliefs about the switch of medium-of-instruction and their influence on lesson planning and teaching practice. *Asia Pacific Journal of Education*, *33*(4), 476-492.

Tang, K.-S., Delgado, C., & Moje, E. B. (2014). An integrative framework for the analysis of multiple and multimodal representations for meaning-making in science education. *Science Education, 98*(2), 305–326.

The New London Group. (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review*, *66*(1), 60–93.

Thompson, G. (2014). *Introducing functional grammar* (3rd ed.). Abingdon: Routledge.

Thompson, G., & Thompson, S. A. (2009). Theme, subject and the unfolding of text. In *Text type and texture: In honour of Flo Davies* (pp. 45–69). London: Equinox.

Touger, J. S., Duresne, R. J., Gerace, W. J., Hardiman, P. T., & Mestre, W. J. (1995). How novice physics students deal with explanations. *International Journal of Science Education*, *17*(2), 255–269.

Tseng, C.-I. (2013). Analysing characters' interactions in filmic text: A functional semiotic approach. *Social Semiotics*, *23*(5), 587–605.

Unsworth, L. (2000). Investigating subject-specific literacies in school learning. In L. Unsworth (Ed.), *Researching language in schools and communities: Functional linguistic perspectives* (pp. 245–274). London: Cassell.

Unsworth, L. (2002). Changing dimensions of school literacies. *Australian Journal of Language and Literacy*, *25*(1), 62–78.

Unsworth, L. (2008). Multiliteracies, e-literature and English teaching. *Language and Education*, *22*(1), 62–65.

van Leeuwen, T. (1999). *Speech, music, sound*. London: Macmillan Education.

van Leeuwen, T. (2005). *Introducing social semiotics*. Abingdon: Routledge.

van Maanen, J. (Ed.). (1983). *Qualitative methodology*. Beverly Hills, CA: SAGE.

Veel, R. (1997). Learning how to mean—scientifically speaking: Apprenticeship into scientific discourse in the secondary school. In F. Christie & J. R. Martin (Eds.),*Genre and institutions: Social processes in the workplace and school* (pp. 161–195). London: Continuum.

Veel, R. (1999). Language, knowledge and authority in school mathematics. In F.Christie (Ed.), *Pedagogy and the shaping of consciousness: Linguistic and social processes* (pp. 185–216). London: Cassell.

Williams, M. (2000). *Science and social science: An introduction*. London: Routledge.

Wu, H. K., & Hsieh, C. E. (2006). Developing sixth graders' inquiry skills to construct explanations in inquiry-based learning environments. *International Journal of Science Education*, *28*(11), 1289–1313.

Yeo, J., & Gilbert, J. K. (2014). Constructing a Scientific Explanation—A Narrative Account. *International Journal of Science Education*, *36*(11), 1902–1935.

Yin, R. K. (1994). *Case study research design and methods: Applied social research and methods series* (2nd ed.). Thousand Oaks: SAGE.

Yin, R. K. (2006). Mixed methods research: Are the methods genuinely integrated or merely parallel? *Research in the Schools*, *13*(1), 41–47.

Yin, R. K. (2009). *Case study research: Design and methods* (4th ed.). Thousand Oaks, CA: SAGE.

Yin, R. K. (2012). *Applications of case study research* (3rd ed.). Thousand Oaks, CA: SAGE.

Young, M. (2006). Conceptualising vocational knowledge: Some theoretical considerations. In *Knowledge, curriculum and qualifications for South African further education* (pp. 104–124). Cape Town: HRSC Press.

Zangori, L., Forbes C., & Biggers, M. (2013). Fostering student sense making in elementary science learning environments: Elementary teachers' use of science curriculum materials to promote explanation construction. *Journal of Research in Science Teaching*, *50*(8), 989–1017.

Zangori, L., & Forbes, C. T. (2013). Preservice elementary teachers and explanation construction: Knowledge-for-practice and knowledge-in-practice. *Science Education*, *97*(2), 310–330.

Zhao, S., Djonov, E., & van Leeuwen, T. (2014). Semiotic technology and practice: A multimodal social semiotic approach to PowerPoint. *Text and Talk*, *34*(3), 349–375.