How is disciplinary literacy addressed in the Science classroom?: A Singaporean case study

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ABSTRACT

Disciplinary literacy is the specific ways of talking, reading, writing, and thinking valued and used by people in a discipline in order to successfully access and construct knowledge in that discipline. This paper reports on a case study of the classroom practices of two physics and two chemistry teachers in Singapore in order to better understand how disciplinary literacy is currently addressed in the teaching of secondary school science. The study found that disciplinary literacy in science teaching was limited to the language aspects of science terminologies and the literacy practice of constructing explanation. Even then, these disciplinary language aspects were only implicitly embedded within the predominant practice of teacher-led talk. Based on these findings, current realities and future possibilities of disciplinary literacy instruction building on science teachers' current teaching practices are discussed.

Introduction

Language and literacy play a crucial role in the teaching and learning of science. Despite its central role in gaining access to scientific knowledge and practices (Norris & Phillips, 2003), disciplinary literacy or the specific ways of talking, reading, writing, doing, and thinking in a particular discipline (Shanahan & Shanahan, 2008) is typically not emphasised in the science classrooms (Moje, 2007). Past research has shown that because many students are not familiar with the disciplinary literacy of science, more needs to be done to help them master the content and processes required in the secondary and tertiary school science curriculum (e.g., Hand et al., 2003; Lemke, 2000; Yore & Treagust, 2006).

In recent years, curriculum reforms and standards around the world are putting more emphasis on disciplinary literacy in all subject areas. For instance, the Common Core State Standards in the United States underscore the place of literacy in preparation for college and life. In the Standards for Science and Technical Subjects, science teachers 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). In the Australian Science Curriculum, 'the language and literacy demands of the Australian science curriculum will be supported by and in turn will reinforce learning of literacy skills' (Australian Curriculum Assessment and Reporting Authority, 2009, p. 11). In Singapore where this study was situated, the importance of subject-specific literacy is also gaining traction with the Ministry of Education and its public schools (English Language Institute of Singapore, 2013). In light of these developments, there is thus much emphasis toward disciplinary literacy instruction calling for 'pedagogical practices for teaching content alongside the linguistic, cognitive, and cultural text-based practices and processes associated with a discipline' (Moje, 2007, p. 10).

From the research literature, the argument for teaching disciplinary literacy in schools stems from the recognition that (a) disciplines have different specialised ways of communication which students need to master in order to be successful in the discipline and (b) these disciplinary demands become more crucial at the secondary school level. Shanahan and Shanahan (2008) conceptualise a pyramid model of literacy progression to differentiate between basic and intermediate literacy skills at the bottom and disciplinary literacy skills at the top of the pyramid. Basic literacy skills are usually learned in kindergarten and lower primary and encompass foundational aspects of literacy required for virtually all reading and writing tasks, such as word decoding, pronunciation, and simple sentence structures for the English language. At upper primary, students are exposed to intermediate literacy skills, which includes more varied and complex text organisation (e.g. parallel plots, cause and effect, informational). By secondary schools, students begin to encounter increasingly complex forms of language and representations that are specific and unique to the discipline (Lemke, 1990).

Although the need to integrate literacy and content instruction is apparent, much remains unclear about how disciplinary literacy instruction might look like in practice, particularly for subjects such as science and mathematics. In theory, disciplinary literacy instruction is more than a set of generic literacy strategies that are uniformly applied in all content areas (Shanahan & Shanahan, 2008). Rather, disciplinary literacy instruction needs to be situated in and built on the disciplinary practices that content area teachers are doing in their classrooms (Moje, 2007). However, there is a general lack of knowledge about teachers' disciplinary practices upon which researchers can build. Furthermore, I also raise the question of how and to what extent is disciplinary literacy currently taught or emphasised in a content area classroom. In other words, how do current disciplinary practices in content area instruction differ from an envisioned goal of disciplinary literacy instruction? Making this distinction will inform researchers' knowledge of how disciplinary literacy instruction may and should look like in practice.

Addressing this question requires a scan of current disciplinary practices of content area teachers, with a lens informed by disciplinary literacy theory. As the scan is important for future research on developing disciplinary literacy instruction, this is the basis of the study reported in this paper. Specifically, the purpose of this paper is to report on the first phase of a research project focusing on science disciplinary literacy in four classrooms in Singapore. This first phase of research consists of naturalistic baseline observations of four teachers' disciplinary practices in physics and chemistry at secondary 3 and 4 (9th and 10th grade). On the grounds that disciplinary literacy can be taught in content area instruction (Fang, 2014), I postulate that there might be some small areas where teachers are currently addressing some aspects of disciplinary literacy in their routine teaching, upon which we can then build in future research. Therefore, the main research question that drives this study is: How is disciplinary literacy currently taught or addressed in the science classrooms?

Theoretical perspectives

To study the teachers' disciplinary practices in the context of their classroom teaching, I adopt a socio-cultural view to conceive literacy as social practices connected to a specific form of language for specific purposes (Scribner & Cole, 1981; Street, 1984). Thus, literacy is not simply isolated acts of talking, reading, or writing, but is always being used in particular ways in a particular social context. This idea is further elaborated through the distinction between literacy events and literacy practices. Literacy events, according to Heath (1983), refer to specific and observable situations in which people engage with reading, writing, or talking. Literacy practices, on the other hand, are larger patterns of literacy events used in the community and they are not overtly observable. According to Barton and Hamilton (2000, p. 8), literacy practices are the 'general cultural ways of utilising written language which people draw upon in their lives'. The relationship between literacy events and literacy practices is mutually constitutive. While literacy practices are manifested in characteristic patterns of literacy events in the way we speak, read, write, and use inscriptional tools, they are developed over time through repeated literacy events in a community. At the same time, literacy events are the 'observable episodes which arise from literacy practices and are shaped by them' (Barton & Hamilton, 2000, p. 8). While earlier research tends to foreground the role of spoken and written language, there is an increasing recognition that literacy events and practices are also multimodal (Kress & van Leeuwen, 2001).

Researchers exploring the intersection between literacy and science education have agreed that two common literacy practices in science are constructing scientific explanations and engaging in argumentations (National Research Council, 2012, 2014). Scientific explanations and argumentations are constructed through the literacy events of reading, writing, or talking, and they are literacy practices because of their characteristic and cultural-specific ways of using language for a particular purpose in science. Scientific explanation involves the application of an accepted theory or formulation of a new theory to make sense of a specific situation or phenomenon (Achinstein, 1983), while argumentation involves the persuasion of peers by justifying a claim or position in light of supporting or contradictory evidence (Driver, Newton & Osborne, 2000). According to Wellington and Osborne (2001), scientific explanations are commonly found in school science discourse while arguments are less frequent.

To investigate the literacy practice of science, I draw on systemic functional linguistics (SFL) to examine the discourse in the classroom. From a SFL perspective, every literacy event, such as reading and writing, is seen as a social meaning-making practice of text in accordance with certain cultural and disciplinary-specific ways of using language associated with that text (Lemke, 1989). This view is based on the central tenet of SFL where language functions as a meaning-making resource that is organised and repeatedly used over time in a social community for the production of three kinds of meanings (Halliday, 1978). These three 'metafunctions' of language are ideational – for construing and representing ideas of and experiences with the subject matter; interpersonal – for enacting our interaction and relationships toward others as well as the subject matter; and textual – for organising and connecting elements of a text into a larger entity. Any text, conceived as a meaningful stretch of written or spoken language, simultaneously makes ideational, interpersonal, and textual meaning by drawing on the lexico-grammatical resources of each of the three metafunctions.

For the analysis in this paper, the ideational and textual metafunctions are most relevant in examining the scientific content that is constructed by the students and teachers. The focus on ideational and textual metafunctions is common among researchers (e.g. Lemke, 1990; Unsworth, 1998) who have used SFL, particularly the grammatical systems of transitivity and conjunction, to analyse scientific text and discourse. Transitivity examines how ideational experiences are construed through the English clause by inquiring into the choices made in terms of the participants, processes, and circumstances. In the grammar of transitivity, there are five major process types – material, relational, existential, mental, verbal – which classify the world into an experiential domain of doing/happening, being/having, existing, thinking, and saying respectively (Halliday, 1985). Conjunctive relations, on the other hand, look at the interconnections between processes and are realised through various types of conjunctions such as additive (e.g. and), comparative (e.g. however), temporal (e.g. first, simultaneously), and consequential (e.g. therefore) (Martin, 1992).

Besides the notions of transitivity and conjunction, another important notion in SFL is genre, which takes into account the sociocultural activity and purpose for which the text was produced. According to Martin (1992), a genre is a staged and purposeful activity and it refers to the way texts are structured in order to fulfil their overall purpose. A genre has distinct functional stages or schematic structures which can be identified on the basis of lexical and grammatical shifts in the text (Martin, 1992). For instance, the schematic structure of an explanation comprises two characteristic stages of Phenomenon Identification (what is being explained) and Implication Sequences (series of logical clauses joined by conjunctions). According to Unsworth (1998), scientific explanations exhibit a particular linguistic pattern in transitivity, conjunction, and grammatical metaphor. In terms of transitivity and grammatical metaphor, there is a tendency to nominalise material processes of phenomena (as verbs; e.g. compress) into an abstract entity (as nouns; e.g. compression) as the explanation develops. In terms of conjunction, the logical relations and rhetorical organisation of the textual sequences in an explanation are joined together through the use of conjunctions (e.g. because, so, while) which realise the reasoning between the sequences. Unsworth (1998) shows that an effective explanation is one that incorporates these linguistic patterning in the text.

Methodology

Research questions and context

With the goal of doing a scan of current disciplinary practices among science teachers in Singapore, the purpose of this study is to provide a multiple case studies (Yin, 2013) from a number of science classrooms. The specific research questions (RQs) that guided this study were:

1. To what extent do various *literacy events* (e.g. talking, reading, writing) occur in the physics and chemistry classrooms?
2. How do science teachers engage in the *literacy practice* of constructing scientific explanations with the students?

The purpose of the first research question was to provide a broad overview of how the teachers enacted various literacy events in the classrooms while the second question narrowed on a particular literacy practice that emerged from the findings of RQ 1.

The data for the study were taken from a research project aimed to develop disciplinary literacy instruction in science with two secondary schools in Singapore. Particularly for this study, I use the data to provide multiple case studies (Yin, 2013) of how four science teachers in Singapore addressed literacy in their classrooms. From each school, one physics and one chemistry teacher were recommended by the school leaders to take part in the research. They were nominated on the basis that they were experienced teachers and were keen to improve their teaching repertoire. Both physics teachers were male while the chemistry teachers were female. All were of Chinese ethnicity. All four teachers had a degree in science or engineering and a post-graduate diploma in education, specialising in secondary science. They also had 3 to 8 years of teaching experiences at the start of the research project.

One class from each teacher was selected for classroom observation. There were 107 students participants, with 87 students in the 9th grade and 20 students in the 10th grade. The average class size was 27. The ethnic composition among the students was 72% Chinese, 10% Malay, 7% Indian, and 11% of other ethnic groups. This was relatively close to the national proportion of the three dominant ethnic groups in multiracial Singapore. More than three-quarter of the students speak English as the first language with their friends in schools. In Singapore, English is designated as the first language and the medium of instruction for all academic subjects, except for second or third language classes. All children learn English formally at the age of seven in primary one, and about half of them grow up in families that predominantly use English.

Data sources and analytical methods

In this study, I used ethnographic methods, comprising classroom observation, video recording, field-note taking, and artefact collection, to collect data from the four observed classrooms. The primary data source for the study in this paper was classroom videos, comprising 55 lessons (51 hours & 42 minutes in total) covering a range of physics and chemistry topics, such as light, pressure, heat transfer, kinetic model of matter, energy from chemicals, the Periodic Table, atomic structure, and atmosphere. The videos were recorded by one camera at the back of the classroom focusing on the teacher. Three research assistants were involved in the data collection process.

Lesson videos were viewed, coded, and tagged using Transana software. Informed by Erickson's (1992) ethnographic microanalysis of classroom discourse, the continuous sequences in a lesson video were segmented into meaningful discrete units. Each segment is determined by clear boundaries demarcating prominent shifts occurring in the classroom, such as a discernible change in the participants' interaction pattern or the texts to which they are oriented. The average duration of a segment is about 1.5 minutes. Each segment was then coded according to the dominant literacy event carried out by the students. Seven major categories were devised based on the data. These are whole class talk, student discussion, reading, writing, observing, solving exercises, and others. For each major category, a sub-category was devised to further differentiate the segmented activity. For instance, the category of whole class talk consists of review, instruction, lecture, worked solution, announcements, and so on. These categories and their defining properties were developed iteratively as the analysis unfolded. See Appendix A for the list of categories and sub-categories as well as their descriptions. The same research assistants were involved in the coding process, and the average interrater reliability score (by percentage of agreement) among them was 83.7%.

For RQ 1, after all the videos were exhaustively segmented and coded, the duration of each literacy event was computed in order to calculate the proportion of time spent for various literacy activities (generalisation of similar literacy events) in the observed classrooms. The purpose of this quantitative analysis is to provide a broad overview of the types of literacy activities carried out by the teachers in their content area instruction. From the results, it was found that the students spent the majority of the time listening to their teachers' explanations of certain observable phenomena or known facts about the world. As such, the subsequent qualitative analysis for RQ2 examined in depth this literacy practice as teachers co-constructed canonical explanations with the students. Thus, the selection of the video segments for further qualitative analysis was filtered based on the sub-category of lecture (at 25.9%) under whole class talk.

Using discourse analysis informed by micro-ethnography (Erickson, 1992) and SFL (Martin & Rose, 2007), I examined the discursive moves made by the participants as the content development unfolded. At this level of analysis, the video segments were transcribed and analysed on a moment-by-moment basis. First, I identified the interactive function of each utterance, such as a question, statement, comment, or request (e.g., question, statement; Chin, 2006). This was necessary because the meaning of an utterance depends on the purpose for which it was raised within its dialogic context (Bloome & Egan-Robertson, 1993). Next, I divided the utterance into its constituent clauses and performed a transitivity analysis of each clause (identifying participant, process, and circumstance) to examine how the ideational meaning of the explanation developed. I also performed a conjunction analysis to examine how the logic and structure of the explanation was achieved through the cohesion of the individual clauses (Martin & Rose, 2007).

Quantitative findings for Research Question 1

Table 1 shows the extent (by proportion) of time spent in various literacy activities in the four observed classrooms.

Dominance of listening to the teacher

Whole class talk in which the students listened to the teacher most of the time was overwhelmingly the most

Table 1. Proportion of time spent by students in various literacy activities in Physics and Chemistry (non-practical) lessons

Literacy Event	Percentage				
	School 1		School 2		
	John 16.6 hrs	Anne 17.1 hrs	Derrick 10.8 hrs	Kathryn 7.2 hrs	**Overall**
Whole class talk	**44.9%**	**53.2%**	**58.6%**	**77.7%**	**58.6%**
Review	4.9%	3.6%	4.7%	9.1%	5.6%
Instruction	4.8%	5.9%	4.0%	5.8%	5.1%
Lecture	22.3%	20.3%	19.1%	41.8%	25.9%
Worked solutions	8.8%	18.4%	22.4%	14.3%	16.0%
Announcement	3.7%	4.6%	5.8%	2.7%	4.2%
Student's Presentation	0.2%	0.1%	0.3%	1.7%	0.6%
Student Discussion	**16.0%**	**1.6%**	**0.2%**	**4.3%**	**5.5%**
Group Discussion	9.7%	0.0%	0.2%	1.6%	2.9%
Group Work	6.4%	1.6%	0.0%	2.7%	2.7%
Reading	**5.0%**	**0.1%**	**0.0%**	**1.1%**	**1.6%**
Notes	1.0%	0.0%	0.0%	0.4%	0.3%
Textbook	3.6%	0.0%	0.0%	0.2%	0.9%
Other materials	0.4%	0.1%	0.0%	0.6%	0.3%
Writing	**4.8%**	**8.2%**	**10.7%**	**4.9%**	**7.1%**
Copying	4.8%	6.4%	10.7%	2.9%	6.2%
Qualitative Writing	0.0%	1.8%	0.0%	2.0%	1.0%
Observing	**3.0%**	**2.4%**	**2.5%**	**0.6%**	**2.0%**
Demonstration	2.8%	1.3%	0.0%	0.0%	1.0%
Video	0.2%	1.1%	2.5%	0.6%	1.0%
Solving Exercises	**19.1%**	**23.4%**	**18.2%**	**5.3%**	**16.5%**
Problem Solving	15.5%	18.1%	9.2%	3.1%	11.5%
Short Response	2.2%	1.0%	2.3%	1.8%	1.8%
Self-checking	1.4%	3.5%	0.4%	0.3%	1.4%
Drawing	0.0%	0.8%	6.4%	0.0%	1.8%
Others	**7.3%**	**11.4%**	**9.8%**	**6.0%**	**8.6%**
Preparing/Clearing	7.3%	11.3%	9.5%	6.0%	8.5%
Classroom distraction	0.0%	0.2%	0.2%	0.0%	0.1%

frequent literacy event in all the observed classrooms. Within this category, the most frequent whole class talk was lecture (at 25.9%), which is defined as the teacher presenting information related to the content of the discipline. This included introducing new terms and definitions of a topic, giving an exposition of scientific concepts, and explaining the processes and causes of a phenomenon. Although the dominant feature of a lecture was the teacher doing most of the talking, the way the lecture was carried out varied among the teachers. For instance, Kathryn tended to interact with her students through an I-R-E (Initiate-Response-Evaluate; Mehan, 1979) interaction more frequently and gave her students more wait time to respond to her questions. Occasionally, she also used an I-R-F (Initiate-Respond-Follow up) interaction to engage in a more open-ended dialogic inquiry (Mortimer & Scott, 2003) with the students. Comparatively, Derrick and Anne tended to use a more authoritative I-R-E interaction to elicit 'correct' responses from the students during their lectures. Such qualitative differences cannot be captured on Table 1 because a student's response was usually short, with a duration of less than 10 seconds. As such, the qualitative nature of these talks will be further analysed.

Table 1 also shows the lack of student talk among themselves in comparison to whole class talk. The exception was John who frequently let his students do a quick 'think-pair-share' or group discussion in answering a difficult question before he gave the explanation through a teacher-led whole class talk. Occasionally, John also designed a lesson where the students did a more extended group work by creating some artefacts for an assignment or subsequent group presentation. Thus, a group work differs from a group discussion in that the students were writing down their discussions in addition to talking among themselves. As for Anne, Derrick, and Kathryn, the proportion of student discussion was 1.6%, 0.2%, and 4.3% respectively. While these percentages were low, the numbers do not imply that most of the students did not talk at all during the lessons. This was because many students were called upon at different times through the teacher's I-R-E interaction sequences. But this would be classified as a whole class talk because at any one time, only one student was responding and the rest of the class was mostly listening to (and for some, taking notes of) the conversation.

Another observation was the lack of reading activities in the classrooms, with the exception of John. This reflects the prevalent resistance among science teachers in using reading to support their content teaching (Wellington & Osborne, 2001). Comparatively, there were more writing activities going on in the classrooms, at an average of 7.1%. However, the nature of the writing activity was not cognitively demanding as the students were mostly copying information from the teachers. This included writing down notes and answers that were dictated by the teacher or written on the whiteboard. By contrast, writing an explanation, argument, report, or summary involves more extended writing, and as such were categorised as qualitative writing. As shown in Table 1, these activities were not common in all the classrooms, at only 1% on average.

In sum, current disciplinary literacy in the observed science classrooms focused a lot on listening to the authoritative way of talking in science, particularly on content information (i.e. lecture), and overlooked the provision of generating talk among students as well as reading and writing activities on scientific texts. Although this finding was not unexpected, it gave a scale of how extensive (averaging at 25.9%) and how common (for all teachers) the practice was. More importantly, the finding provided a clearer picture of what constituted presenting and listening to a lecture, which predominantly involved an explanation of natural phenomena or processes using some scientific principles. This thus allowed us to pinpoint and narrow further into the next phase of analysing how the literacy practice of science explanations was typically constructed in the classroom.

Qualitative findings for Research Question 2

Qualitative analysis of the literacy events in whole class lectures revealed two major patterns on how the teachers *implicitly* taught the disciplinary language of science to the students. These patterns revolved around the teachers' use of I-R-E interactions and logical conjunctions.

Using I-R-E to frame science terminologies and explanation sequences

Science terminologies play an important function in the language of science and often present challenges for secondary school learners (Fang, 2005). Few science teachers employ explicit literacy strategies, such as concept mapping, word taxonomy, or direct vocabulary instruction, to help students master science vocabulary (Wellington & Osborne, 2001). However, this did not mean that students were not learning new specialised terms in the classrooms. In this study, it was observed that scientific vocabulary was often implicitly highlighted through the questions asked by the teachers and the ensuing I-R-E interaction pattern. An example is shown in the following excerpt when Anne was asking the students to define oxidation:

1	Anne	How would we define oxidation?
2		Okay, Han Wei, how could we define oxidation?
3		Oxidation is the what of oxygen by a substance?
4	Han Wei	Gain.
5	Anne	Gain. Very good.
6		Brandon, how about this?
7		Reduction is the?
8	Brandon	Reduction is the gain …
9	Anne	Reduction is the?
10	Brandon	The loss
11	Anne	Is the opposite to your oxidation.

Another example can be seen in the following when John was reviewing what the students had learned from a previous lesson. This example also illustrates that specialised terms in science extend to the standardised units of measurements used in science:

1	John	Zac, what is the SI unit for force?
2	Zac	Newton per square metre.
3	John	Force leh. (*leh – a colloquial Singapore English term which adds a quizzical tone or emphasis to the sentence*)
4	Zac	Newton.
5	John	Newton, alright.
6		So the unit for force is Newton.

Vocabulary instruction of science terminologies often takes in the form of teaching and recalling definitions. Embedding such vocabulary instruction within the teacher's I-R-E teaching practice is one way, albeit a subtle one, where science terminologies are taught.

In addition to science terminologies, it was also frequently observed that the teachers implicitly used the I-R-E interaction as a structure to frame the logical sequences of an explanation. As an illustration, consider the next excerpt when Kathryn was explaining why fractional distillation is a preferred technique over simple distillation:

1	Kathryn	Now next, why do I choose to use fractional distillation rather than simple distillation?
2		Can I use simple distillation?
3	Student	No.
4	Kathryn	From what you recall, simple distillation we use it to separate what, ah?
5	Student	Boiling point more than 25.
6	Kathryn	Boiling point more than 25.
7		Apart from that?
8		What kind of mixture do I use?
9		Or maybe you give me one example.
10	Student	Salt and water.
11	Kathryn	Salt?
12	Student	Seawater.
13	Kathryn	Ah okay.
14		We separate your seawater into salt and distilled water.
15		Correct or not?
16		Okay, so that is one way that you use simple distillation.
17		But why is it that we use fractional distillation here?
18		What's the main reason?
19	Student	Difference in boiling point.
20	Kathryn	Ya, take a look at the difference in their boiling point.
21		What do you notice about the difference in boiling point?
22	Student	They're very close.
23	Kathryn	Ya, they're very close.
24		So, because they're very close,
25		And they are both, uh, gases, over here (*pointing using the cursor*)
26		So I need to cool it down, alright,
27		in order for it to be liquid to undergo fractional distillation, alright?
28	Kathryn	So first of all, liquid air is a mixture of liquids, alright,
29		having similar or, or, close boiling points, alright.
30		So therefore I use fractional distillation.

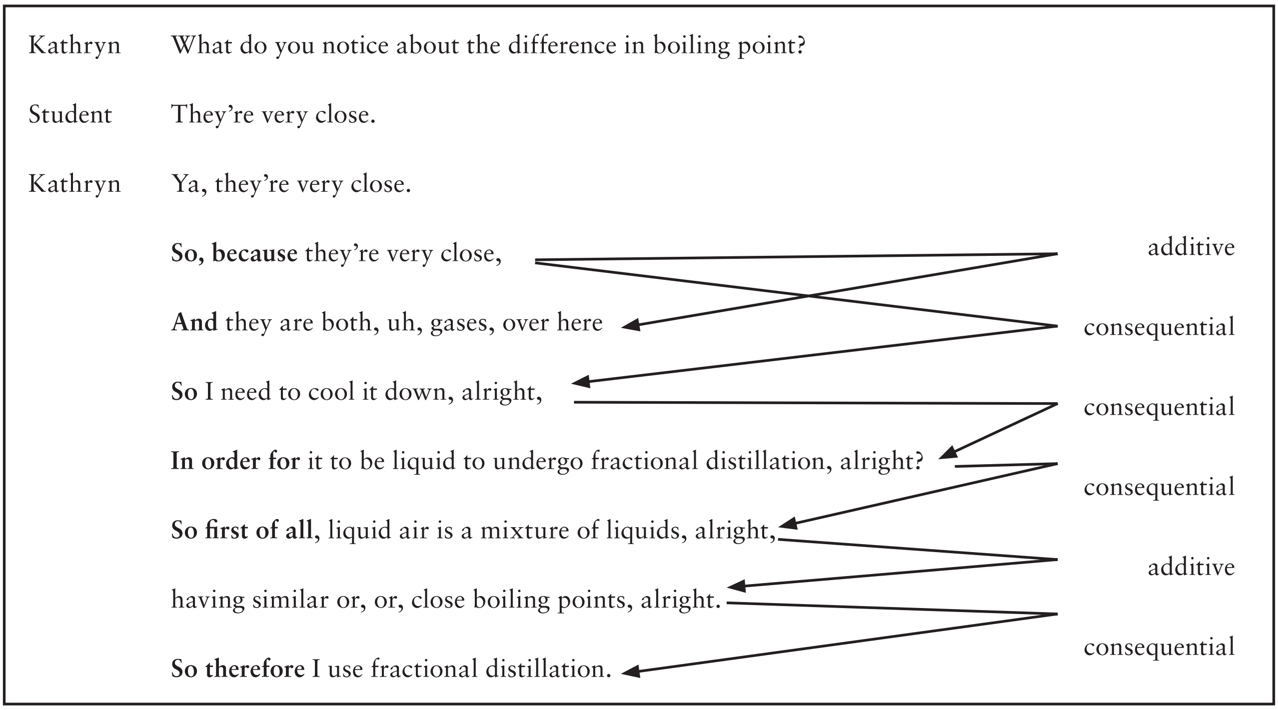

Figure 1. The use of conjunctions in the chain of Kathryn's reasoning.

From line 2 to 16, Kathryn used the I-R-E sequences to elicit information pertaining to simple distillation. Then, from line 17 and 27, the discussion shifted to fractional distillation, which again was framed through her two questions on line 17 and 18. Finally, after staging these two cases, she juxtaposed them together for direct comparison in her summary from line 28 to 30. Thus, this is a common way where a teacher, such as Kathryn, uses the I-R-E interaction sequences to frame and co-construct a certain rhetorical structure in the explanation with the students.

Although I-R-E interaction is useful in guiding the teachers and students to co-construct the explanation, it puts the thinking process too much on the teacher and less so on the students. This is because the rhetorical structure of the explanation was embedded in the questions. A causal explanation genre usually has a three-part rhetorical structure consisting of (i) an identification of phenomenon stating what is known (ii) a temporal or casual sequence of events which construes the reasoning, and finally (iii) a conclusion or outcome of the event to be explained (Veel, 1997). In the above excerpt, the reasoning of the explanation (i.e. similar boiling point of two liquids) was foregrounded by Kathryn through her questions on lines 18 and 21, and then further elaborated by her through four causal sequences from line 24 to line 27. (These four sequences were joined by the conjunctions of 'because', 'and', 'so', and 'in order to'). In other words, the questions in Kathryn's I-R-E sequences functioned as important mediators in structuring the rhetorical organisation of the explanation.

Using implicit conjunctions in questions and statements

Together with the use of the I-R-E questioning sequences, the teachers also implicitly used conjunctions to construct the canonical explanations. This could be seen from the previous example. Earlier, we saw how Kathryn structured the question and answer dialogue about distillation in two segments: simple distillation from line 2 to 16 and fractional distillation from line 17 and 27. These two segments were then textually joined together through the conjunction 'but' on line 17 which sets up a contrasting relationship between the two segments. Not only does this conjunction establish the rather obvious relationship between simple and fractional distillation as two alternative modes of distillation, it also determines two other contrasting relationships between the underlying reasoning; that is, (i) the contrast between 'boiling point more than 25' (line 5–6) and the 'very close' 'difference in boiling point' (line 19–24) and (ii) the contrast between 'seawater' (line 12–23) and 'mixture of liquids' (line 28). Subsequently, from line 24 to 30, Kathryn used additive and consequential conjunctions (and, first of all, so, because, in order for) successively to build up the chain of reasoning for the use of fractional distillation, as shown in Figure 1.

Besides Kathryn, the use of conjunctions was also frequently found among the other three teachers' lectures on various science explanations. Figure 2 shows another example where John constructed the causal sequences of why liquid flows to our mouth when we

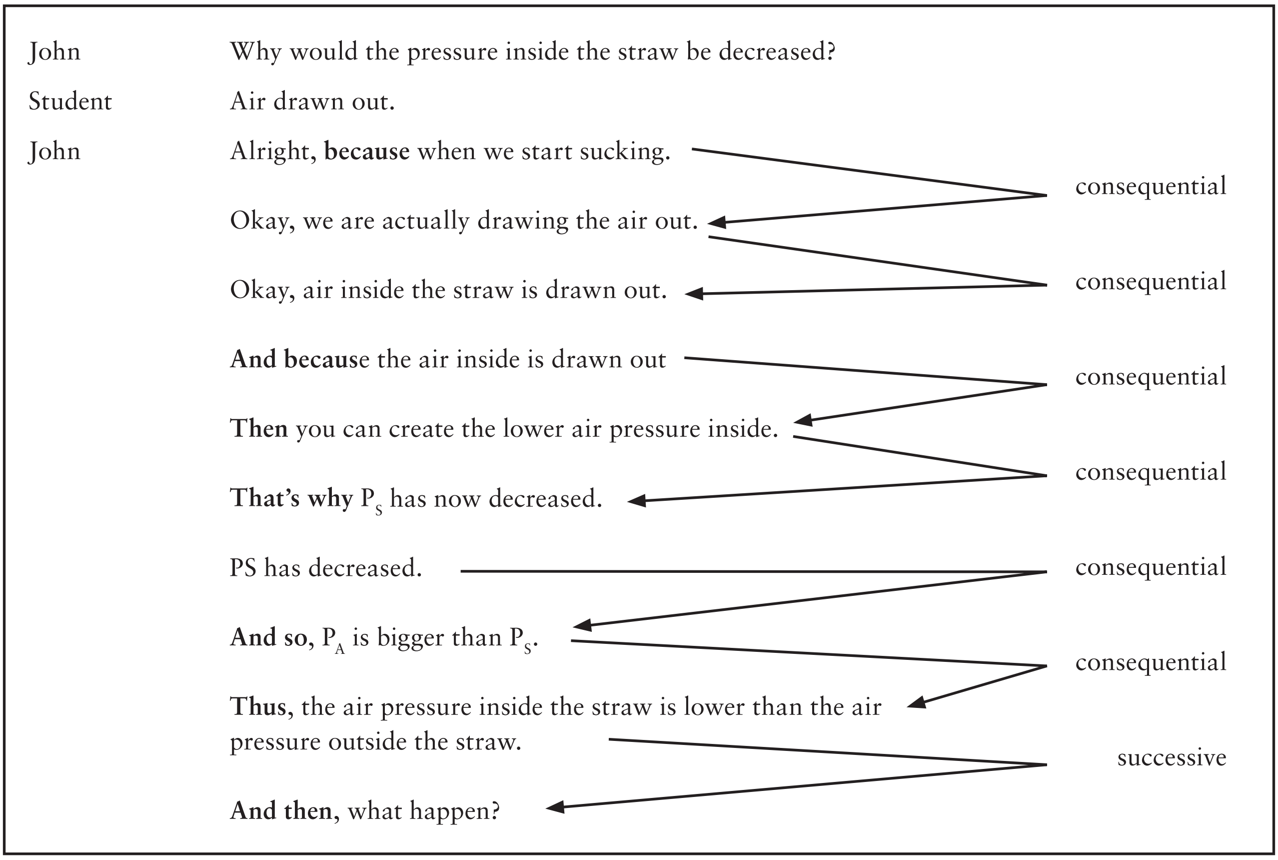

Figure 2. The use of conjunctions in the chain of John's reasoning.

suck a straw, again through the use of conjunctions like because, and, then, so, thus:

The previous two examples (Figure 1 and Figure 2) show the use of the conjunctions within the third move of an I-R-F exchange whereby the teacher 'follows up' from an earlier student's response with further elaboration. Thus, within this extended elaboration, each conjunction is embedded in the form of successive clauses made by the teacher. It is important to note that although the conjunctions perform a very important function in the logic of the explanations, their functions were not highlighted by the teachers. Thus, the logical relationships made by the conjunctions remain implicit within the teachers' statements. In the next example (Figure 3), the logical relationships were even more implicit as most of the conjunctions were not found in the teachers' statements, but were embedded in the form of questions within a series of successive I-R-E exchanges. In Figure 3, each I-R-E exchange is enclosed within a box:

As shown in Figure 3, the chain of reasoning constructed by Anne differs from Kathryn's and John's in two ways. First, Anne used short and quick I-R-E interactions to build up the consequential relations between successive exchanges. Second, because the third 'evaluate' move of the I-R-E exchange was short, most of the conjunctions were not found within this move (with one exception in the second last exchange where the evaluation was longer). Instead, the important conjunctions came from the word 'so' and they were embedded as a question within the first 'initiate' move of the I-R-E exchange. These conjunctions within the 'initiate' questions established the necessary additive and consequential relationships between the successive exchanges. In other words, the logic of the explanations is embedded within the questions, and not the answers.

It is debatable whether the words 'so' in Anne's I-R-E exchanges were used as conjunctions, or as discourse markers which people tend to use at the beginning of their utterances, along with words like 'okay' and 'now'. It seems likely that Anne used 'so' to serve particular functions such as signalling topic change, reformulating, or stressing importance. However, in this analysis, it is inconsequential to consider the intention of Anne – whether she meant the word 'so' to function as a conjunction or discourse marker. Instead, by considering the logic of this science explanation, either an additive or consequential relationship is implied between successive exchanges (see Figure 3). In this sense, the word 'so' does function as an additive or consequential conjunction in this conversation. Whether the word 'so' functions as a conjunction or

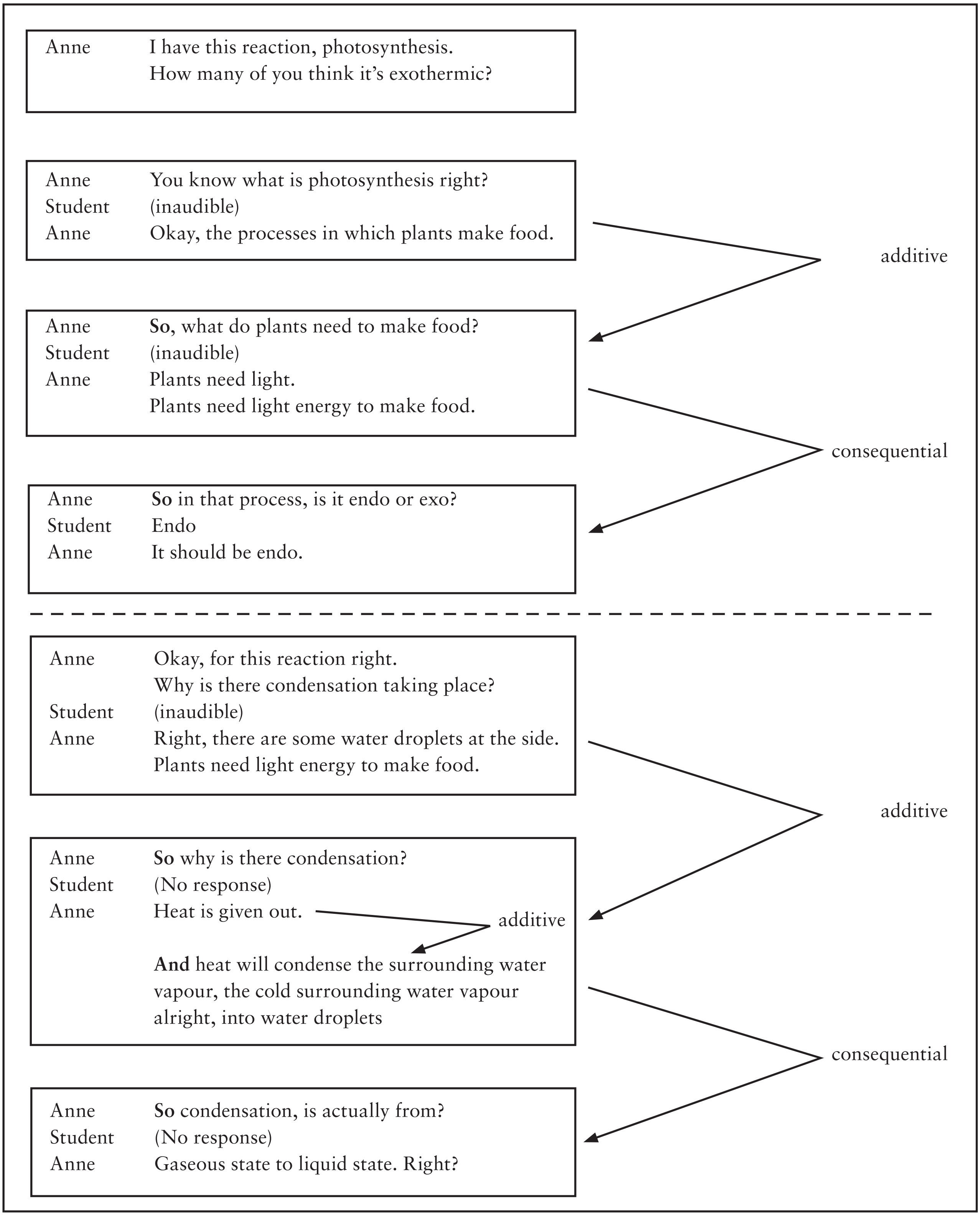

Figure 3. The use of conjunctions in the chain of Anne's reasoning.

discourse marker, or both, further reinforces my argument that teachers like Anne used conjunctions rather haphazardly and implicitly, and their proper uses in the logical construction of science explanations remain subtle and elusive to most science students.

Discussion and future research

From the findings of this case study, we can begin to ask ourselves some questions regarding disciplinary literacy teaching. First, did the lessons analysed exhibit any form of disciplinary literacy instruction where there was some teaching of the 'linguistic, cognitive, and cultural text-based practices and processes associated with a discipline' (Moje, 2007, p. 10)? Second, what elements of disciplinary literacy were and were not emphasised in the observed lessons? Third, how can we build on what we have observed about the teachers' existing practices to develop disciplinary literacy instruction? Although I do not foresee these questions could be answered completely in this paper, my aim in this section is to provide the basis for further deliberation in this area.

On the first question of whether the lessons exhibited any form of disciplinary literacy instruction, instead of a binary answer, it is perhaps more instructive to unpack aspects of disciplinary literacy and to what extent they were or were not taught. From the findings for the first research question, we saw the predominant mode of communication was talking and there was hardly any opportunity for specific reading and writing instruction. As for talking, while a lot of time was spent in this area, the focus was limited to content delivery. However, we noted that there were two specific areas of disciplinary language where the teachers tended to emphasise, albeit implicitly. These were the use of science terminologies and the logical relationships of explanations. If we were to consider these two areas as examples of the linguistic and cultural text-based practices associated with science, then there would be some form of disciplinary literacy instruction happening in the classrooms (involving specific ways of using language and explanation sequences). Nevertheless, we need to remember that these pedagogical practices were implicit because they were embedded within existing common classroom practices – through the use of I-R-E and logical conjunctions, rather than an explicit form of disciplinary literacy instruction.

In addition, if we consider constructing scientific explanation as an important literacy practice in science, then it seems that this is a potential area of development as the teachers paid a lot of attention in this area. However, we noted there was a lack of emphasising the epistemic nature of explanation as a disciplinary literacy practice. The teachers tended to emphasise students' understanding of the accepted explanations rather than evaluating how that knowledge came about through the disciplinary practices of science. In other words, a large part of what is missing in the classrooms is the focus on the epistemic process of constructing explanations. Thus, instead of embedding the logical relationships of an explanation within the teachers' instruction, a more explicit instruction could be to teach the genre or rhetorical structure of scientific explanation so that students are aware of what is an explanation and how does it work. Future research could build on this opportunity by transforming existing practices of how teachers teach explanations (see Tang, In press; Tang & Rappa, under review).

Finally, if what we observed is the state of current teaching practices in science, how can we build on the existing practices to develop disciplinary literacy instruction in the future? Perhaps one way of making the shift towards more pervasive disciplinary literacy instruction is to find ways to shift the implicit teaching of the language features towards a more explicit one. For instance, we saw that teachers implicitly highlighted specialised terms in science through the introduction and recall of definitions in the form of I-R-E questioning sequences. Embedded within these practices, we could ask teachers to also explain why precise terms must be used in science or how some words have different meanings in different contexts (e.g. reduction, pressure). Teachers could also extend their current vocabulary instruction beyond the level of recall through an I-R-E interaction, and use other direct vocabulary methods to help students use appropriate scientific terms in various contexts.

In conclusion, this study begins by asking what are the existing pedagogical practices among science teachers upon which we can draw to develop disciplinary literacy instruction, in a way that is building on teachers' existing practices instead of a radical transformation from scratch? This led us to work with the selected teachers to examine their current disciplinary practices in their classrooms. Through the observations, the study reveals various possibilities of situating discipline-specific literacy instruction in current teaching practices. This finding is important in order to reach out to content area teachers who are hesitant toward the idea of teaching generic literacy strategies (Shanahan & Shanahan, 2008). Showing them practical ways of shifting their implicit teaching of disciplinary literacy toward a more explicit approach of disciplinary literacy instruction will be more effective compared to adopting a set of strategies developed outside their disciplinary area and implemented through researcher-led intervention projects. Further work in this direction will be important for teacher education as content area teachers will be more empowered to develop literacy instruction that is specific and relevant to their own disciplines.

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Appendix A

Literacy Event		Description
Whole class talk	Review	When students are listening to the review of the previous lesson. This is usually at the beginning of a lesson.
	Instruction	When students are listening to information / instruction related to the content of current lesson which requires follow-up action within the lesson. The follow-up action should be an (whole class) activity, e.g. set exercises, group discussion, copying. Almost all the follow-up actions are immediate except for lesson objectives.
	Lecture	When students are listening to new information on the content of the current lessons. This includes IRE/F. It includes teachers using exemplar questions to introduce new concepts or information.
	Worked solutions	When students are listening to teachers' or students' solutions to exercise questions. This includes questions that the students have attempted beforehand. This includes IRE/F. This overrides self-checking.
	Announcement	When students are listening to information not related to the content of the current lesson which may not require follow-up action.
	Student's Presentation	When students are listening to other student's presentation e.g. gallery walk.
Student discussion	Group Discussion	When students are discussing questions, assignments, etc.
	Group Work	When students are having discussion AND writing down their discussions. Usually involves creating some artifacts as a result of some discussion.
Reading	Notes	When students are reading their notes as instructed by teachers.
	Textbook	When students are reading their textbooks as instructed by teachers.
	Other materials	When students are reading their other materials such as newspaper articles, web pages as instructed by teachers.
Writing	Copying	When students are merely copying information from teachers, without higher cognitive skill. This includes writing down notes, copying answers, highlighting, and diagram. It can be assumed that students are copying after 'lecture', 'worked solutions' and 'instruction', especially when silence entails.
	Qualitative Writing	When students are attempting qualitative and open-ended questions.
Observing	Demonstration	When students are observing or doing experiments.
	Video	When students are watching videos that demonstrate experiments in which the videos serves as a substitute to the demonstration. It also includes watching videos and simulations that contain mainly moving images (e.g. movement of molecules, atom arrangement).
Solving exercises	Problem Solving	When students are attempting numerical and close-ended questions.
	Short Response	When students are attempting multiple-question-choice and short close-ended questions.
	Self-checking	When students are checking their answers. This includes peer checking using rubrics. It's similar to listening to worked solution except no one is talking.
	Drawing	When students are drawing diagrams on their own, without copying from textbooks or teachers' drawing.
Others	Preparing/Clearing	When students are transiting from one activity to another. This includes passing notes, waiting for instruction while teacher is doing non-content related activity.
	Classroom distraction	When students' learning is interrupted by unforeseen circumstances, e.g., interruption by other teacher giving announcement, fire alarm.