Chapter 8
Developing Multimodal Communication Competencies: A Case of Disciplinary Literacy Focus in Singapore

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Introduction

In science education, there is a growing understanding that learning science involves developing a repertoire of disciplinary-specific literacy skills to engage with the knowledge and practices of the scientific community (Kelly 2008). Such 'disciplinary literacy', or the specific ways of talking, reading, writing, doing, and thinking valued and used by the discipline (McConachie et al. 2006; Moje 2007), is central rather than peripheral to the development of scientific understanding (Norris and Phillips 2003). For decades, researchers from multiple disciplines have shed light on the language and discursive features of academic science (Halliday and Martin 1993; Lemke 1990) as well as pioneering various reading and writing strategies to help students master scientific discourse (Hand et al. 1999; Yore and Shymansky 1985). However, in more recent years, there has been increasing attention toward the role of visual, graphical, mathematical, and gestural modes of representation in scientific communication (Kress et al. 2001; Lemke 1998). Research in this area reveals how each mode of representation plays a unique function in representing different aspects of scientific meaning. More studies are also beginning to show how scientific knowledge in specific content consists of a characteristic and recognizable pattern of relationships among multimodal representations (e.g., Hubber et al. 2010; Tang 2011; Tytler et al. 2006).

Building on our increasing understanding of the role of language and representations in science, current research has begun to focus on developing students' competencies in disciplinary literacy. With the aim of raising the literacy levels of

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students in all subject areas, there is now a growing recognition of the importance of disciplinary literacy in several national curricula in the learning of all subject areas (e.g., US Common Core Standards, New South Wales National Curriculum). For instance, the Common Core Standards in the United States underscore the importance of literacy in preparation for college and life. In its 'Standards' document for English Language Arts (ELA) and Literacy in History/Social Studies, Science and Technical Subjects, teachers of these subjects are expected to use their "content area expertise to help students meet the particular challenges of reading, writing, speaking, listening, and language in their respective fields" (Council of Chief State School Officers 2010, p. 3).

The purpose of this chapter is to report on findings from a recent research study that focuses on the development of disciplinary literacy in Singapore. As part of a national curriculum shift toward subject-specific communication skills, this research study aims to help science teachers' focus on the teaching of disciplinary language in their classroom. In particular, we worked with teachers to develop pedagogical activities and strategies to help grade 9 (secondary 3) students in physics and chemistry write scientific descriptions and explanations based on observable phenomena. The activities required the students to interpret, translate, and integrate multimodal forms of representations that were introduced at various stages of the science lesson. Through the illustration of selected lesson enactments, we intend to discuss the role of multimodal activities in science disciplinary literacy teaching, as well as highlight the pedagogical issues in implementing disciplinary literacy within the science classrooms.

Theoretical Perspectives

Our research is informed in part by the theory of social semiotics (Lemke 1990), which posits that language and all other symbol systems (e.g., images, gestures) function as meaning-making resources for people to make different kinds of meaning in any social context. Social semiotics is a generalized theory that derives from earlier work in systemic functional linguistics (SFL; Halliday 1978). SFL has been widely applied in science education to investigate the nature of language in science classroom discourse. Early work in the 1990s examined the relationship between a text's linguistic function and students' content development in science. For instance, Lemke (1990, p. 12) identified the repeated and characteristic "thematic pattern of semantic relationships" of words and utterances that constitutes what one would recognize as talking about a particular topic in science. The peculiar features of the specialized language of science were also elaborated by Halliday and Martin (1993), who shed light on several unique linguistic features of scientific texts that present a challenge to students' learning of science. These features include interlocking definitions, technical taxonomies, lexical density, and nominalization. Other researchers (e.g., Schleppegrell 2004; Veel 1997) provided rich descriptions of science genres, such as report, exposition, explanation, and experimental procedure, which students typically go through and need to learn in science lessons. Within the genre of explanation, Unsworth (2001) further examined how different language choices optimize the effectiveness of science explanations in school texts. According to Moje (2007), the SFL approach to disciplinary literacy focuses on teaching the linguistic processes of the disciplines. This involves guiding students through the process of highlighting the grammatical and lexical features of texts, deconstructing various text genres, and jointly constructing new texts using the features of the disciplinary language.

In more recent years, multimodality – the study of multiple modes of representation- has further expanded research from SFL to incorporate other semiotic resource systems such as images, graphs, symbols and gestures (Jewitt 2008). This area of work brings to attention the importance of multimodal integration in science classroom teaching and learning. For instance, Kress et al. (2001) documented the complex ensemble of multiple modes of representation orchestrated by the science teacher as a way of shaping scientific knowledge in the classroom. They argued that learning should not be seen as centrally dependent on oral and written language, but rather as a "dynamic process of transformative sign-making." In addition, they also pointed out the "semiotic affordances" of different modes of representation in realizing different kind of meanings. Lemke, in his analysis of canonical scientific texts (1998), also came to the same conclusion that scientific knowledge is constructed through joint meaning-making across multiple modes of representation. In particular, he highlighted that the possibility of making different meanings increases when multiple modes of representation are combined. This "multiplying meaning" effect is what makes possible the concepts of science to evolve historically as "semiotic hybrids of verbal, mathematical, visual-graphical, and actional-operational mode" (Lemke 1998, p. 87). Therefore, multimodal integration is an indispensable part of science learning as well as disciplinary literacy teaching in the sciences.

Education Context in Singapore

In Singapore, English is the medium of instruction for all subjects, except for the Mother Tongue languages. As such, the way that the English language is used by both teachers and students in the teaching and learning of content subjects plays an important role in the overall development of students' language and communication skills. In recent years, the Singapore Ministry of Education (MOE) launched an initiative to support the development of English competence and effective communication in all schools. Called the Whole School Approach to Effective Communication in English (WSA-EC), this program is a strategic endeavor to improve students' communication skills in English (ELIS 2011). The MOE has argued that a key aspect of developing students' effective communication in English should be the understanding that language competency applies to all subject classrooms, and should not be restricted to the English language arts (ELA) classrooms. However, it is recognized that as every academic subject has its own unique disciplinary literacy, effective communication by subject teachers involves the skilful use of disciplinary-specific language to help students better understand, process and internalize subject knowledge effectively.

The focus on subject-specific communication in WSA-EC is timely and relevant in reinforcing the focus areas of MOE's twenty-first century competencies framework that will prepare students for the demands of this century (MOE 2010). One of the core competencies in this national framework is communication skills: "Communicating effectively refers to the delivery of information and ideas coherently, in *multimodal* ways, for specific purposes, audiences, and contexts" (Standards and Benchmarks document for twenty-first century competencies, MOE 2011). Communication is conceptualized as the interactive process of sharing concepts, thoughts and feelings between people using the medium of language as a resource. In addition, this process involves the co-construction of meaning by those involved in communication. Effective communication occurs when the audience or reader understands a message in the way the communicator intended it to be understood, or when the co-construction of meaning satisfies all parties involved. Thus, communication is at the very heart of learning. Research into effective communication across the curriculum, given the emphasis on spoken, written, and multimodal communication skills and the need to explore interaction in subject classrooms is thus critical.

Research Context and Methodology

With the WSA-EC program providing a relevant context, the research project discussed in this chapter aimed to help two secondary schools in Singapore achieve the desired outcome of development of effective communication for science students. One of the objectives in this 3-year research project was to develop good disciplinary literacy teaching strategies with several collaborating teachers. To accomplish this, a design-based research approach (Collins et al. 2004) was adopted whereby pedagogical interventions, such as lesson activities and worksheets, were designed, implemented, evaluated, and refined through several iterative cycles. All instructional materials were co-developed by the researchers and the collaborating teachers based on a disciplinary literacy framework that we developed for this research project.

In this chapter, the lesson activities and worksheets presented were based on the first intervention cycle. The analysis also focused on two teachers – Derrick and Kathryn – from one of the collaborating schools. (All names are pseudonyms to protect privacy). Derrick was a physics teacher with 5 years of teaching experience while Kathryn was a chemistry teacher with 8 years of teaching experience. Both Derrick and Kathryn taught grade nine students from diverse ethnic groups comprising Chinese, Malay and Indian. The average class size was 28 students. The students were generally quiet but some could be active and vocal when presented with questions.

Ethnographic methods consisting of participant-observation, video recording, field-note taking, and artifact collection were used to collect data from the observed classrooms. The primary data source for the study reported in this chapter is classroom videos, comprising 12 lessons (11 h and 10 min in total) covering the topic of waves for physics and chemical bonding for chemistry. The videos were recorded by one camera at the back of the classroom focusing on the teacher. Another data source is students' writing on all the worksheets designed for the intervention research.

The analytical framework is based on a previous framework developed to examine the role of multiple and multimodal representations for science meaning-making (Tang et al. 2014). Multiple representations refer to the practice of re-representing the same phenomenon using different instructional resources, while multimodal representations refers to the use of multiple modes of representation (e.g., words, diagrams, graphs) to construct meaning. This framework incorporates the theoretical notion of "re-representation" (Hubber et al. 2010) and "transformative sign-making" (Kress et al. 2001) as the transformation of representations from one instructional resource to another across a series of activities in a lesson, as well as the notion of "semiotic affordances" from SFL (Kress et al. 2001) in examining the "multiplying meaning" effect (Lemke 1998) of combining multiple modes of representation. In addition, we also use the framework from Mortimer and Scott (2003) to analyze the various types of communicative mode (e.g., dialogic, authoritative, interactive, non-interactive) between the teacher and students. In particular, we focused on whether the teacher used a dialogic approach in considering multiple "voices" from the students (Bakhtin 1986) or an authoritative approach in considering only the scientific point of view.

Based on this analytical framework, lesson videos were viewed, coded, and analyzed using Transana software in two stages. The first stage involved the segmentation of the continuous sequences in a lesson video into meaningful discrete units. The boundaries of each segment are determined by the demarcation of prominent shifts occurring in the classroom, such as a discernible change in the participants' interaction pattern or the texts to which they are oriented. Each segment is then coded and tagged according to four categories: teaching activity (e.g., teacher explanation or group experiment), communicative mode (e.g., dialogic, authoritative; Mortimer and Scott 2003), instructional resource (e.g., video, worksheets; Hubber et al. 2010) and the mode of representation (e.g., words, diagrams; Kress et al. 2001; Lemke 1998). At this stage of analysis, the dialogue was not transcribed at this point due to the time-consuming nature of transcription. However, the analysis allowed us to construct the teaching sequence of every lesson and the corresponding communicative mode, use of resources, and mode of representation (see Appendix 1). This analysis also facilitated the identification of relevant episodes for the next stage of analysis.

The second stage of analysis involved an in-depth micro-analysis (Erickson 1992) of the teachers' and students' dialogue and multimodal interactions (e.g., gestures) and artifacts (e.g., students' writing). Spoken language was first transcribed and, together with written language, analyzed at the level of a clause

(Halliday 1978). The meaning of each clause was interpreted through the semantic relationship among the words in the clause. For instance, the clause "the water molecules are balanced" is an attributive relationship between a medium (water molecule) and its attribute. For visual image and gesture, a similar analysis was carried out using Kress and van Leeuwen's (1996) and Martinec's (2000) frameworks. Thus, the same example of "water molecules are balanced" is also realized visually through the drawing of circles (signifying the medium) and wavy lines (signifying the attribute) and gesturally through the left and right hands (signifying the medium) moving up and down alternatively (signifying the action of balancing). See these examples in the later analysis.

A Multimodal Approach to Disciplinary Literacy Teaching in Physics

The first example of a multimodal approach to disciplinary literacy teaching is based on two 1-hour physics lessons on the topic of waves. The overall lesson objective was for the students to describe the movement of particles and the transfer of energy in transverse wave motion. In particular, the students needed to discern that the particles in a wave vibrate about a fixed point instead of moving along with the forward propagation of the wave. From this distinction, the students were then asked to explain how energy can be transferred in a wave motion without the physical transfer of matter.

One month before the physics lessons took place, the researchers met with the teacher, Derrick, to discuss the lesson activities and design the worksheets to be used in the lesson. It was recognized from the discussion that many students tend to have difficulties observing the vibration of the wave particles amidst the dynamic fast-changing motion of a wave. Furthermore, to give a scientific description of the wave motion would entail a multimodal competency involving making connections between a series of disciplinary-specific diagrams and a set of scientific terminologies, such as vibration, kinetic energy, transfer, fixed position, medium, perpendicular, and adjacent particles. As such, a series of progressive activities was planned which involved the students doing a hands-on experiment with ropes at the beginning and writing an account of the wave motion by the end of the lesson. At the same time, attention was also given to the literacy activities in the lesson by planning several group discussions, and individual writing and multimodal integration exercises.

To illustrate the role of multimodal activities in the development of the students' scientific description of wave motion, three specific episodes will be analyzed and presented in this section. These episodes were selected primarily due to a notable shift in the communicative mode (from dialogic to authoritative and vice-versa) and/or the mode of representation (physical, visual, written text). In our analysis, it was found that rich multimodal integration often occurred during these shifts. Table 8.1 shows the teaching activity, communicative mode, instructional resource and

Table 8.1 The teaching activity, communicative mode, instructional resource and modes of representation for selected episodes

Video time	Teaching/learning activity	Communicative mode	Instructional resource	Mode of representation
Episode 1, Lesson 1				
1:00–8:59	Teacher introduces and demonstrates the rope experiment	Non-interactive/ authoritative	Rope with colored knots (see Fig. 8.1)	Physical
8:59–20:54	Students carry out rope experiment in pairs	Interactive/dialogic	Rope with colored knots	Physical
	Students discuss their observation in pairs and write individually on a given worksheet		Worksheet (page 1)	Written/visual (static diagrams)
Episode 2, Lesson 1				
41:24–46:27	Teacher discusses with students their responses	Interactive/dialogic		
47:43–52:40	Teacher summarizes the discussion and relates the video to the rope experiment	Interactive/ authoritative	Video Worksheet (page 1 and 2)	Visual (animated) Written/visual (static diagrams)
Episode 3, Lesson 2				
12:30–16:32	Teacher discusses with students their written responses from the last lesson	Interactive/dialogic	Worksheet (page 3)	Written/visual (static diagrams)
16:32–26:29	Teacher generalizes the structure and the sequences in the explanation	Non-interactive/ authoritative	Fill-in-the-blanks notes	Written
26:29–33:08	Students revise their explanations to the earlier questions		Worksheet (page 3)	Written/visual (static diagrams)

modes of representation for these three episodes. The entire teaching sequence for the two lessons is shown in Appendix 1.

Episode 1. From Physical Demonstration to Initial Observation

The lesson began with Derrick giving an overview of what the students would be doing in subsequent activities:

1 Derrick: We will do some activities first, using the rope that I placed at your bench. You work in pairs, then. While you are doing the activity, these are the key words to take note of. Okay, observe, to feel, and think how you describe. How you draw. These are the

things you consider when you do the activity. Then we move on to the discussion. When we do the activities and the discussion right, I will be gathering your feedback and views. But I won't be clarifying. I will help to consolidate first.

Derrick's initial instruction overtly pointed to the multimodal nature of the subsequent activities and then set the stage for further student activity. First, the students carried out a hands-on activity in pairs using a rope. The aim of this activity was to generate a physical representation of wave motion. From this physical representation, the students would then be asked to re-represent (Hubber et al. 2010) their sensory and kinesthetic experiences into words and diagrams in a worksheet; according to the teacher's instruction to "describe", use "key words" and "draw". The worksheet is designed to help the students make connections among the various modes of representations (see Figs. 8.2 and 8.3 for samples of students' completed worksheet). After the students re-represented the physical representation into words and pictures in their worksheets, they would then "move on to the discussion" where the teacher would gather their preliminary ideas about wave motion. In sum, the students would be going through successive activities of doing, writing, drawing, and talking. Six minutes later, Derrick demonstrated to the students how to generate the wave motion by vibrating one end of the rope resting on a table, while a student held firmly on the other end (see Fig. 8.1). After the brief demonstration, Derrick then gave further instructions on how to fill out the worksheet:

2 Derrick: [pointing at screen] Right, so you look at it. From the observation, there are some sequential diagrams below. Right, there are some diagrams here [pointing at screen]. What you want to observe is. ugh.. excuse me. You take note of position A and B. It can be any of the two colors. Then, use arrows to indicate direction of motion for A and B. Right, pay attention to any of the two colors. And the direction of their motion. Describe what you see and how you feel.

Derrick pointed to several parts of the worksheet (see Fig. 8.2) projected on the screen as he gave these instructions. First, he directed the students' attention to the sequence of diagrams in the left column of Fig. 8.2, where each diagram shows a snapshot of the wave motion at different times. He then asked the students to "take note of position A and B." In the rope experiment, four colored knots were tied onto the rope at intervals of approximately 10 cm apart. The purpose of these knots was to help the students observe that the movement of the knots is perpendicular to rather than along the rope. In the worksheet, the circle labelled A and B on the first diagram represented the positions of those colored knots. The students would then indicate, for subsequent diagrams, the positions of A and B as well as their direction of motion, according to their observation. In this way, the activity aided students in re-representing the positions and motion of the knots on the physical rope into circles and arrows on the worksheet. This initial re-representation from the demonstration (activity of doing) to the diagrams (activity of drawing) is an important first step in the multimodal integration process required in understanding wave motion.

After the completion of the diagram, the students were asked to "describe what [they] see and feel" on the worksheet. Figure 8.2 shows the completed worksheet from student Hidayah. Her writing at this stage revealed the emerging language she had for describing her observation of the wave motion. Hidayah only described the

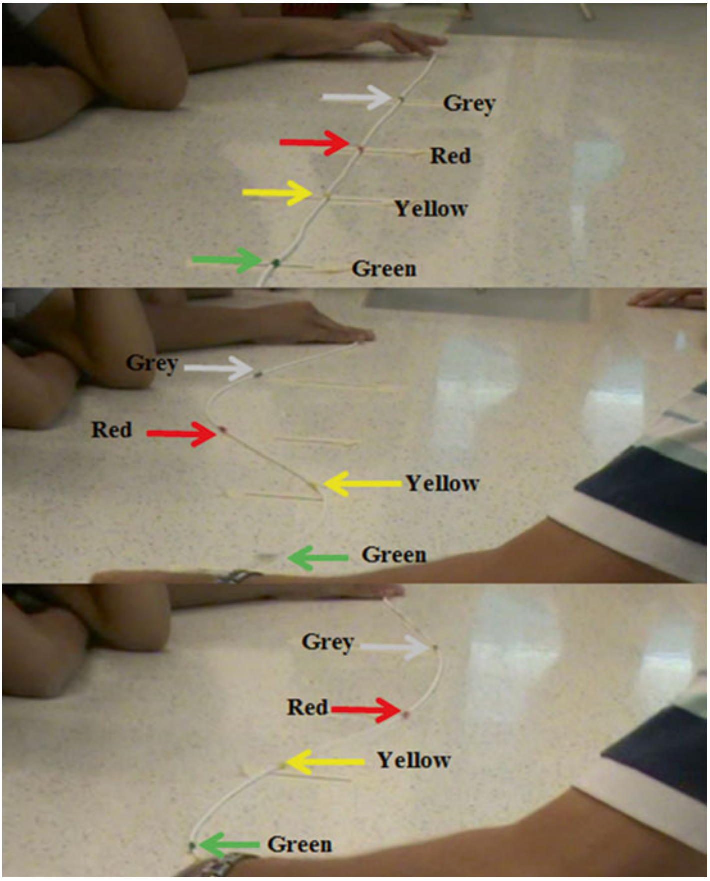
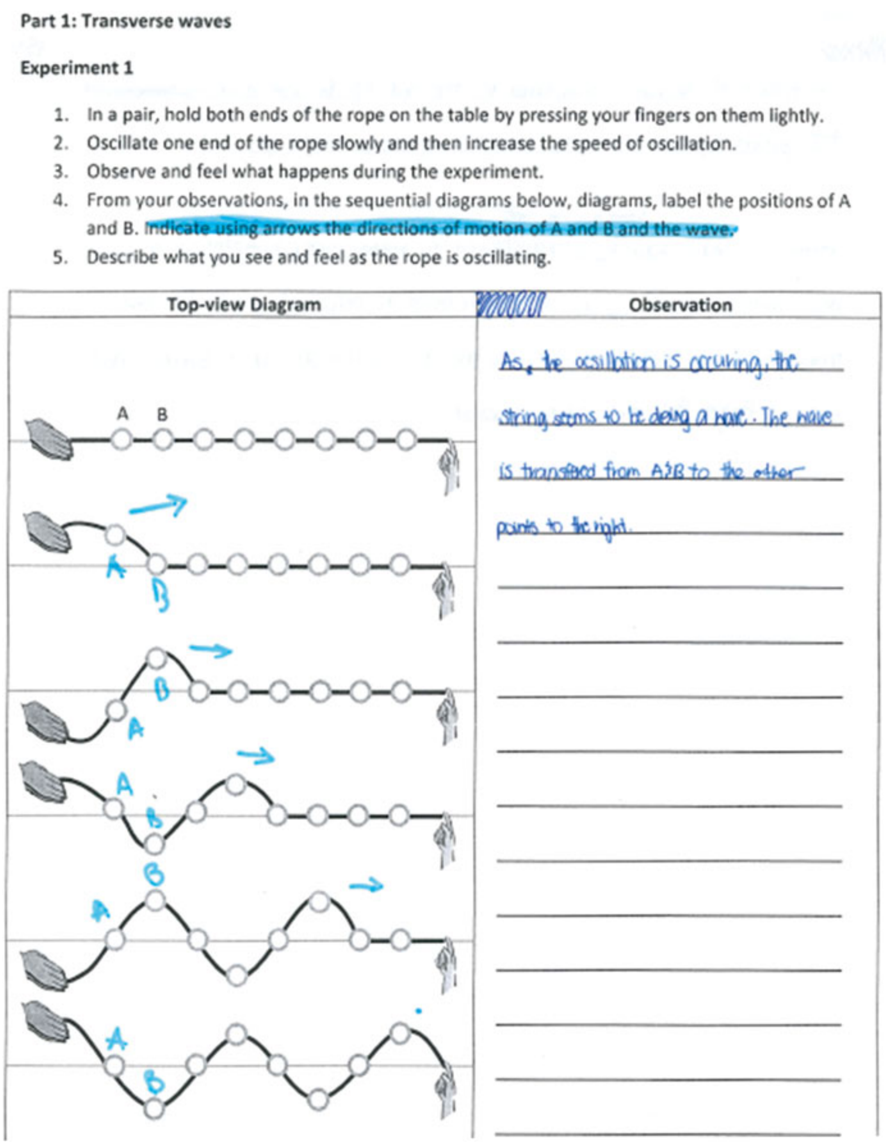


Fig. 8.1 Demonstration of wave motion using a rope by Derrick

wave motion in general (i.e., "the string seems to be doing a wave"). Her statement "The wave is transferred from A and B to the other points to the right" indicates her observation of the transfer of the wave motion in general, but not the specific motion of the particles, as represented by A and B. Furthermore, her sequential diagrams did not indicate the directions of motion of A and B. Thus, it was not clear whether this student could differentiate between the vibration of A and B (perpendicular to rope) and the direction of the wave motion (parallel to rope). This was a common challenge faced by many other students at this stage of the lesson.

At this stage, there are two major characteristics of Hidayah's worksheet that indicate she has not provided a complete description of the concept. First, she has not developed the language specificity to give an accurate account of wave motion in her writing. Second, there was little connection between her drawing and writing. In the next episode, we move forward in the lesson to look at how Derrick and the students, in talking about a water wave phenomenon, developed the necessary language and multimodal connection to give a scientific account of wave motion.


Part 1: Transverse waves

Experiment 1

1. In a pair, hold both ends of the rope on the table by pressing your fingers on them lightly.
2. Oscillate one end of the rope slowly and then increase the speed of oscillation.
3. Observe and feel what happens during the experiment.
4. From your observations, in the sequential diagrams below, diagrams, label the positions of A and B. Indicate using arrows the directions of motion of A and B and the wave.
5. Describe what you see and feel as the rope is oscillating.

Top-view Diagram	Observation
A B	As, the ocsillation is occuring, the string seems to be doing a wave. The wave is transfered from A&B to the other points to the right.

Fig. 8.2 Page 1 of Hidayah's completed worksheet

Episode 2. Refining Language from Video Observation

After most students have completed page 1 of the worksheet (i.e., Fig. 8.2), Derrick went on to discuss some of the students' writing. He picked a few students' work and showed them to the class using a document camera. As stated by Derrick at the beginning of the lesson, his purpose at this point was only to consolidate the students' initial responses. He refrained from providing the "model answer" to the students.

Instead of giving an authoritative answer to the question of how to describe wave motion, Derrick used a more dialogic approach (Mortimer and Scott 2003) to elicit and discuss students' views concerning the motion of the particles in relation to the wave propagation. Halfway through the lesson, Derrick showed a video of a water wave passing from left to right and a ball floating up and down on the surface of the water wave. The students were then given time to discuss the question of "what is moving in a wave motion, and in what direction?" The following transcript shows one of the pivotal moments in the discussion between Derrick and the class:

[Lesson 1, Time: 42:27]

1 Derrick: … Audrey? What did you all discuss?
2 Audrey: The particles don't move sideways, they move up and down.
3 Derrick: Particles don't move sideways, they move up and down. When you talk about particles, what particles are you talking about?
4 Audrey: (inaudible)
5 Derrick: When you refer to particles, what particles are you talking about?
6 Audrey: The particles in the water
7 Derrick: The particles in the water, are you talking about water molecules? So you are saying water molecules. I mean, particle is nothing wrong. I just want to be more specific. Yah? (pointing at Amu)
8 Amu: The ball is not moving because the particles in the liquid is.. (inaudible)
9 Derrick: The ball is not moving because the particle in the liquid is?
10 Amu: Is balanced. Because it's moving. The particles are, the water molecules are moving.. (left and right hands gesturing a vibration motion)
11 Derrick: Balanced. Alright. Okay, so that is some idea you have in mind.. Alright. Who else?.. Rui En? What did you all discuss?
12 Rui En: It's like erm.,
13 Derrick: Quite interesting to hear.
14 Rui En: It's like the.. what's that call ah? The wave molecules, right? The water molecules.
15 Derrick: Water molecules, uh huh.
16 Rui En: Balanced.
17 Derrick: Balanced. Meaning?
18 Hwee Ling: It's like when one is like..
19 Rui En: It's up, then the other is down
20 Derrick: So water molecule is balanced when one is up, the other one is down.
21 Rui En: Yah, so it is like pushing. So like it stays put..
22 Derrick: So it's pushing what?
23 Rui En: Cause like one is up and one is down, right? (Left hand raises up while right hand moves down). Then the base is here right? (Points at the middle). Then it like it goes here So like..
24 Derrick: More like a see-saw, is it?
25 Rui En: Yah
26 Derrick: Like a see-saw, you, you..
27 Rui En: Something like that
28 Derrick: Is that what you are saying? Okay. So she's saying that it is more like a see-saw. When one is moving up (left hand raises up), one is moving down (left hand moves down), so it would just be just rocking left and right (right hand animates a waving action.

There are two important insights regarding multimodal integration from this episode. The first insight is the joint refinement of ideas that developed in tandem with the increasing specificity of the language used by the speakers. In line 2, when Audrey was talking about the movement of the particles, Derrick asked her to specify what particles she was referring to (line 3, 5). Through Audrey's response in line 6 and Derrick's paraphrasing in line 7, they began to use the more specific term "water molecules" instead of the generic "particles." This term was subsequently appropriated by other students. For instance, Amu consciously changed "particles" to "water molecules" in line 10, and Rui En took a while to recall the correct term to use in line 14. This refinement of the language is important as it allowed the teacher and students to distinguish between the water molecules (as carrier) and the ball (as object being carried) in the subsequent discussion. Only through this distinction can we understand the nuanced meaning of the word "balanced", which was first brought up by Amu (line 10) and later elaborated by Rui En and Hwee Ling (line 16–27).

To summarize the discussion, what Rui En meant by the "water molecules are balanced" (line 14–16, 20–21) is that the two sides of the water surface surrounding the ball are alternatively moving up and down (as seen from the gestural action of her left and right hands in line 23). Because of this "balanced" motion – analogous to a see-saw motion as suggested by Derrick (line 24) – the ball will not be carried along with the water wave. This was indirectly stated in line 21 when Rui En said "it [the ball] stays put." Derrick, in line 28, tried to summarize Rui En's idea by giving the analogy of a see-saw. He also reiterated that the water molecules are moving up and down, while the ball is rocking left and right due to the see-saw motion of the surrounding water molecules. It must be noted that there is some ambiguity in Derrick's summary in line 28 due to the imprecise use of the pronouns ("one", "it") to indicate different aspects of the observation: the water wave motion, the water molecules, and the ball. Nevertheless, what is crucial in this discussion is the consensus that the water molecules are moving up and down, rather than left to right, along the direction of the water wave. Furthermore, the teacher and students recognized that this distinction accounts for why the ball does not travel along with the water wave.

The second insight we can gain from this episode is the actions taken by Derrick to explicitly support the students in developing the language and multimodal integration competency in order to accurately describe the wave motion from a physics viewpoint. It has already been demonstrated how Derrick aided the students in the use of "more specific" terms to describe the wave in line 7 and to clarify what students meant by the word "balanced" in line 17. Another important aspect of the teacher's action was to help students make the connection between what they saw in the video and how they described the animated motion. The following excerpt provides an instance where this multimodal connection was made directly by Derrick. This excerpt occurred about 3 min after the last discussion. Derrick paused at a particular scene on the video and asked the following question:

[Lesson 1, Time: 47:43]

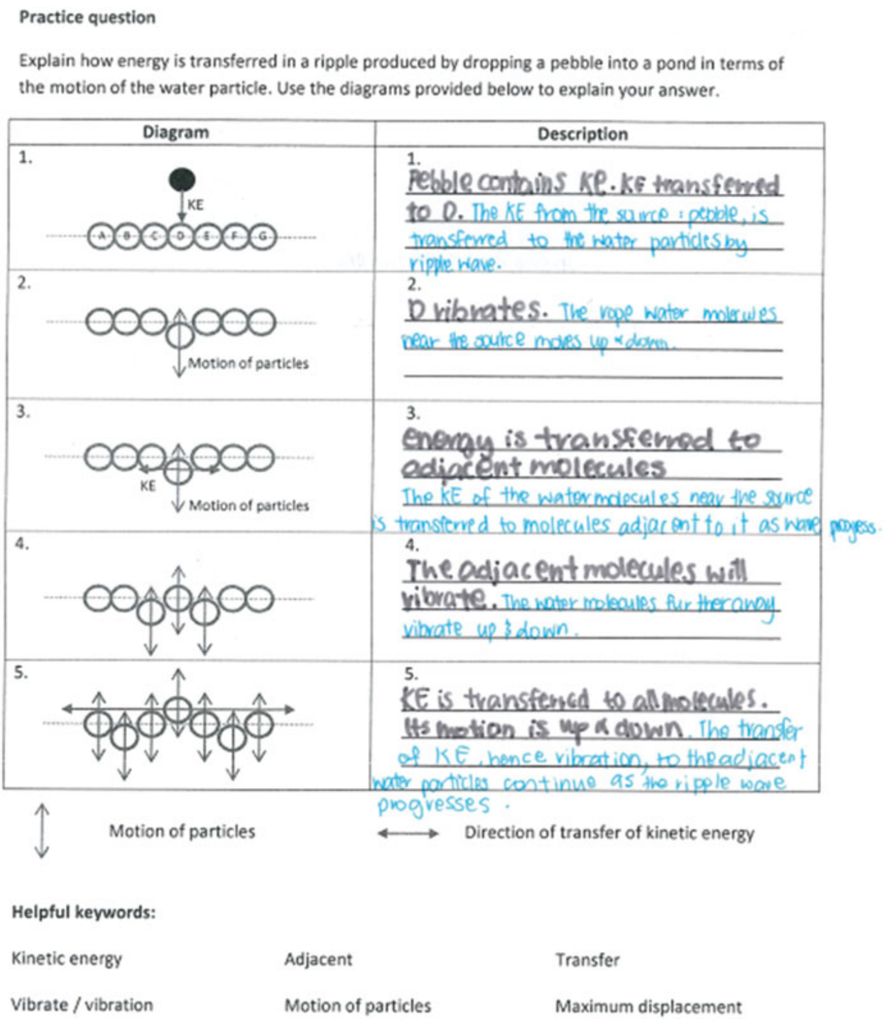
29 Derrick: (Pointing at the screen) Which direction is the wave traveling?
30 Class: Right to left.
31 Derrick: Right to left. Alright, right to left ah. (Pointing at a particular point on screen) Which direction is this point traveling?
32 Class: Up and down.
33 Derrick: Is it moving along with it? (Gesturing from right to left)
34 (Several students shook their heads)
35 Derrick: No. Turn back to the first page. Did you indicate that? That the particle A B is moving up and down? Did you indicate that the particle is moving up and down or have you actually indicated that it has moving toward the right? Does that clarify how the particle is moving?

At this point, Derrick was doing a summary to round up the earlier discussion. Unlike the earlier part of the discussion where he was using a dialogic approach to elicit various viewpoints, there is a notable shift toward a more authoritative approach (Mortimer and Scott 2003) where he channeled the discussion toward the scientific description. This could be seen from the highly distinguishable I-R-E (Initiate-Response-Evaluate) pattern in this discussion (Mehan 1979). At the same time, he used this authoritative approach in conjunction with the visual scenes in the video to guide the students in discerning the right-to-left and up-down motion of the traveling wave and vibrating particle respectively. In line 35, Derrick then made a very important move, which was to link the discussion back to the rope experiment the students had earlier completed on "the first page" (line 35) of the worksheet, as shown in Fig. 8.2. In particular, Derrick directed the students to differentiate the up-down vibration of points A and B in contrast to the left-right movement of the wave motion. This multimodal connection across the specific activities of doing (the rope experiment), drawing/writing (Fig. 8.2), talking (episode 2), and viewing (video in episode 2) is an important aspect of the disciplinary literacy teaching observed in this lesson.

Episode 3. Explaining Energy Transfer Using More Refined Language

Near the end of the first lesson, Derrick signaled a change in the focus toward talking about energy transfer in a wave motion. In particular, the students were instructed to fill out page 3 of the worksheet. This part of the worksheet was designed to help them "explain how energy is transferred in a ripple produced by dropping a pebble into a pond in terms of the motion of the water particle" (see Fig. 8.3).

Earlier, the quality of Hidayah's description of the wave motion was examined (see Fig. 8.2) and it was indicated that she lacked the language specificity to give an accurate account of wave motion. This part of the worksheet shows her writing after the intervening discussion we described in episode 2. In Fig. 8.3, the words in bold and black were written by Hidayah at the end of the first lesson. Comparing her writing in Fig. 8.2 with that in Fig. 8.3, there are notable changes in how she was



Practice question

Explain how energy is transferred in a ripple produced by dropping a pebble into a pond in terms of the motion of the water particle. Use the diagrams provided below to explain your answer.

Diagram	Description
1. KE A B C D E F G	1. Pebble contains KE. KE transferred to D. The KE from the source : pebble, is transferred to the water particles by ripple wave.
2. Motion of particles	2. D vibrates. The rope water molecules near the source moves up & down.
3. KE Motion of particles	3. energy is transferred to adjacent molecules The KE of the water molecules near the source is transferred to molecules adjacent to it as wave progess.
4.	4. The adjacent molecules will vibrate. The water molecules further away vibrate up & down.
5.	5. KE is transferred to all molecules. Its motion is up & down. The transfer of KE, hence vibration, to the adjacent water particles continue as the ripple wave progresses.

Motion of particles

Direction of transfer of kinetic energy

Helpful keywords:

Kinetic energy	Adjacent	Transfer
Vibrate / vibration	Motion of particles	Maximum displacement

Fig. 8.3 Page 3 of Hidayah's completed worksheet

able to distinguish the vertical motion of the water molecules in relation to the horizontal motion of the ripple wave. There is also an increased specificity in the language in terms of identifying different parts of the wave (e.g., adjacent molecules, all molecules) as well as the direction of motion (e.g., up, down). Part of this change could be due to Derrick's facilitated discussion described in episode 2. Another factor is likely the design of the worksheet in terms of the sequential diagrams placed next to the writing and the "useful keywords" provided such as "vibrate", "adjacent", and "transfer". Although these keywords were provided, it is important to note that the students' understanding of these words also depends on the discussion that was facilitated by Derrick. Thus, each of these methods is an important disciplinary literacy strategy that has helped Hidayah and other students produce a more scientific account of wave motion.

In the second lesson, Derrick discussed the students' writing on page 3 of the worksheet. He chose a few students' work and showed them to the class. Hidayah's worksheet was one of those he chose to discuss. In the following excerpt, Derrick read Hidayah's writing in line 1 and went on to refine her language in line 2:

[Lesson 2. Time: 12:30]

1 Derrick: Pebble contains KE. KE transferred to particle D. Particle D vibrates. Energy is transferred to adjacent molecules. Adjacent molecules vibrate. KE transferred to all molecules. Motion is up and down. Alright. Alright with the sequence?

2 Derrick: Um, possible choice of words, okay you can reconsider. It says pebble contains KE. Now I think we don't usually use the word contains right? Probably the word possess. Pebble possesses KE. D vibrates. But vibrates we want to be a bit more specific. In what direction? In what way? Because vibrate can be what? Circular? Swinging? Left, right? Up, down? Alright. Can be a bit more specific.

After Derrick discussed samples of students' writing and went through their explanations, he then proceeded to break down the required explanation into several parts in order to help the students analyze the structure and sequential steps in this explanation. About 10 min later, he gave the students time to revise and rewrite their explanation on page 3 of the worksheet. In Fig. 8.3, the words in blue were the revisions written by Hidayah after this part of the lesson. Again, comparing her revision with her earlier writing (in bold and black), we can see further improvement in her language. For instance, she has replaced the phrase "contains KE" with a more disciplinary appropriate phrase – "KE from the pebble".

A Multimodal Approach to Disciplinary Literacy Teaching in Chemistry

The second example of a multimodal approach to disciplinary literacy teaching in chemistry is presented here to provide a contrasting case to the earlier example in physics. However, due to space constraints, we will only narrate the key episodes without the supporting excerpts and analysis.

In these six 1-hour lessons, the overall lesson objective was to understand chemical bonding and the properties of each type of chemical substance. At the end of the lesson series, students were expected to be able to explain the properties each chemical substance exhibits. Based on a discussion with Kathryn prior to the lesson series, it was determined that students had difficulty discerning the chemical bonds in simple covalent substances and understanding how some substances only exhibit electrical conductivity in particular conditions. With this in mind, a lesson series was designed that required students not only to write but also to draw diagrams. The multimodal integration of written and visual representations was a necessity in the design of the lesson worksheet as we predicted that drawing diagrams would help students visualize and understand bonding between particles, and eventually write appropriate explanations of the properties exhibited by the substances. Literacy activities such as student discussion were also planned in the design of the lesson.

Episode 1: Drawing to Learn

In a lesson prior to this episode, the chemistry teacher, Kathryn, showed a video of an experiment designed to test the conductivity of an ionic compound, sodium chloride (table salt). In the video, when a circuit was connected across solid sodium chloride, a light bulb did not light up, thus demonstrating the non-conductivity of solid sodium chloride. However, when the solid sodium chloride in the set-up was heated and melted, the bulb lit up. Kathryn used this video as a context to teach chemical bonding and the properties of ionic and covalent compound. This video showed a macroscopic representation (Treagust et al. 2003) of the phenomenon, which is the illumination of the light bulb as seen by our naked eyes. To give a scientific account of why different solutions can conduct electricity, students would need to give a microscopic representation of the chemical substance in terms of the ions and electrons, which are invisible to us. Subsequently, Kathryn asked students to imagine the same experiment but with the solid sodium chloride replaced with ice made of de-ionized water, and to predict the outcome of the new experiment. Kathryn nominated a student Zhiwen to share her thoughts. Zhiwen predicted that neither the ice nor the melted ice could conduct electricity and, hence, light the light bulb due to the absence of charged particles. However, she could not elaborate why there was no charged particles.

Kathryn saw Zhiwen's difficulty in explaining the absence of charged particles and took the opportunity to get students to draw a microscopic diagram to show that there was indeed no charged particle in the ice and melted ice. This re-representation from a verbal to a visual mode taken by Kathryn was necessary and crucial to students' understanding of the nature of simple covalent substances. Unlike ionic substances whose bonds are broken upon heating, covalent bonds in simple covalent substances are not broken upon heating but their intermolecular forces of attraction are. This is the most common misconception in this sub-topic that Kathryn was hoping to address by having her students make drawings.

Despite having established that water was H_2O and despite the fact a diagram of ice (solid H_2O) was provided in the worksheet (Fig. 8.4), there were still students who drew the microscopic representation of water inaccurately. Figure 8.4 shows a diagram drawn by a student, Melissa. Following the diagram of ice provided, she represented the oxygen atoms as white circles while she represented the hydrogen atoms as black circles. However, instead of keeping the water molecules intact upon heating by drawing two black circles attached to one white circle, she drew the circles separately, suggesting the breaking up of strong covalent bonds. From her diagram, we could infer that Melissa might have difficulty in recognizing covalent bonds and intermolecular forces of attraction, and in understanding which forces of

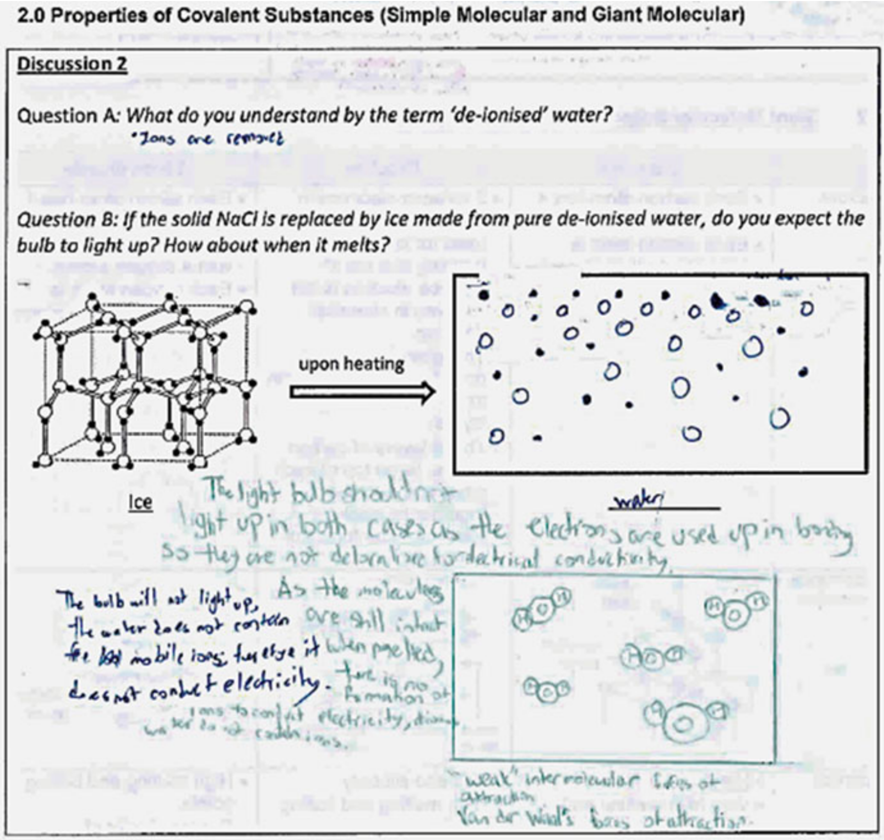


Fig. 8.4 Page 3 of Melissa's worksheet

attraction are broken upon heating simple covalent substances. Kathryn highlighted to students that such a drawing implied that "if (we) heat it (water) until gas, maybe it will split into electrons, and neutrons, and protons" which is inaccurate. Kathryn then drew the more accurate representation on the whiteboard and Melissa redrew her representation below the initial one as shown in Fig. 8.4.

After establishing that only intermolecular forces are broken upon heating ice, Kathryn instructed students to write an explanation why water cannot conduct electricity in any state with reference to the light bulb experiment they had watched. In Melissa's writing, she explained that "The bulb will not light up, the water does not contain free mobile ions; therefore it does not conduct electricity." In this explanation, she merely stated the condition of the water that it had an absence of mobile charged particle (e.g., ions) but failed to account for the absence by indicating that electrons are all used up for bonding and ions are already removed. This is an incomplete explanation as compared to the suggested answer given by Kathryn (shown in Fig. 8.4 in lighter ink).

Melissa's writing suggested that she may have had difficulty in constructing a complete explanation of why deionized water does not conduct electricity in any state. She linked a reason to a phenomenon without giving the principle that accounts for the reason she provided. As a logical, accurate, and complete scientific explanation is the central aim of learning science, Kathryn needed to address Melissa's issue. In the next episode, we examine how Kathryn attempted to address this issue of incomplete explanation through a hands-on literacy activity.

Episode 2: Supporting Student Writing through Hands-On Literacy Activity

After learning about ionic and covalent bonds through various activities such as watching videos, drawing, and discussions, students had to write scientific explanations of what they had learnt and Kathryn attempted to support students in their writing through hands-on literacy activity. She did so by providing students with paper strips that contain a jumbled-up sequence to explain why NaCl has higher boiling point than CCl_4. In this activity, students were asked to work in pairs to discuss, re-arrange the paper strips (Fig. 8.5 as an example), and ultimately write down the explanation. This task was not a simple re-arrangement of clauses and phrases to make grammatical sentences. Students were required to make connections between what they had learnt about ionic and covalent bonds and the ideas represented in the paper strips, and apply those ideas to explain the phenomena, and, at the same time, learn how to construct a scientific explanation. In the next episode, we examined how students write scientific explanation without such explicit support.

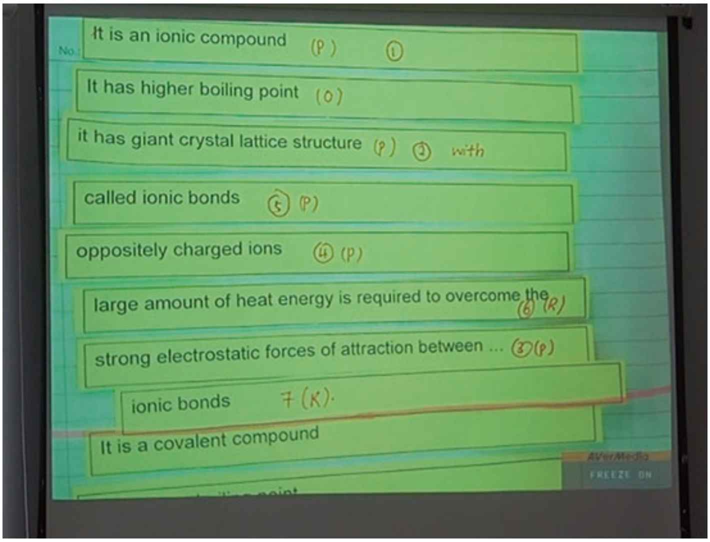


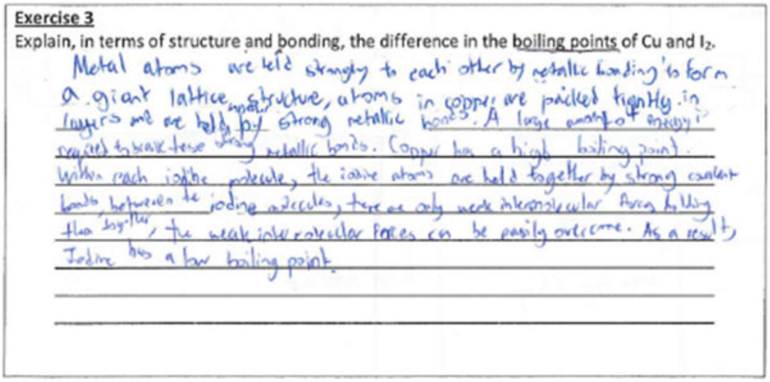
Fig. 8.5 Student's arrangement of the jumbled-up explanation sequence

Episode 3: Writing Without Explicit Support

Unlike the earlier episode, Kathryn did not give students explicit support in the form of strips of paper. Instead, she only reminded students of the writing structure that they had learnt earlier through using the strips of paper. This episode highlights the removal of the multimodal scaffold that Kathryn had previously provided students. Students were expected to be able to construct their own mental scaffold before writing down their answer.

In examining Melissa's answer (Fig. 8.6), it appears Melissa improved in terms of writing a thorough and complete, as well as scientifically accurate, explanation. Even without explicit scaffolding, Melissa was able to write a complete explanation. She did not merely state the reason that the heat energy required to break the weak intermolecular forces is low, but also gave the principle behind this reason, that is, simple covalent substances such as iodine have strong covalent bonds within the molecules but weak intermolecular forces between them. She also used the logical connective "as a result" to show a cause-and-effect relationship between the fact that the weak intermolecular forces can easily be overcome and thus, the low boiling point results.

Based on this writing, the multimodal scaffoldings in the forms of drawing and the strips of paper appear to have had a positive impact on Melissa's understanding



Metal atoms are held strongly to each other by metallic bonding and form a giant lattice structure, atoms in copper are packed tightly in layers and are held by strong metallic bonds. A large amount of energy is required to break these strong metallic bonds. Copper has a high boiling point. Within each iodine molecules, iodine atoms are held together by string covalent bonds . Between the iodine molecules, there are only weak intermolecular forces holding them together; the weak intermolecular forces can be easily overcome. As a result, iodine has a low boiling point.

Fig. 8.6 Melissa's answer in exercise 3 of covalent compounds as well as her ability to construct a good scientific explanation. She has demonstrated understanding that strong covalent bonds are between the atoms within a simple covalent substance while weak intermolecular forces only hold the molecules together. Her writing also reflects that she is able to not only state the reason (heat energy requirement) but also the principle behind boiling point (bonding and forces).

The actions taken by Kathryn in scaffolding students' scientific explanation in this series of episodes highlight some potential uses of multimodal integration in disciplinary literacy teaching. First, Kathryn used the video of melting NaCl projected in the first lesson as the context of the question. This helped students identify which points in the strips of paper belong to NaCl, for example, the strips that describe high boiling points. Second, Kathryn gave students strips of paper as a visual aid in constructing the explanation as each of the strips represents an idea or a point. This encourages students to think of all the possible points discretely and then synthesize them in one explanation, just like rearranging the strips of paper. The multimodal integration across various activities utilized by Kathryn in teaching in this episode highlights an important aspect central to disciplinary literacy teaching.

However, we note that future improvement in this lesson series is to get students to provide diagrams in this explanation. The purpose is for them to further illustrate (visually) what they meant by "a giant lattice structure", "atoms in copper are packed tightly", "iodine atoms are held together by strong covalent bonds." This requirement of a multimodal linkage between texts and diagrams would strengthen their multimodal competency in writing a scientific explanation.

Conclusion

The main question emerging from this analysis is what we can infer about how multimodal integration competency can be developed through an explicit teaching of disciplinary literacy. Two major findings can be gleaned based on the illustrations given in this chapter.

First, it is important to deliberately plan lessons to involve several sequential stages of re-representation. In the physics lessons, for example, it was observed that Derrick planned a series of multimodal activities from a hands-on rope experiment to a group discussion to a visually-scaffolded writing exercise. As illustrated in the three episodes, the re-representation from an activity of doing to talking, drawing, and writing guided the students toward accurately explaining the wave motion. A similar sequence of re-representations was observed in Kathryn's case, although her lesson did not have a "doing" activity at the beginning. Instead, this was replaced by a video which showed macroscopically the outcome of an experiment – the lighting of a light bulb based on a liquid's conductivity. Through sequential activities of talking, drawing, and writing, the students were guided to explain in a microscopic sense the reasoning behind the experiment.

Second, during lesson implementation, teachers need to be very explicit in pointing out to the students the specific language and multimodal connections that are required in the scientific explanations. This attention to the language and representation specificity can occur during the shift from a dialogic communicative mode where the students' ideas were elicited to an authoritative mode where the discussion became more directed by the teacher. During this shift, we saw from both Derrick's and Kathryn's lessons how they guided the students to (i) use more specific terms (e.g., water molecules, de-ionized), (ii) link what they saw in the videos to their verbal explanation, (iii) make corrections of their diagrams, and (iv) visualize and discuss the logical sequence of their written explanation. Such actions taken by the teachers are necessary in developing the students' competency in using multimodal representations in their scientific explanations.

These two findings provide insights for researchers and teachers on how to design and carry out multimodal activities as part of the focus on disciplinary literacy teaching to develop students' competencies in multimodal communication. Although this research project started with an awareness of the importance of multiple and multimodal representations, we did not have a clear idea of how to translate the theoretical ideas into classroom practices within the context of the Singapore educational system. Thus, the rich description of the teaching sequences presented in this chapter was aimed to provide exemplars for educators to learn as well as to replicate or modify. In this respect, the findings and analysis here provide a starting point that will inform us of the next phase of our research. In particular, we will continue to extend our findings to other lesson observations and develop a pedagogical framework or guiding principles that could inform teachers on the design and implementation of multimodal activities to teach disciplinary literacy in science.

In sum, past research has separately shown the importance of giving students the opportunity to talk and write in science classrooms. While each literacy activity is crucial to science learning, we argue, in this study, that it is equally important for each of these talking and writing activities to be connected not just to each other, but also holistically to other activities of doing and drawing. The integration of these multimodal literacy activities of talking, writing, drawing and doing is an important aspect of what we see as *disciplinary literacy teaching* in science.

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Appendix 1

Teaching sequence and corresponding communicative mode, use of resources, and modes of representation for the physics lessons. Selected segments shown in the analysis are shaded in grey.

Video Time	Teaching/Learning Activity	Dominant Communicative Mode (Mortimer & Scott, 2003)	Instructional Resource (Hubber et al, 2010)	Mode of Representation (Kress et al, 2001; Lemke, 1998)
Lesson 1				
1:00 – 8:59	Teacher introduces and demonstrates the rope experiment	Non-interactive/ Authoritative	Rope with colored knots (see Figure 8.1)	Physical
8:59 – 20:54	Students carry out rope experiment in pairs Students discuss their observation in pairs and write individually on a given worksheet	Interactive/ Dialogic Interactive/ Dialogic	Rope with colored knots Worksheet (page 1)	Physical Written/Visual (static diagrams)
20:54 – 36:53	Teacher discusses with students their preliminary observations	Interactive/ Dialogic	Worksheet (page 1 and 2)	Written/Visual (static diagrams)
36:52 – 38:59 38:59 – 41:24	Teacher plays a video of water wave motion Students discuss in pairs the question: "In a wave motion, what is moving and in what direction?"	Non-interactive/ Authoritative Interactive/ Dialogic	Video	Visual (animated)
41:24 – 46:27	Teacher discusses with students their responses	Interactive/ Dialogic		
47:43 – 52:40	Teacher summarizes the discussion and relates the video to the rope experiment	Interactive/ Authoritative	Video Worksheet (page 1 and 2)	Visual (animated) Written/Visual (static diagrams)
52:40 – 57:14	Students write an explanation of "how energy is transferred in a ripple in terms of the motion of the particles"	Non-interactive/ Dialogic	Worksheet (page 3)	Written/Visual (static diagrams)
Lesson 2				
2:38 – 12:30	Teacher recaps last lesson and introduces key terms of wave motion	Non-interactive/ Authoritative		
12:30 – 16:32	Teacher discusses with students their written responses from the last lesson	Interactive/ dialogic	Worksheet (page 3)	Written/Visual (static diagrams)
16:32 – 26:29	Teacher generalizes the structure and the sequences in the explanation	Non-interactive/ Authoritative	Fill-in-the-blanks notes	Written
26:29 – 33:08	Students revise their explanations to the earlier questions	Non-interactive/ Authoritative	Worksheet (page 3)	Written/Visual (static diagrams)
33:08 – 42:56 42:56 – 53:09	Teacher discusses the solutions with the class Students attempt last question on their worksheet	Interactive/ Authoritative Non-interactive/ Authoritative	Worksheet (page 4)	Written/Visual (static diagrams)

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