International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: http://www.tandfonline.com/loi/tsed20

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To cite this article: Kok-Sing Tang (2016): The interplay of representations and patterns of classroom discourse in science teaching sequences, International Journal of Science Education, DOI: 10.1080/09500693.2016.1218568

To link to this article: http://dx.doi.org/10.1080/09500693.2016.1218568

Published online: 08 Sep 2016.

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, 2016
http://dx.doi.org/10.1080/09500693.2016.1218568

The interplay of representations and patterns of classroom discourse in science teaching sequences

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ABSTRACT

The purpose of this study is to examines the relationship between the communicative approach of classroom talk and the modes of representations used by science teachers. Based on video data from two physics classrooms in Singapore, a recurring pattern in the relationship was observed as the teaching sequence of a lesson unfolded. It was found that as the mode of representation shifted from enactive (action based) to iconic (image based) to symbolic (language based), there was a concurrent and coordinated shift in the classroom communicative approach from interactive–dialogic to interactive–authoritative to non-interactive–authoritative. Specifically, the shift from enactive to iconic to symbolic representations occurred mainly within the interactive–dialogic approach while the shift towards the interactive–authoritative and non-interactive–authoritative approaches occurred when symbolic modes of representation were used. This concurrent and coordinated shift has implications on how we conceive the use of representations in conjunction with the co-occurring classroom discourse, both theoretically and pedagogically.

ARTICLE HISTORY
Received 10 January 2016
Accepted 26 July 2016

KEYWORDS
Representations; classroom discourse; teaching sequence; video analysis; timescale

Introduction

Classroom discourse and interaction has been a subject of much interest among science education researchers since Lemke's (1990) work in illuminating the norms of language and communication in most science classrooms. Early work in classroom discourse has documented the 'triadic dialogue' or IRE exchange (Initiate–Response–Evaluate; Mehan, 1979), that teachers often used to facilitate classroom talk. Subsequent studies also shed light on teacher questioning (Chin, 2006; Van Zee & Minstrell, 1997), dialogic discourse (Kelly, Crawford, & Green, 2001; Pappas, Varelas, Barry, & Rife, 2004; Wells, 2008), and classroom communication patterns (Mercer, Dawes, Wegerif, & Sams, 2004; Mortimer & Scott, 2003). In particular, Mortimer and Scott (2003) found a recurring pattern in the way teachers shift between an authoritative and dialogic approach of communication in order to develop scientific ideas with their students. Although research in classroom discourse has provided insights into how science teaching and learning occurs

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as social norms and interactions in the classrooms, most of the studies focus primarily on verbal language and bracket the role of multiple and multimodal representations in the discourse.

Separately, there is a growing emphasis on the role of representations in the last decade (Yore & Treagust, 2006). Many researchers have examined, from multiple perspectives, various forms of representations, such as the macro–micro relationships in chemistry (Gilbert & Treagust, 2009; Kozma, Chin, Russell, & Marx, 2000), canonical usage for physics problem solving (Rosengrant, Etkina, & Van Heuvelen, 2007), functions of representations for cognitive processing (Ainsworth, 2006), embedding representations in science writing (Gunel, Hand, & Gunduz, 2006), and affordances of various semiotic modes (Airey & Linder, 2009; Lemke, 1998). Besides these studies that investigate the intrinsic nature or structure of representation, another line of research examines the use of representations as situated in classroom discourse, focusing particularly on the dynamic transformation of representation occurring in the classroom, termed variously as 're-representation' (Tytler, Prain, Hubber, & Waldrip, 2013), 'cascades of inscriptions' (Roth & Tobin, 1997), and 'sign-making process' (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001).

In recent years, the role of representations and multimodality in classroom talk is gaining more attention in science education research. There have been several studies that examined how representations were used or manipulated to mediate the talk among students and teachers in the classroom (e.g. Fredlund, Airey, & Linder, 2012; Hubber, Tytler, & Haslam, 2010; Pozzer-Ardenghi & Roth, 2007; Tang 2013b; Tang, Tan, & Yeo, 2011). However, most of the studies focused on only small segments of the talk, lasting from seconds to a few minutes. For instance, Givry and Roth (2006) analysed the interplay of talk, gestures and semiotic structure in episodes that lasted no more than 10 utterances per episode. Similarly, Tang et al. (2011) analysed short episodes (few minutes) of how a group of students integrated diagrams, gestures, and mathematical symbolism in their group discussion. While many of these studies shed light on the interplay between representations and classroom talk in micro-analytic timescale, few have explicitly documented the relationship between the use of multiple representations and patterns of classroom talk continuously in larger timescale throughout the teaching sequence of one or more lessons.

Therefore, this study aims to explore and document the relationship between the use of representations and patterns of classroom talk throughout a teaching sequence. Specifically, the research question in this study was: *What is the relationship between the communicative patterns of classroom talk and the modes of representations used by science teachers throughout the teaching sequence of a lesson unit?* Unlike previous studies that have used mainly micro-discursive analysis to examine the relationship in a short timescale, this study utilised a different methodology involving exhaustive video segmentation and systematic coding to examine the relationship in a longer timescale from the start to end of a lesson unit.

Theoretical frameworks

According to Vygotsky's (1986) sociocultural theory, learning first occurs on a social plane through the cultural tools of communication before it is internalised into an individual's psychological plane. As Vygotsky (1986, p. 218) posited, 'the development of concepts belongs to the semantic aspect of speech development', the speech patterns fostered with peers and knowledgeable others within a zone of proximal development would subsequently form the inner structures of a child's conceptual development. From this theoretical perspective, language (as a system of signs) provides a critical semiotic tool that mediates conceptual development through the discourse of inner speech.

Based on Vygotsky's theory, education researchers consider classroom teaching as the crucial social plane that provides the social language of a discipline outside the experiences of most students, such as academic science. Thus, a key role of science teachers is to introduce scientific ideas and develop them on the social plane while assisting the students to internalise those ideas through a carefully planned and staged sequence of activities (Leach & Scott, 2002). When a new scientific word or concept is made available by the teacher, this does not mean that students will directly internalise its scientific meaning. Instead, extrapolating the ideas from Bakthin's (1981) dialogism, what usually occurs is a joint negotiation of meanings in which the students' views and the teacher's scientific ideas are juxtaposed and intertextually linked (Bloome & Egan-Robertson, 1993).

Communicative approach framework

To describe the negotiation process of meaning making in the classroom, Mortimer and Scott (2003) developed a framework to examine what they call the 'communicative approach' of classroom talk. The communicative approach considers how the teacher interacts with the students as well as how the teacher takes into account of students' point of views in the classroom discourse. In this framework, the communicative approach occurring in the classroom is divided into four categories along two independent dimensions: (a) dialogic versus authoritative and (b) interactive versus non-interactive.

The dialogic–authoritative continuum considers the heteroglossic nature of speech genres (or multiple voices) within an utterance or string of utterances. A dialogic talk is one that is opened to multiple points of view or 'voices' such that there is an 'interanimation' of ideas in the talk (Bakhtin, 1981). On the other extreme, an authoritative talk is one where there is only one point of view, typically from a scientific point of view, and there is no exploration of different ideas. The interactive–non-interactive continuum, on the other hand, considers the nature of interaction among the participants in the talk. An interactive talk is characterised by more than one people involved in the production of the talk (e.g. an exchange uttered between people) while a non-interactive talk is produced by an individual for an extended period (e.g. a lecture). Given these four possibilities, there are therefore four types of communicate approaches, summarised as follows:

1. Interactive–dialogic – two or more parties (e.g. teacher and students, or one student to another) engaging in a discussion with each side offering and considering different points of view.
2. Interactive–authoritative – two or more parties engaging in a discussion with one party directing it towards one point of view (typically the scientific point of view).
3. Non-interactive–authoritative – only one party presenting the scientific point of view while the others listen.
4. Non-interactive–dialogic – one party considers and talks about different points of view while the others listen.

Using this framework, Mortimer and Scott (2003) reported that a typical teaching sequence is repeated through a cycle of interactive–dialogic to interactive–authoritative to non-interactive–authoritative. They further related this observed cycle to the repeated step of *exploring* students' ideas, *working on* new ideas, and *reviewing* the 'scientific story'.

Representation framework

As Vygotsky (1986) articulated the intertwined relationship between thought and language, his conception of language clearly includes other modes of communication besides verbal and written language. As such, multiple representations are important semiotic tools that mediate conceptual development and are part of the 'assemblage of signs' used by science teachers in their classroom teaching (Kress et al., 2001).

In science education research, representations are seen as artefacts that symbolise an idea or concept in science and can take the form of written texts, analogies, diagrams, graphs, and simulations. There is a diverse range of perspectives (see introduction for examples) that researchers have used to study the role and nature of representations used in science teaching and learning (Yore & Treagust, 2006). This study builds on two areas of research in representation. The first area focuses on *multiple representations* as the practice of representing to students with the use of more than one representational form (Prain, Tytler, & Peterson, 2009), and emphasises representation as an inscription (Roth & Tobin, 1997) to be used for instructional mediation. The second area focuses on *multimodal representations* as the integration of multimodal semiotic systems (or modalities) for meaning making (Kress et al., 2001; Lemke, 1998). This area emphasises that the action of representing involves drawing on the affordances of multiple semiotic systems.

To integrate these two areas of research in representation, as well as relate the use of representations to the teaching sequence of classroom activities, Tang, Delgado, and Moje (2014) proposed analysing the timescales of reoccurring classroom events when a particular representation was used. The timescale can range from a single utterance in seconds to a series of activities spread over minutes or hours. In other words, for an ecological view of the complex relationship between representations and classroom discourse, we need to study how the processes at a shorter timescale of using a representation can build up to the processes at a longer timescale of using multiple representations in sequence; and conversely how the longer timescale processes of using multiple representations can constrain and enable the kind of processes that can occur at a shorter timescale of making meaning with a particular representation.

Drawing from this framework, I define a representation as a semiotic artefact or inscription designed and created by a social group of people (e.g. scientists, teachers) for specific purposes. The creation and use of a representation (e.g. written text) would involve drawing from a semiotic system (e.g. language) (Halliday, 1994). At the same time, a representation has the potential to be transformed from one artefact to another across a continuous chain of human activities. In this transformation of representation, or 're-representation' (Tytler et al., 2013), representation is thus also viewed as a process of making meanings through the use of representations (as artefacts) as mediating objects. As such, the term 'representation' should be conceived as both a semiotic artefact as well as an action of making meanings (i.e. representing) with semiotic artefacts (e.g. see Tang, 2013a).

It is important to point out that speech and written texts are two forms of representation drawing from the same semiotic resource – language (Halliday, 1994). Another way to look at this relationship is that language (as a system) is constituted by an infinite instances of spoken and written words (see Tang, 2013b). However, due to the transient nature of speech, spoken words cannot be used as an artefact or mediating object in the chain of re-representation across a teaching sequence. Furthermore, the affordances of spoken and written language are also different in that one is concrete and dynamic while the other is synoptic and abstract (Tang et al., 2011). Therefore, spoken language (or talk) serves more to mediate classroom discourse, rather than as a semiotic artefact in and of itself.

In the process of re-representation, it is useful to denote different stages of representation where learners typically go through in any instructional context. For this purpose, I make use of Bruner's (1966) three modes of thought associated with different types of representations (as artefacts) that are introduced and used in various stages of a lesson. Bruner theorised that learning occurs through three different modes of thinking with the use of representations: enactive (action based), iconic (image based), and symbolic (language based). The enactive stage is a concrete stage that involves a tangible hands-on mode of learning. This stage typically involves the use of physical objects accompanied by bodily or gestural actions. Common examples include observing the motion of a ball rolling down a slope or manipulating an electrical circuit with batteries, resistors, ammeters, switch, and wires. Next, the iconic stage is a pictorial stage that involves images resembling the concrete situation enacted in the first stage, for instance, a circle and slanted line representing the ball and slope, or drawings that look like electrical components (see Figure 1). These images can be drawn explicitly or pictured in one's mind. Finally, the symbolic is an abstract stage that involves written words and symbols. These words and symbols have no direct connection with the objects or ideas being represented, other than through social conventions. For example, a free-body diagram or a circuit diagram comprising of well-defined lines, shapes and arrows are symbolic representations for the iconic representations mentioned earlier. In addition, mathematical equations and graphs are also symbolic representations due to the social convections involved in these representations.

Bruner's initial theorisation was very much influenced by Piaget's (1964) stage theory of development in that the three modes of representation were bounded by ages and followed the ontogenetic development of a child's cognitive structures. However, Bruner later

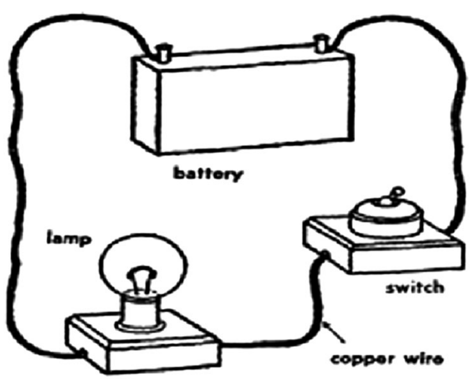

Figure 1. An example of an iconic representation.

emphasised that the three modes of representation can occur laterally during the course of instruction (at a microgenetic timescale), rather than vertically in a linear Piagetian age-bounded sequence (Bruner, 1990). Thus, recontextualising Bruner's ideas in an instructional context, Gardner (2001, p. 93) suggests that the three modes of representations, enactive, iconic, and symbolic, enable 'children to transform experiences into knowledge: through action, through imagery and, eventually, through a range of symbol systems'. In summary, the enactive, iconic, and symbolic mode of representations will likely occur in most lessons and their dominance in the classroom will constantly shift from one mode to another. However, how these modes of representation correspond with the patterns of classroom talk remained unclear, and will thus be the focus of the study to be described in the next section.

Methodology

Research site and data sources

The data in this study come from a larger three-year research project in Singapore that examined how teachers used language and representations in four science classrooms. Two physics and two chemistry teachers were involved in this research project. From an earlier study that reported on the general teaching practices of these teachers (see Tang, in press; Tang, Ho, & Putra, 2016), it was noted that there was a trend among the physics teachers in their use of representations. Thus, in this study, I carried out an in-depth examination focusing on the dataset from the two physics teachers. In particular, the data comprise videos of classroom lessons taught by both physics teachers across a wide range of topics taught at grade 9.

From the richness of video data, I developed analytical cases that chronologically document the complex interplay between classroom talk and representations used in the science classrooms. The presentation of the data as 'cases' serves to preserve the unitary character of a case and focus attention on its details (Goode & Hatt, 1952), instead of claiming generalisability to all science teachers and classrooms. This case study approach is necessary for an early stage of research to explore the qualitative nature of the talk-representation relationship observed within a case. The preservation of the teaching sequence within each case is also crucial because the interpretation of any present event in the classroom needs to be chronologically contextualised with what has happened earlier as well as how the event is unfolding.

The research project was situated in two public secondary schools in Singapore. At the start of the research, the physics teachers, John and Derrick (all names are pseudonyms to protect privacy), had 3 and 5 years of physics teaching experience respectively. Both teachers were identified as experienced teachers by the school leaders, who nominated them to take part in the research project. John taught in a co-ed school while Derrick taught in an all-girls school. The academic performance of the students in these schools, according to results from national examinations, was considered average and above-average. One class from each teacher was selected for classroom observation. There were 31 students (20 boys, 11 girls) in John's class and 27 students (all girls) in Derrick's class. Most of the students were 15 years old, which is the typical age for 9th grade. More than three-quarter of the students speak English as the first language with their friends in schools. In Singapore, all academic subjects, apart from second language classes, are taught in English.

The primary data source for this study comes from classroom videos, comprising 20 lessons (about 25 hours) covering a range of physics topics, such as Newton's Laws, pressure, density, thermal physics, light, wave, and sound. Laboratory-based practical lessons were not observed. This was because practical lessons in Singapore, which focus on standard experimental procedures and analysis, are normally carried out in isolation from non-practical lessons. The videos were recorded with one primary camera at the back of the classroom focusing on the teacher and a secondary camera used at times to record the group interactions among students. Two research assistants were involved in the data collection process.

Secondary data source for this study consists of student artefacts and teacher interviews. Every student's completed worksheets were collected at the end of each lesson, and they were used to support the analysis of the classroom videos when the students looked at their worksheets. Teacher interviews were conducted informally through frequent meetings and discussions between the teachers and the research team. At the end of the study, a stimulated video-recall interview was conducted with the purpose of doing member checking on the validity of the research findings.

Data analytical methods and procedures

Data analysis was carried out in three distinct phases: (a) segmentation, (b) coding, and (c) case interpretation. A video qualitative analysis software called *Transana* was used to facilitate the viewing, transcription, and coding process.

First, the continuous sequences in a lesson video were exhaustively segmented into meaningful discrete units according to Erickson's (1992) ethnographic microanalysis methods. Each segment was determined by clear boundaries demarcating prominent shifts occurring in the classroom, such as a discernible change in topic of discussion, participants' interaction pattern or type of representations they were oriented to. The average duration of a segment was 3 minutes and 14 seconds. The shortest segment observed was 23 seconds while the longest was 7 minutes and 41 seconds. Short segments were frequently brief teachers' instructions while long segments tended to revolve around student group discussions.

Next, each segment was then coded according to Mortimer and Scott's (2003) framework of communicative approach and Bruner's (1966) modes of representation. For communicative approach, a segment was coded interactive–dialogic (I–D), interactive–authoritative (I–A), non-interactive–authoritative (NI–A), or non-interactive–dialogic (NI–D). In most cases, an interactive segment was characterised by a triadic exchange structure led by the teacher (e.g. IRE) or student discussions in pairs or groups. On the other hand, a non-interactive segment was typically seen from a long monologue given by a teacher, usually instructions for an activity or summary of key points learned from a previous activity. As for the dialogic–authoritative dimension, a dialogic segment was typically observed when the teacher elicited and discussed the ideas from the students while an authoritative segment was characterised by the teacher elaborating on the 'scientific story' and rejecting students' ideas that deviated from the acceptable range of answers. A dialogic segment could also be seen during group discussions when students exchanged ideas among themselves without any particular student dominating the conversation. Two analysts (the author and a research assistant) were involved in the coding of the communicative approach. The inter-rater reliability score between them (by percentage of agreement) was 81.8%.

For the coding of representation, a segment was coded enactive, iconic, or symbolic depending on the *dominant* type of representations used during the segment. It is important to acknowledge that multiple representations are often juxtaposed and used simultaneously at any moment (e.g. talking with visuals projected on a screen, pointing at or gesturing over different parts of a diagram). To resolve this issue, I identified what Goodwin (2000) calls the 'contextual configuration of physical representations' that participants orient to in order to frame, make visible, and constitute the actions of the moment in their ongoing interactions. Thus, the representation in which the teacher and students orient themselves towards most of the time in the segment would be coded as the *dominant* representation. For instance, when the teacher drew the diagram shown in Figure 1 and used it to mediate an IRE discussion with the students, the mode of representation was coded as iconic. The same analysts were involved in this coding and the inter-rater reliability score was 90.9%.

Figure 2 shows a sample of video segments from a lesson by John with their corresponding video timestamp and duration. The codes for communicative approach and mode of representation for every segment are also shown. Segments that support the key findings to be presented in the next section are shaded in yellow, while segments that are boxed will be further illustrated in this paper.

The final phase of analysis was the development of the analytical cases where the unitary character of each case was examined. Each case was bounded from the beginning to the end of a lesson topic, which usually lasted for one to two lessons. This process involved analysing key segments in greater detail and paying attention to the participants' meaning making as well as the moment-by-moment interactions among them. The relationship between representations and communicative approaches, which emerged during the earlier coding phase, was also interpreted in light of the unfolding meaning making and interaction analysed at this phase.

Findings

From the analysis, it was found that there was a recurring pattern in the shift of representations in conjunction with the shift in communicative approaches. In general, as the stage of representation moved from enactive to iconic to symbolic, there was a concurrent and coordinated shift in the communicative approach from interactive–dialogic to interactive–authoritative to non-interactive–authoritative. Furthermore, the shift from enactive to iconic to symbolic representations occurred mainly within the interactive–dialogic approach while the shift towards the interactive–authoritative and non-interactive–authoritative approaches occurred when symbolic modes of representation were used. This concurrent and coordinated shift is illustrated visually in Figure 3.

To illustrate this concurrent and coordinated shift in greater detail, two analytical cases from the data (one lesson from each teacher) will be presented in next two sections. These cases, provided as exemplars, were representative of seven other cases observed in John's and Derrick's lessons that support the above-mentioned trend of the concurrent shift. As mentioned earlier, the selection and presentation of these

Time stamp	Duration (hr:m:s)	Description of Segment	Comm	Rep
0:41:46	0:01:36	Teacher gave the context for scenario 1a and asked the students to discuss: what will happen when 2 skaters of the same mass push each other?	NI-D	Enactive
0:43:22	0:05:38	Students discussed and predicted the outcome for scenario 1a in pairs	I-D	Enactive
0:49:00	0:02:11	Two students demonstrated scenario 1a by pushing each other as each of them stood on a skateboard.	I-D	Enactive
0:51:11	0:01:05	Teacher gave instruction for the students to represent their observations on a diagram	NI-D	Iconic
0:52:16	0:00:49	Students drew the diagram on the given worksheet	I-D	Iconic
0:53:05	0:01:40	Students wrote an explanation of the observed outcome for scenario 1a	I-D	Symbolic
0:54:44	0:00:54	Students shared their explanation with a partner	I-D	Symbolic
0:55:39	0:00:52	Teacher introduced a model for the students to explain their answer	NI-A	Symbolic
0:56:31	0:04:41	Students revised and continued to work on their written explanation	I-D	Symbolic
1:01:12	0:00:52	Teacher gave the context for scenario 1b and asked students to discuss - What will happen when one skater pushes the other skater of the same mass?	NI-D	Enactive
1:02:04	0:04:25	Students discussed and predicted the outcome for scenario 1b in pairs	I-D	Enactive
1:06:29	0:01:10	Two students demonstrated scenario 1a with one student pushing the other as each of them stood on a skateboard	I-D	Enactive
1:07:39	0:00:36	Teacher gave instruction to fill in the activity sheet and write explanation for scenario 1b	NI-D	Iconic
1:08:15	0:06:45	Students wrote explanation of the observed outcome for scenario 1b	I-D	Symbolic
[Repetition of segments for scenario 1b and scenario 2. Truncated for presentation purpose]				
1:28:05	0:04:31	Teacher gathered the responses from students and rephrased them on the board	I-A	Symbolic
1:32:36	0:03:46	Teacher led discussion towards Newton's 3rd law	I-A	Symbolic
1:36:22	0:01:42	Teacher introduced Newton's third law and wrote it on the board	NI-A	Symbolic
1:38:04	0:01:36	Teacher modelled how to construct the explanation using the explanation model	NI-A	Symbolic

Figure 2. Sample of video segments and their corresponding codes from a lesson by John.

two cases were to exemplify the details of how the shifts in representations and communicative approaches came about. The generalisability of these cases, both within John's and Derrick's lessons as well as across science teachers in general, will be further discussed at the end of this paper.

John's lesson on Newton's third law of motion

In this 1.5-hour lesson, John wanted the students to learn about Newton's third law of motion through a series of demonstrations and discussions. He presented these demonstrations as three 'scenarios' consisting of two objects interacting with each other.

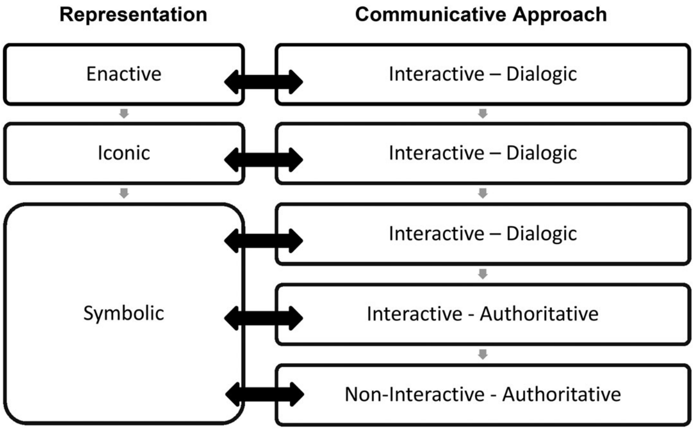

Figure 3. Key finding: concurrent and coordinated shift between representation and communicative approach.

Interactive–dialogic, enactive to iconic

In the first scenario (called scenario 1a in the lesson), there were two skaters of the same mass pushing against each other with their arms. Using a Predict–Explain–Observe–Explain (PEOE) instructional strategy (White & Gunstone, 1992), John asked the class to predict and explain what would happen to the skaters. The students then discussed their predictions with a partner. Some of their responses discernible from the video recording were: '*Nothing happens*', '*There will be no motion*', and '*They will fall down*'. Although it was clear that John heard these responses and knew they were incorrect, he chose not to correct their predictions at this point.

After about five minutes, John nominated two boys to perform the demonstration in front of the class. As the two boys pushed each other while standing on a skateboard (see Figure 4), John asked the class to observe what happened. The following excerpt shows three segments after the PEOE instruction. (See Figure 2 for the positon of these segments with respect to the lesson sequence.) The first segment (5 min 38 s) was the think-pair-share discussion among the students on their prediction and initial explanation. The second segment (2 min 11 s) was the enactment of the demonstration, and line 1 occurred near the end of the demonstration. The third segment (1 min 5 s) was John's instruction for the students to write and draw their observations on a given worksheet, as shown from line 8 to 16. (The boys' movement to their seats in line 7 marks the boundary of the last two segments.)

Segment 1 (5 min 38 s)	I–D	Enactive
(Students doing think-pair-share discussion)		
Segment 2 (2 min 11 s)	I–D	Enactive

(John began the demonstration ...)
1 John: Let's do that again.
2 John: Okay, so. Ah, hands. Two hands. Palm facing and then a light push to one another.
3 *(Both boys pushed each other and they gently moved backwards)*
4 John: So. What did you observe? Yah, this is just what I want to see. So, what did we observe?
5 Azman: They moved backwards
6 John: Okay, so both simply moved backwards right?
7 *(Both boys returned to their seats)*

Segment 3 (1 min 05 s) NI–D Iconic

8 John: Can you go and. Okay, after you have observed, turned to the next page. Draw a labelled diagram to illustrate your observation.
9 Hui Ling: Stick diagram?
10 John: Yah, a stick diagram will do. For example, you could actually even draw this.
11 *(12 seconds pause as John drew a stick diagram on the worksheet which was projected on the screen.)*
12 John: And then, uh.. Depending on how you want to draw. You might want to include your forces. Because. Since they are moving, so could there be any force in place? Where are the forces acting on? So. So these are the things you can think of and include in your diagram.
13 John: Alright? So you will just need to complete, draw a labelled diagram and explain your observation.
14 John: Alright, you need to explain your observation. What happen? Describe what happen. And, why did it happen? What happen and why did it happen?
15 *(John walked around the classroom. 20 seconds later)*
16 John: On your own, draw a labelled diagram. On your own, describe what happen and why did it happen.

For the first two segments (from beginning to line 7), the communicative approach was interactive–dialogic. They were interactive due to the student–student interactions during the pair discussion and the teacher–students interaction during the demonstration. They were also dialogic because of several ideas that were put forward by the students during the pair discussion. Notably, these ideas were not rejected by John even though many were incorrect (e.g. ‘nothing happens’, ‘they will fall down’).

For the last segment (lines 8–16), the communicative approach was non-interactive–dialogic. The last segment continued to be dialogic because John accepted various non-scientific ways of drawing the motion. This was most notable in line 9 when a student asked whether she could use ‘stick diagrams’ and John was open to the idea. His openness can also be seen from several low modal auxiliary and phrasal verbs (Halliday, 1994), he used to suggest alternative ways of drawing, as such ‘You *could* actually even draw this’ (line 10), ‘*Depending on* how you want to draw’ (line 12), and ‘You *might* want to include’ (line 12). On line 16, John asked the students to draw and explain ‘on your own’. As observed in John’s other lessons, he often reminded his students to come up with their own answers before he would discuss the physics explanation with them. He would also assure them that it was alright to make mistakes at this point. Thus, this further supports the dialogic nature of this segment. Finally, although this segment was dialogic, it was non-interactive because, apart from a brief student’s question in line 9, the rest of the segment was a one-minute monologue of the teacher’s instruction for the next activity (lines 10–16).

On the whole, the nine-minute part of the lesson shown here was interactive–dialogic, with a short segment of non-interaction in the last minute from lines 10 to 16. These brief non-interactive moments were observed to be frequently interspersed between interactive segments in John’s lesson (see Figure 2), and they tended to serve two functions. First, they tended to mark an important transition point from one activity to another as the teacher gave instructions for what to do next (e.g. demonstration to writing). Second, they served as ‘ad hoc interruptions’ to group discussions when the teacher felt the need to clarify or add further instructions to the current task. In either case, these non-interactive moments were often brief and lasted around a minute or less, as opposed to other non-interactive segments (e.g. lecture, lesson

Figure 4. A demonstration of scenario 1a in John's lesson.

summary) observed in the lessons that often lasted longer. The nature of these segments, which do not support the key finding presented in Figure 3, will be further discussed in the limitation section.

In terms of the mode of representation, the dominant mode during the first two segments was enactive (action based). This started at the beginning when the students were asked to predict the outcome of the skaters. During the group discussion, bodily movement were commonly seen as the students' utterances were frequently accompanied by gestural action of their hands pushing forward. This indicated that the students were trying to imagine what would happen if they themselves were the skaters. Given that many students might have ridden a skateboard, skate scooter or some other similar vehicles, it is possible that they were also trying to relate to their prior experiences as they tried to predict the outcome. As the students' own bodies were used as the physical objects where they oriented their thoughts and actions towards, this is seen as an enactive mode of representation. In the second segment (lines 1–7) when the scenario was demonstrated by the two boys on skateboards, their bodily actions and subsequent movement observed by the class was also a form of enactive mode that mediated the students' thinking at this stage.

In the third segment (lines 8–16), after the demonstration was over, the mode of representation began to transit towards the iconic (image based) mode of representation. This began in line 8 when John asked the students to 'draw a labelled diagram' of what they observed. From the student artefacts collected, every student drew a 'stick diagram' on their worksheets. An example of a student's worksheet is shown in Figure 5. Interestingly, this student included the facial expression of what she imagined the skaters were feeling. These stick diagrams are iconic representations because they have a close resemblance to the two skaters as observed by the students.

Interactive–dialogic, iconic to symbolic

Immediately after the instruction to 'draw a labelled diagram', John continued the instruction for the students to 'explain your observation' (line 14) and 'describe what happen and why did it happen' (lines 14 and 16). This continued into the next three segments (3 min 23 s in total):

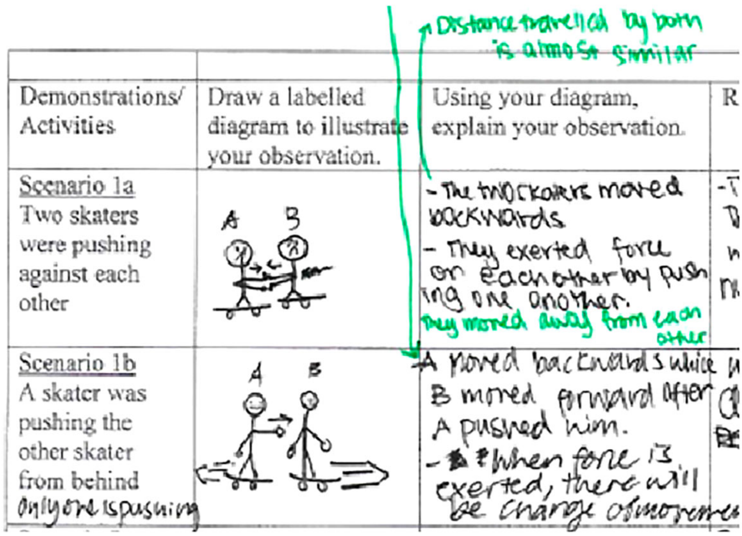

Figure 5. A student's drawing and writing on a worksheet.

Segment 4 (0 min 49 s) I–D Iconic

17 *Students began on the worksheet while John walked around. Some discussion among students took place. Most students started by drawing on the worksheet)*

Segment 5 (1 min 40 s) I–D Symbolic

18 (A pair of students began writing the explanation)

Segment 6 (0 min 54 s) I–D Symbolic

19 John: Once you are done with your answers and then perhaps you might want to revise your explanation if you want to. You can choose to revise your explanation.

20 (Students discussed their written observations and explanations)

In this segment, the mode of representation transited towards a symbolic mode of representation as the students were required to 'describe what happen and why did it happen' in their own words on paper. Effectively, they had to re-represent or transform their observations from the enactive mode and the diagrams from the iconic mode into written language in the symbolic mode. This segment is interactive because many students were interacting with their partners in various ways. For example, a pair of students was chattering about what to write in the worksheet. A few students were observed to be looking at their peers' written explanation, presumably to get some ideas of what to write or check whether their answers were consistent. In this case, we see that written language functioned as the dominant mode of representation that mediated the participants' interaction; that is according to Goodwin (2000), the students' talk and actions centred around and were made possible through their written responses.

Lastly, this segment continued to be dialogic because the students' ideas were still bouncing around and the teacher had not yet introduced the accepted scientific idea into the discussion. In fact, after the students had discussed their written responses, John noted that some of them were quite confused about the 'correct' answer. Nevertheless, he assured the students that 'it's okay' at this point and they should move on to the next scenario, as shown in the following:

21 John: Okay. I know some of you are like quite confused with what you should write here, but it's okay. We just move on first.

Immediately after this, John introduced the next scenario (scenario 1b):

22 John: Okay, just now right, both of them were pushing against one another. So that's why you all will predict that they will move backwards and probably your observation is correct.

23 John: What will happen then if only one of the skaters is pushing? So, can you go and discuss with your partner now what do you think will happen when only one skater is pushing.

From here onwards, the teaching sequence in addition to the communicative approach and mode of representation repeated the same cycle which we have seen earlier, first for scenario 1b and subsequently for scenario 2, which involved two spring balances pulling each other in opposite direction. At the beginning of each scenario, a PEOE instructional approach was again introduced, followed by the same skater demonstration for scenario 1b and a group hands-on experiment for scenario 2. As illustrated earlier, these segments were mainly interactive–dialogic and dominated by an enactive mode of representation. After the demonstration (for scenario 1b) and experiment (for scenario 2), the students were asked to draw their observations, thus transiting to an iconic mode of representation. Finally, in every scenario, the students wrote a revised explanation for their observation, which was dominated by a symbolic language-based mode of representation. In total, this cycle repeated three times (for scenarios 1a, 1b, and 2) for about 46 minutes.

Interactive–dialogic to interactive–authoritative, symbolic

After all the three scenarios had been demonstrated and discussed, John then moved on to a class discussion to help the students make connections across all the three scenarios. According to his lesson plan, this was where the scientific knowledge of Newton's third law of motion will be introduced.

To elicit the observations from the students, John drew a table on the whiteboard with three columns, each with the heading of 'Scenario', 'Observation' and 'Explanation' (see Figure 6). John used the table to write down the students' observations during the discussion, as shown in the following:

Segment 19 (4 min 31 s)

24 John: For scenario 1a, we were talking about 2 skaters pushing against each other. So we saw Zack and Sim Ho pushing one another. Applying the force on one another. So what did we observe over here? Sorry, you were saying?	I–A	Symbolic
25 Priya: move away from each other		
26 John: They both move away from each other. They moved away from each other (*wrote 'They moved away from each other' on the board).*		
27 John: Any other observation that you all made?		
28 Ping Loong: Both then move back.		
29 John: Both move back, backwards. They move away from each other.		
30 John: Sorry?		
31 Ming Loo: At the same speed… (inaudible)		
32 John: At the same speed? *(moved towards the board but didn't write down the response)*		
33 Hui Ling: Hard to tell		
34 John: I think. I think just now Susan made a good observation that actually the distance travelled by both are almost similar (*wrote 'Distance travelled by both are similar)'.*		
35 John: And then when we move on to 1b *(wrote '1b)'*, where only Sim Ho is pushing Zack. When Sim Ho is pushing Zack right, what is the observation?		
36 Azman: Both of them moved backwards		
37 John: Again they move away from each other. Move away from each other. *(wrote 'moved away from each other)'*		
38 John: Anything else?		
39 Samantha: Distance almost the same		
40 John: Distance travelled also almost the same. *(wrote 'Distance travelled about the same')*		

Similar to the last segment (lines 19 and 20) we saw earlier, this segment was dominated by a symbolic language-based mode of representation as the teacher and students oriented themselves towards the written texts on the whiteboard (including the table that provided the organisation of the written words) in their interactions. As the teacher was writing the responses, it was also observed that almost every student took notes in their notebooks.

In terms of the communicative approach, a shift towards interactive–authoritative was beginning to occur. At the beginning, John's elicitation of the students' responses seems to suggest a dialogic interaction was taking place. However, a closer examination revealed that, unlike the earlier segments, he was narrowing the discussion towards a range of acceptable answers. This can be seen from the way he chose to write the students' responses on the board. When the responses were in line with the 'scientific story', these were written on the board (e.g. lines 26, 34, 37, and 40). A telling moment occurred in line 31 when a student stated that the skaters moved away 'at the same speed'. Although John did not explicitly reject that response, his repetition of the student's response in a rising intonation (line 32) suggested a question rather than an acknowledgement. More importantly, that response was not written on the board because it was not deemed to be correct. Instead, John changed the topic by relating to a valid point about distance mentioned earlier by Susan in line 34. Thus, it was apparent that he was steering the conversation towards a point of view.

Besides narrowing the students' responses, another important indicator of authoritative talk is also the use of scientific words and language. This can be seen immediately after the last excerpt, as shown here:

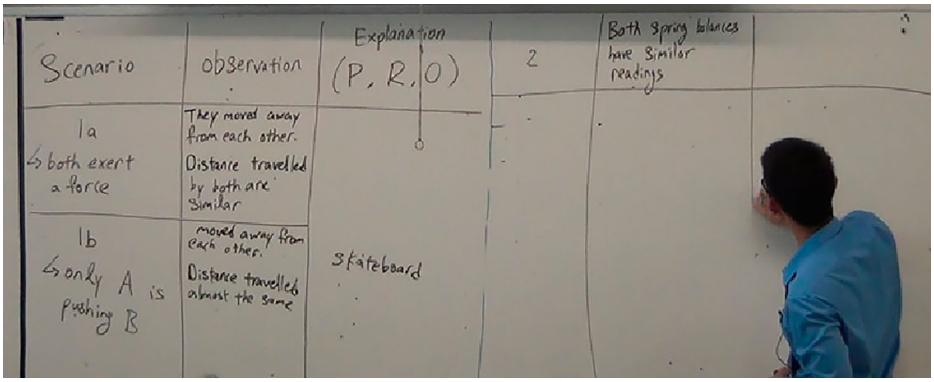

Figure 6. Consolidation of students' responses on a whiteboard.

Segment 20 (3 min 46 s)

41 John: But, isn't it weird? Because, in this case, both exert a force each (wrote down 'both exert a force' under 1a). But in this case right, only A is pushing B. (wrote 'only A is pushing B' under 1b)
42 John: So how come B also start to move?
43 Hui Ling: Skateboard
44 John: Because of the skateboard, so there is something to do with the skateboard. *(wrote 'skateboard')* Right and then I think our most telling. Something that give us a lot more idea is when we have the numbers in place. When we play with our spring balance. And then we look at scenario 2. Scenario 2 when our spring balance was pulled. One exert a force, one exert a force. Or 2 of you used different forces. What do you all observe about the reading?
45 Class: (in chorus) Same
46 John: Same. So both spring balances have similar readings. *(wrote 'both spring balance have similar readings)'*
47 John: When there are 2 spring balance and all the spring balance register the same reading. What are they trying to suggest, what does this suggest to us?
48 Hui Ling: same amount of forces
49 Seow Boon: both are (inaudible)
50 Tim: same (inaudible)
51 John: What is the word that we used in chapter one ah? When we say that there is a same amount of force
52 Seow Boon: Huh?
53 Hui Ling: Equilibrium
54 John: No, no, no, in chapter 1. Same amount of force, numerical value
55 Ping Loong: Magnitude
56 John: Same magnitude *(pointed to the student)*. So both forces are of the same magnitude. But what about their direction then? I–A Symbolic

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In this excerpt, we can see that John elicited from the students that the forces on both spring balances (as indicated by readings on the scale) were the same (lines 44–50). At line 51, a typical indicator of authoritative talk was observed as he got the students to recall a specific word to describe the same amount of force. When a student gave the wrong answer in line 53, he corrected that and gave further clues about the word; until someone uttered the correct answer in line 55. Thus, lines 47–56 is a good example of the IRE exchange structure typical in an interactive–authoritative talk.

Thus far, we have seen that the interactive–authoritative talk occurred together with the use of a language-based mode of representation. In what follows, I will show that an interactive–authoritative talk could also occur with other symbolic modes of representation, such as schematic diagrams and symbols. The following excerpt occurred about 3 minutes after line 56:

Segment 20 (3 min 46 s)			
57	John: Ah, the opposite force acting on it. That means. So when the black colour guy pushes on the blue colour guy, he will exert this black colour force onto him. *(Drew an arrow to the right with black marker).*	I–A	Symbolic
58	John: And what will the blue colour guy do onto him? He will exert an?		
59	Samantha: Blue colour force		
60	John: Opposite, yah, blue colour force acting backwards like this. *(Drew an arrow to the left and the symbol F_{BA} with blue marker)*		
61	John: Okay, so I write this F-AB (pointed to symbol F_{AB}) is because the force comes from A acting on B. And from this one, because the moment they have contact like what you have observed or you have seen, there will an equal and opposite reaction force (pointed to symbol F_{BA}) that is from B onto?		
62	Samantha: A		
63	John: A. So they are acting on different body. One force is on B, one force is on A. Then how do we craft this explanation then. What you have observed here is actually this law called?		
64	Kris: Newton's third law		
65	John: Newton's third law of motion. Some of you have already read the textbook. So Newton's third law of motion states this.		
Segment 21 (1 min 42 s)			
66	(John recited Newton's Third Law of Motion and wrote it on the board; See Figure 7)	NI–A	Symbolic

In this segment, the teacher led the discussion further into an explanation of why both skaters in scenario 1b moved backwards, even though only one skater was pushing. Again, while the communicative approach was interactive, it was also authoritative as John was mostly eliciting a specific range of acceptable answers from the students, as seen from his questioning in lines 58, 61, and 63. His authoritative stance here was also evident from the introduction of physics-specific terms and phrases such as 'equal and opposite' (line 61), 'force from A acting on B' (line 61), and 'Newton's third law' (lines 64 and 65).

In terms of the mode of representation, besides written language, other modes were equally important in this segment. In lines 57 and 60, John drew symbolic arrows to represent the forces acting on A and B according to the conventions of a free-body diagram – although he was superimposing these arrows on the iconic 'stick diagram' that was drawn earlier. Symbols like F_{AB} and F_{BA} were used to mediate the interactive–authoritative talk. Finally, at the end of this segment, John summarised the discussion and wrote a formal statement of Newton's third law of motion on the board (see Figure 7). As such, three different symbolic modes of representations were used to mediate the interactive–authoritative talk in this segment: written language, symbols and schematic-conventional diagrams.

Derrick's lesson on waves

In this section, I will illustrate the concurrent and coordinated shift between representation and classroom discourse from another teacher, Derrick. In this one-hour lesson on waves, the instructional objective was for the students to describe the movement of particles and the transfer of energy in a transverse wave motion. In particular, the students

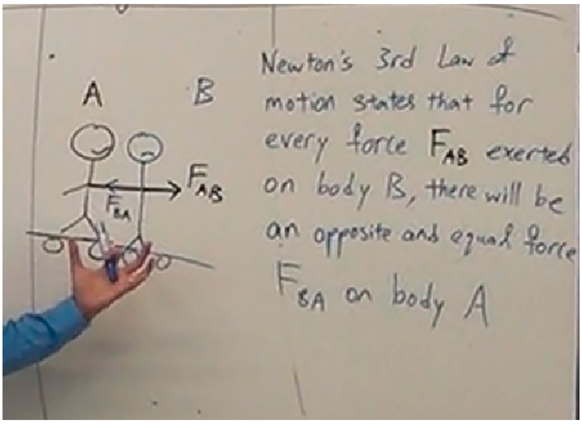

Figure 7. Symbolic diagram and wordings in the second segment.

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. In this example, I will only briefly narrate the key segments and the important shifts that occurred in the communicative approach and mode of representation cycle. Figure 8 shows the video segments with the corresponding communicative approach and mode of representation for this lesson

Interactive–dialogic, enactive to symbolic

Derrick began the lesson with a 'rope activity' designed to help the students observe and later describe a wave motion. In the segment shown below, Derrick gave the following instruction on what the students needed to do in this activity:

Segment 1 (2 min 29 s)

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.		
2	Derrick: 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.	NI–D	Enactive

Derrick's instruction alluded to the modes of representation that would subsequently dominate the rope activity in the next segment for 2 minutes and 53 seconds. First, he asked the students to carry out a hands-on activity in pairs using a rope. The aim of this activity was to generate a physical wave motion, thus providing the enactive mode of representation for the students to, in the words of Derrick, 'observe' and 'feel' the wave motion. Subsequently, the students would then transform their sensory and kinesthetic experiences from the enactive mode of representation into diagrams and written language in a given worksheet; according to Derrick's instruction to 'describe' and 'draw'. Finally, the students would then 'move on to the discussion' where Derrick would gather their preliminary ideas about wave motion.

In terms of the type of talk, Derrick's instruction for the group discussion (line 2) was telling. He specifically informed the students that he would only be 'gathering [their]

Time stamp	Duration (hr:m:s)	Segment	Comm	Rep
0:06:20	0:02:29	Teacher gave instruction and demonstrated the rope activity	NI-D	Enactive
0:08:49	0:02:53	Students carried out the rope activity in pair	I-D	Enactive
0:11:43	0:04:28	Students drew the diagram and indicated the direction of wave	I-D	Iconic
0:16:11	0:05:18	Students discussed the observations and wrote the description of the wave motion	I-D	Symbolic
0:21:29	0:04:32	Teacher read out some the students' responses and gave his comments	I-D	Symbolic
0:26:01	0:07:41	Students continued their discussion for the 2nd question	I-D	Symbolic
0:33:42	0:03:11	Teacher read out some the students' responses and gave comments	I-D	Symbolic
0:36:53	0:01:54	Teacher played an educational video that shows a floating ball on a wave and narrates the motion of the wave. Teacher paused the video and gave instruction.	NI-A	Enactive
0:38:47	0:02:24	Students discussed and continued the 2nd question on the worksheet	I-D	Symbolic
0:41:11	0:06:34	Teacher gathered the responses from the students to build up the scientific explanation	I-A	Symbolic
0:47:45	0:01:31	Teacher summarized the discussion and related it back to the rope activity	NI-A	Symbolic

Figure 8. Video segments and corresponding codes from a lesson by Derrick.

feedback and views' and he 'won't be clarifying'. By saying he would 'help to consolidate first', he was signalling his intention to gather the students' ideas before he clarified the 'scientific answer'. In a later interview with Derrick, we learned that he often had to repeat such instructions because the students tended to rely on him to provide the accepted answer and thus would not participate in the discussion. Thus, to foster their independence in coming out with their own ideas, he had to state his stance at the beginning.

After Derrick's instruction, the students proceeded to carry out the rope activity, drew what they observed at various stages of the wave motion, and described in written words the observed wave motion. Interactive–dialogic talks between pairs of students ensued during the group discussion. In total, the group activity and discussion took about 12 minutes over three segments (see Figure 8). When most students had completed the written description, Derrick picked a few students' work and showed them to the class using a visualiser (document camera). In accordance with his earlier instruction to 'consolidate first', he used a dialogic approach to elicit and discuss the students' views. An example is shown here:

Segment 5 (4 min 32 s) I–D Symbolic

3 Derrick: I show a few samples of what your classmates have written. You can comment okay about what they wrote, or you want to clarify, then you can also do that. But we are not talking about any answers yet.

4 *(Teachers shows Amelia and Cheryl's work using a visualiser. Students read what was projected on the screen)*

5 Derrick: This one says no vibration, no movement, movement of life side wave pass onto the other end. Each colour alternate up down until it reaches the right side. So the arrows … Are the arrows indicating, errmm. waves or the point A and B?

In the above excerpt, it is important to point out that although the students were quiet, this segment was considered interactive–dialogic because the teacher was interacting with the students' voices through their written words. This occurred in line 4 when the class was reading Amelia and Cheryl's writing on the screen. The teacher also 'projected' the students' voices (Halliday, 1994) when he mentioned '*this one* says … .' in line 5. Thus, for a multimodal analysis, dialogic and interactive talk is not confined solely through an auditory talking-listening mode, but can be mediated via a visual writing–reading mode as well. In this case, the students' writing also functioned as a symbolic mode of representation.

Interactive–dialogic to interactive–authoritative, symbolic

Towards the end of the lesson, Derrick consolidated the discussion on the difference between the individual wave particle movement and the overall wave motion. Similar to the earlier segment shown (lines 3–5), Derrick's strategy was to wait for the students to complete their written responses before asking a few students. However, unlike the earlier segment where he used a visualiser, this time he called the students to give their answers to the class. As most students were looking at their worksheets and writing notes or revising their written answers during the discussion, the dominant representation which the participants was oriented to was symbolic written language. Although there was some gesturing during the discussion (e.g. lines 11–14, see segment 10), this only occurred in a small part of the segment. Furthermore, they did not play a crucial role in mediating the thinking process compared to the written worksheets; unlike the earlier segments 1 and 2 where the gesturing and bodily movement during the skater demonstration was the dominant representation that the students were oriented towards. As such, the dominant representation in this segment was symbolic rather than enactive.

As for the communicative approach, the discussion shifted towards an authoritative mode when Derrick began to shape the students' responses towards the scientific answer. One telling example where this shift occurred can be seen in this particular exchange between Derrick and Amanda:

Segment 10 (6 min 34 s)

6 Derrick: If you compare the direction of particle with direction of the wave, ah, what can you say about these two? I–A Symbolic
7 Amanda: *(softly)* They are moving the same
8 Derrick: They are moving?
9 Amanda: Same direction
10 Derrick: They are moving the same direction? So you are saying that the particle is moving which direction?
11 Derrick: Which way? *(finger vibrating sideway)*
12 Amanda: *(holding a pen and vibrating it sideway)*
13 Derrick: This way? *(finger moving up and down)*
14 Amanda: *(moving pen up and down)*
15 Derrick: Up, down?
16 Amanda: Nob her head
17 Derrick: The wave is?
18 Amanda: *(moving pen up and down)*
19 Derrick: From right to left? Is it going back?
20 Amanda: Shakes her head
21 Derrick: No ah. So are they the same?
22 Class: *(in chorus)* No
23 Derrick: No ah. Okay?

In the above excerpt, it was apparent that Derrick was channelling the discussion towards the expected answer that the movement of the particle and the wave are not the same. Amanda was initially not sure about the answer, which explained the softness of her response in line 7. Derrick's evaluation of her response in line 10 was telling. First, his repetition of Amanda's response in a rising intonation hinted that this was not the answer he was looking for. Next, he proceeded to question Amanda what was the direction of the particle in line 10 and followed by the direction of the wave in line 17. From lines 11 to 16, it was also visible that Derrick, instead of hearing Amanda out, led her to agree with him that the wave particle is moving up and down. Then in line 17 when Derrick asked Amanda what is the direction of the wave motion, Amanda's gesturing motion again indicates her confusion. However, in line 19, Derrick ignored her gesturing and led her to agree that the wave motion is moving horizontally in one direction. Through this discussion, Derrick then led the class to conclude that both movements are not the same (lines 21–23). This is a very typical example of an interactive–authoritative talk carried out by Derrick during the consolidation stage of the lesson unit.

In sum, these segments show how the teaching sequence in Derrick's lesson, similar to John's, also follows a similar pattern in the shift of representation from enactive to iconic to symbolic within an interactive–dialogic communicative approach, and subsequently a shift towards an interactive–authoritative approach using symbolic modes of representation.

Limitations and discussion of findings

There are several limitations in this exploratory study. First, the concurrent shift in communicative approach and representation presented in Figure 3 is only a general trend. Due to the complexity of classroom teaching and the contingency of human interaction, we should not expect all the segments to fit so neatly into the identified pattern. In my analysis, I have shown several segments (see unshaded portion in Figures 2 and 8) that do not conform to the general pattern, such as the frequent but brief non-interactive–authoritative moments when the teacher needed to give instructions or interrupt the student discussions when things went astray. Thus, there is a certain level of generalisation required in order to identify the general trend within a teaching sequence.

Second, the concurrent and coordinated shift observed in this study cannot be generalised to every lesson conducted by science teachers. Although the shift was observed in many of John's and Derrick's lessons other than the two exemplars shown in this paper, we should not expect the same pattern to be observed in every lesson. Whether the shift may occur will depend on the instructional goals of the lessons and the nature of the topic. For instance, some topics in science provide more opportunities for the use of enactive and iconic modes of representations. Moreover, various teachers adopt different pedagogical approaches in their teaching. Future similar studies with more teachers can be carried out to (a) test whether a similar shift may occur in other classrooms and (b) examine how teachers' background (years of experiences, teaching preferences etc.) might influence the relationship between representations and communication modes.

As an exploratory study, this study focused the analysis on the physics teachers. As mentioned earlier, the focus on the physics teachers was due to preliminary observations from an earlier study. Although the same trend was not prominently observed among the chemistry teachers, it could be that a different pattern or sequence may emerge from a more thorough analysis of the chemistry teachers in the study. It would be interesting to find out whether disciplinary differences across the natural sciences would influence the combination of communicative approaches and modes of representation. More research is thus needed to expand this work into chemistry, biology and earth science. Finally, although this study reveals a pattern in the interplay between the use of representations and classroom discourse, it does not explain why this pattern occurred. To provide an explanatory account of why the pattern shifted in the way described in the two analytical cases would require another study of a different methodology. In particular, it would require a more detailed micro-discursive analysis at a shorter timescale of the participants' multimodal actions in conjunction with the semiotic affordances of the representations that were used (e.g. see Tang et al., 2014).

Nevertheless, based on the analytical cases presented in this study, we can speculate some reasons why the shift occurred the way it was described here. In particular, the nature of the concurrent and coordinated shift raises two puzzling questions. First, why did the shift from an enactive to iconic and symbolic occurred mainly during the interactive–dialogic communicative mode? Second, why did the shift from an interactive–dialogic to interactive–authoritative and non-interactive–authoritative mode occur mainly when a symbolic mode of representation was used?

For the first question, there are two possible reasons why the shift in representation modes occurred mainly during the interactive–dialogic approach. One reason is because enactive and iconic representations (e.g. gestures, objects, sketches) are semiotic tools which the students are more familiar with, and this explains why they were readily used to elicit the students' ideas during the early stages of the lesson. Conversely, another reason would be that enactive and iconic representations are not suitable to be used for an authoritative way of communicating scientific ideas. This is because the discourse and ideology of science tend to favour a more abstract form of language and representation (Lemke, 1990). Either way, both reasons imply that enactive and iconic representations are predominantly used in a dialogic manner to engage with the students' initial ideas. They also suggest that the shift of representation from enactive to iconic and symbolic would serve as a form of scaffolding to prepare the subsequent class discussion for an authoritative communicative mode, as Bruner (1966) had theorised.

For the second question, a likely reason why the shift towards an authoritative approach occurred mainly with the symbolic mode of representation is due to the flexibility of language that mediated the transition. As we have seen in both analytical cases, the transition from dialogic to authoritative was mediated with written language that was either written on the board for John's case or on the students' worksheets for Derrick's case. At the same time, every communicative approach is mediated predominantly by spoken language. Thus, the interplay between the spoken and written language used in classroom discourse, in addition to the transition from enactive and iconic representations to written language, could be the key to understand how the process occurred. If this so, the unique role of written language would warrant further investigation and future studies could be carried out to validate these conjectures.

Implications and conclusion

From this exploratory study, the key finding of the concurrent and coordinated shift provides a useful way of thinking about how the use of the representations relates to the co-occurring classroom discourse. For many years, research in classroom talk and the role of representation has tended to focus on each of them in isolation. Although there have been several studies (e.g. Givry & Roth, 2006; Tang et al., 2011) that examined the role of representations in classroom talk within a micro-analytical timeframe (seconds to minutes), few have systematically investigated their relationship throughout the teaching sequence of numerous lessons (in hours). In this respect, this study found empirically a direct and explicit connection between them in the form of a concurrent shift as the teaching sequence unfolded. The findings from this study therefore emphasise the importance of considering the role of representation and its transformation process within the context of the classroom communicative approach (e.g. dialogic or authoritative), and conversely, how the shift from one communicative approach to another is mediated through the use of representations. Linking these two crucial aspects of classroom interaction can potentially help to synthesise research findings from the two research areas towards a broader theoretical framework of language and representation use in classroom discourse.

In addition, this paper offers a methodological approach to investigate the interplay between the use of representations and classroom discourse. The video methodology in this study relies on segmenting a lesson video exhaustively and coding each segment as the basic unit of analysis. This methodology is not commonly used in science education but has been found to be very useful in systematically and comprehensively documenting the constant shifts occurring in classroom interaction. The coding process by individual segments also enables transparency and allows inter-rater reliability and member checking to be carried out. In my study, I have chosen to use Mortimer and Scott's (2003) and Bruner's (1966) framework for the coding scheme. This methodological choice is based on my theoretical stance from a Vygotskian perspective. However, it is possible to use other frameworks or typologies of classroom discourse and representations in the coding scheme based on the same methodological approach. In fact, it is even desirable to do so in order to complement the same study from multiple theoretical perspectives.

Although the findings in this study cannot be generalised to every science lesson, I argue that the concurrent and coordinated shift between representations and classroom discourse is a sound pedagogical principle for science teachers to follow, especially when the use of multiple representations is prevalent in a particular topic. This is because the shift from an enactive to a symbolic mode of representation is aligned with years of research that show that children learn better when instructional scaffolding is provided for them to move from their concrete experiences to abstract knowledge (Bransford, 2000; Bruner, 1966). On the other hand, the cycle from dialogic to authoritative and from interactive to non-interactive talk is also a good pedagogical principle advocated by many science education researchers (e.g. Mortimer & Scott, 2003; Scott, Mortimer, & Aguiar, 2006). Hence, it makes logical sense that the shifts in each thread should be aligned as instructional representations are always used together with classroom talk. This study has therefore not only verified the concurrent shift from an empirical study, but it has also shed light into the nature of the coordination between the shift in representational modes and classroom discourse; particularly the shift from enactive to symbolic representation within an interactive–dialogic talk as well as the shift towards an interactive–authoritative talk within the symbolic mode of representation.

A greater understanding of the concurrent and coordinated shift between representations and classroom discourse can also offer science teachers a useful pedagogical tool to plan teaching sequences and choose appropriate communicative approaches to use with a particular instructional representation. This understanding is important because past research has found that science teachers tend to use a diversity of representations to promote interest or cater for individual differences in learning styles without considering the appropriate sequencing and use of such representations (Prain & Waldrip, 2006). From the findings in this study, several pedagogical guidelines can be distilled. For example, during an activity when enactive representations are used, teachers are recommended to use an interactive–dialogic communicative approach to elicit students' ideas and explore various points of view. However, as the lesson progresses and symbolic representations are introduced, there will be lesser alternative viewpoints due to the conventional rules surrounding the symbolic representations as well as students' unfamiliarity in using them. Thus, teachers will need to shift towards a more authoritative mode as symbolic mode of representations become more dominant.

Conversely, as the transition from dialogic to authoritative communicative approach occurred, teachers may want to consider how symbolic representations, in particular written language, can be used to better mediate the transition. Two strategies on how to do so can be learned from John's and Derrick's analytical cases. The first strategy is to use a table drawn on a board to write down and organise students' ideas. The second strategy is to get the students to write their individual ideas first, then project these written ideas for the class to read, and finally responding to and building on the students' written ideas. The key idea is to harness written language in order to consolidate the students' dialogic responses and subsequently work on and develop the students' ideas in an authoritative manner towards the 'scientific story'. More case studies such as these two examples need to be researched in order to provide more useful guides that will enable teachers to become more skilful in using representations to mediate the shifts in classroom discourse as well as managing appropriate classroom talk to mediate the transformation of representations in the teaching sequence.

In conclusion, classroom discourse and the use of representations are two important aspects that mediate student learning in the science classrooms. This study has shed light on the complex interplay between them and raised pertinent theoretical questions for future research. This study has also developed analytical cases that would be useful for researchers and teachers to examine and engage in a common dialogue on how to forge further integration between representations and classroom discourse.

Acknowledgement

This paper refers to data from the research project 'Developing Disciplinary Literacy Pedagogy in the Sciences' [OER 48/12 TKS], funded by the Education Research Funding Programme, National Institute of Education (NIE), Nanyang Technological University, Singapore.

Disclosure statement

No potential conflict of interest was reported by the author.

Funding

This work was supported by Ministry of Education – Singapore [grant number OER 48/12 TKS].

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