Title: Using visual representation in realising the concept of "Heat" in primary science

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Using visual representations to realise the concept of "Heat" in primary science

Abstract

Science teachers often use visual images to help students visualise the abstract concepts of science. Yet, they may not support students in making sense of these visual representations, wrongly assuming that the students can intuitively do it on their own. Pre- and in-service teacher professional development programmes also seldom explicitly teach how visual representations can be purposefully selected and utilised to help students comprehend abstract concepts of science. Thus, the aim of this study is to examine how an elementary science teacher made use of visual representations to realise the meaning of the concept of "heat", and to identify design considerations when using visual representations for concept teaching. Using multimodal analysis, the findings showed how the teacher orchestrated a sequence of ensembles of visual representations which bore conceptual, pedagogical, and epistemological roles in unpacking the concept of "heat" to facilitate his students' understanding. The findings indicate the importance of teachers developing representation-content-pedagogical competences in order to select representations apt for the targeted content knowledge, the students' profile, the learning environment, and the nature of the science.

Introduction

Visual representations are commonly used to make abstract scientific concepts visible (Lemke, 1998; Kopenen, 2007). In science, visual representations are semiotic tools that may refer to objects that have some kind of material or physical existence (e.g., picture of a dog) but may also refer to purely mental, conceptual and abstract concepts (e.g., magnetic field lines) (Pauwels, 2006). We can count schematic diagrams, flow charts, and graphic sub-forms such as tables, line graphs, scatter plots as forms of visual representations as well (Gilbert, 2010).

In science, we can think of visual representations functioning as knowledge products as well as objects for knowledge construction. As products (referred to as scientific models), these visual representations are used to signify objects, phenomena, processes, ideas and/or their systems (Gilbert & Boulter, 2000). Some common examples include the light model, wave model, atomic model, and cell model. These visual models make use of spatial (e.g., cell and atomic models) and geometrical properties (light and wave models) of images to "stand in" for unobservable entities within each of the phenomenon. As products of scientists' inquiry work, these canonical models have been the mainstay of many science curricula.

Inquiry into scientists' theory-building work invariably shows that visual representations are extensively used in constructing scientific knowledge (Gooding, 2004). One of the much investigated knowledge building work is that of Michael Faraday who was found to draw iconic images of speckles of iron filings around a magnet, symbolic lines to represent the pattern produced by iron filings and vector arrows as representation of magnetic field lines in developing the concept of "magnetic field", for example. The series of images used by Michael Faraday demonstrates the function of visual representations as important epistemic objects in the knowledge construction endeavor (Evagorou, Erduran, & Mantyla, 2015) and the representational passes as providing an important pathway for knowledge to progress from empirical to abstract conceptualization.

Similar to the knowledge building work of scientists, visual representations are used extensively to help students learn science. There are possibly two main uses of visual representations in mediating science learning: interpretive and constructive (Tippett, 2016). Of the former, students learn from visual representations aimed at helping students "see" abstract scientific concepts. Examples include the ball-and-stick model used in chemistry to help students visualise the three-dimensional arrangements of atoms and bonds of a chemical substance (Copolo & Hounshell, 1995), and anatomical models in biology lessons to show the spatial locations of different parts of human system that are otherwise unobservable with our naked eyes (Jansen, Knippels, & van Joolinger, 2019). Interpretive use of visual representations are often underpinned by the conception that they are alternative forms of the same concept (Tang, Delgado, & Moje, 2014). In recent years, there is an increasing focus on the epistemic role of visual representations in science learning, and students are encouraged to generate visual representations to learn science instead. Examples of such pedagogies include model-based inquiry (Khan, 2007), representation construction approach (RCA) (Tytler, et al., 2013), drawing to learn science (Ainsworth et al., 2011) and image-to-writing approach (Authors). These constructive approaches are said to help students learn the process of how scientific knowledge is developed as well as develop conceptual understanding (Gilbert & Justi, 2016). Regardless of the interpretive or constructive use of visual representations for science learning, these various uses demonstrate their potential to realise conceptual and epistemological of science through their pedagogical use in the science classrooms.

The use of visual representations in school science learning is not without problems. Studies (e.g., Authors) found that students often have difficulties using a given visual model to make sense of abstract concepts on their own. For example, Carney and Levin (2002) reported that students were not being able to identify relevant and important elements of visual models given by teachers to make sense of the intended scientific concepts, while Krajcik and Varelas (2006) found that students have difficulties using multiple representations for translation and transformation necessary for the increasingly abstract reasoning needed for scientific thinking. Considering that arriving at conceptual ideas and to use them to solve problems with visual representations requires an active coordination of features within and across multiple representations as shown by the visual work of scientists, teachers need to support students in recognizing the relevant elements of visual representations and coordinating them for meaning-making in ways that will help them realise the conceptual meanings (Flevares & Perry, 2001).

Yet, findings about the sufficiency and competency of teachers in providing this support is worrisome. Eilam (2012) found that teachers tend to fill the board with images of processes or hierarchical diagrams but they do not explain how these representations bring about the intended conceptual ideas (Eilam, 2012). This could be due to teachers perception that these visuals are alternative forms of the same concept (Tang, Delgado, & Moje, 2014), and hence are self-explanatory. In relation to the more constructive-based approaches, teachers in Waldrip and Prain (2013) reported that they found it hard to help students use their self-generated representations to arrive at the canonical ideas. In Author's (2013) study, she showed that the teacher was unsure what to focus on, and how, when facilitating a discussion around the student-generated models. In cases whereby teachers attempted to incorporate the use of student's constructed models, they tend to assume that students were able to integrate and connect the representations that were used to explain a phenomenon (Lemke, 1998; Scott, Mortimer, and Ametller, 2011). These studies suggest the need to provide some guidance to teachers on the use of visual representations as epistemic objects for thinking and reasoning about a phenomenon.

The literature is abound with broad guidelines about what teachers should do to effectively use visual representations in science classroom – e.g., mindfully select visual representations to facilitate students' gains (e.g, Eilam & Gilbert, 2014), carefully design interventions (e.g, Klopfer, 2003; Slotta & Chi, 2006; Wilensky & Reisman, 2006); allocate time to discuss the visual representations and reality (e.g, Eilam, 2012). Despite the availability of guidelines for the effective use of visual representations for teaching, detailed examination into the actual enactment of these guidelines and investigation into the design considerations of providing these supports are scarce. Some of these examples include Roth's (2006) work on science teachers' use of gestures in teaching and Kress et al.'s (2001) analysis of multimodal representations in meaning making in a biology classroom. Kress et al.'s (2001) study demonstrated that individual visual representation is seldom used on its own, but as an ensemble of modes including gestures and verbal text that may be translated from one mode to another. Existing studies on teachers' use of visual representations, however, tend to focus on the types of visual representations used and their frequency (e.g., Coleman, McTigue, & Smolkin, 2011), rather than the sequence of representational modes in mediating meaning-making. Considering that experts' use of visual representations shows the need for careful selection and coordination of different representations to think and reason about a phenomenon, likewise, teachers should support students who are novices in using visual representations as knowledge production tools. Thus, the aims of this study are to examine a case example of a teacher's use of visual representations as a knowledge production tool in supporting primary school students to explain for changes in temperature and hence to learn the concept of "heat", and to identify the design considerations involved. While findings of a single case study might not be generalizable, the rich description of students' meaning-making with the visual representations made available should demonstrate how visual representations can be coordinated to bring across the abstract ideas and nature of science. The findings also provide a glimpse into the complexity of this pedagogical work, which can inform professional development of teachers to develop their visual representational competences.

Theoretical Framework

In this study, we adopt the concepts of “Design” (New London Group, 2000) and “multimodality” (Kress, 2009) to foreground our interest in examining teachers’ selection and use of representations to convey the meanings of abstract scientific concepts. The concept of “design” considers teaching and learning as a meaning-making activity, while the concept of multimodality foregrounds the meaning-making potential of representations for engendering science learning.

Teaching and learning as design

All science teaching and learning are meaning-making activities, which necessarily make use of different modes of representations (referred to as just *modes*) such as writing, speech, gesture, writing, dynamic and static images (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Pozzer-Ardenghi & Roth, 2010). A mode is a semiotic resource for meaning-making (Kress, 2009; Kress et al., 2001). As orchestrators of learning, teachers are thus the designers of this meaning-making process, whose job is to select and use the modes that he/she deems apt for supporting students’ meaning-making (Selandar & Kress, 2010). For example, the biology teacher in Kress et al.’s (2001) study used a sequence of simple to complex images of the blood circulatory system, complemented by verbal explanation and gestures, to demonstrate the complex process of blood flow among the parts of the system that would otherwise be invisible to our human eyes.

In a more student-centered classroom, a teacher may select and make available modes that are considered apt for students to produce representations to learn the intended meaning. For example, in using the Representation Construction Approach for the teaching of force (Tytler et al, 2013), students were engaged in a set of representational challenges involving different modes, ranging from everyday and scientific language, and informal and formal drawings, that helped to shift their conception from everyday actions and words related to pushes and pulls to the scientific notion of force. Students’ work on the visual representations involve a *transformation* process whereby there is no change in the mode even though new meanings are realised (e.g., from simple to complex drawing of a human circulatory system) or a *transduction* process whereby one mode is changed to another (e.g., from drawings of how a plasticine's shape is changed to verbal text that describes these actions). The findings meant that examination of teachers' use of visual representations cannot be limited to the types used and their frequency, but how they are used with other modes and how their transformation/transduction realise the abstract meanings of science. In this respect, the present study will focus on analyzing how a sequence of (ensemble of) modes can support the meaning-making process of explaining why temperature changes and hence realizing the concept of "heat" in the process.

Meaning-making potential of modes

The concept of *"design"* assumes that meaning is made through many modes (Kress & van Leeuwen, 2001) and focuses our attention on their meaning-making potential. (Jewitt, 2006, 2008). While modes may be generally referred to by its form, Kress (2009) highlights that their meaning-making potentials are socially and culturally shaped. According to Lemke (1998), science is defined by a unique set of language resources drawing from linguistics, mathematical symbols, graphs, tables, images for their capability to produce meanings that matter to the scientists. For example, mathematics as a semiotic system of resources is widely considered the language of physics for its potential to construe complex quantitative properties such as ratios of quantities, arbitrary geometrical shapes and spatial motions and temporal changes that textual and visual modes lack (Lemke, 1998). In other words, teachers need to consider the discipline-specific modes that afford the kinds of meanings to be made in regard to the phenomenon. As these discipline-specific modes also make possible disciplinary ways of thinking, the choice of discipline-specific modes has epistemological implications (Lemke, 1998). While the ultimate goal of science education is to enculturate students into the language of science, it should not be the starting point because of its abstract and technical nature (Halliday & Martin, 1993). Traditionally, teachers would sequence the learning process to progress from empirical/specific ideas to abstract/general ones. This calls for a pedagogical considerations in selecting and sequencing the modes for meaning-making, so teachers need to be aware of the utility of the range of available semiotic resources for science teaching and evaluate how they afford the meaning-making process. When a teacher is more semiotically aware, it is also more likely that he/she will gain a greater perspective into noticing the modes used by the students and the possible meanings made as well.

Multimodal Analysis of Lesson Enactment

"All meaning making, whatever [modalities] are deployed, singly or jointly, has become organized around three generalized semiotic functions" (Lemke, 1998, p. 91). These three meta-functions, presentational, orientational and organizational, are constructed simultaneously during meaning making in relation to associated participants (agents, instruments) and circumstances (where, why, under what conditions). The ideational function of modes is what Lemke (1998) refers to as the presentational aspect of meaning. In the context of science teaching and learning, it can refer to the scientific *conceptual* aspects such as explaining meanings, making predictions and arguments, and understanding of content (Jaipal, 2009).

Orientational aspects of meaning refer to the statuses and roles of the participant in the communicative event as well as the social relationship between the producer and audience (Lemke, 1998). In the context of teaching science, this can refer to how teacher and student position themselves with respect to each other, as well as in relation to the nature of science through the semiotic resources selected (Jaipal, 2009). Since this study focuses on how semiotic resources convey scientific meanings, our interest lies in the latter, which we refer to as *epistemological* function.

The organizational aspects of meaning indicates the compositional function of semiotic tools to organize a representation into its elements and to link different aspects of the information in a coherent whole. In the context of a multimodal science classroom, organizational meaning refers to the *pedagogical* aspects of teaching (Jaipal, 2009), including the structure and sequencing of topics, lessons, concepts, and the various modes of representations planned and enacted in the classroom.

Various researchers like Jaipal (2009) and Author have carried out empirical studies examining the meanings that were construed using the meta-functions in science classroom. Their studies highlighted the importance of the use of multimodality to enhance the teaching and learning of science as well as the semiotic functions to understand the meaning-making process in the classroom. However, their studies did not examine the semiotic awareness of the teacher. As Kress et al. (2001) argued, the effectiveness of a teacher's teaching is hampered if the teacher is not aware of the affordances of the semiotic tools and how these tools come together to make meaning. By examining a case example of a teacher who was successful in getting students to develop a definition of "heat", we sought answers to these research questions:

1) What was the sequence of modes used by the teacher in supporting primary school students in learning the concept of "heat"?
2) How did the sequence of modes used by the teacher support primary school students in learning the concept of "heat"?
3) What were some considerations made by the teacher in the selection and use of these modes?

Research Methods

Background and context

This study is part of a larger design research which investigates the efficacy of an image-to-writing (Authors) approach designed to support elementary students in the learning of abstract concepts of science. In this approach, students create images as models of the phenomenon they are inquiring into, and use them to explain the phenomenon. One activity developed under this study is for the concept of "heat" where students infer why temperatures of two objects (hot potato and cold water) change when they are placed in contact with each other. Temperature changes in the objects are made visible through colour change with the use of a thermal camera. For this study, students were introduced to the concept of energy – that a body has more energy when it has a higher temperature, prior to this activity. To represent the relative differences in energy possessed by each body, a pictorial symbol (i.e., crosses) was used. For the same body, more crosses will represent more (thermal) energy possessed compared to fewer crosses. In groups, students created energy diagrams to represent their inferences of the amount of energy objects had at different temperature/time and used them to explain the observed temperature change when the objects came into contact. It has to be noted that crosses (representation) used here function to give semiotic materiality (much like the way Faraday used lines to represent magnetic field) to the abstract idea so that it can be thought and reasoned about. Aided by the whole class discussion the teacher had with the students of the energy diagrams they created, students then explained how changes in temperature came about (refer to Figure 1, last picture for a sample response). Figure 1 shows the activity sequence designed for students to develop their understanding of "heat".

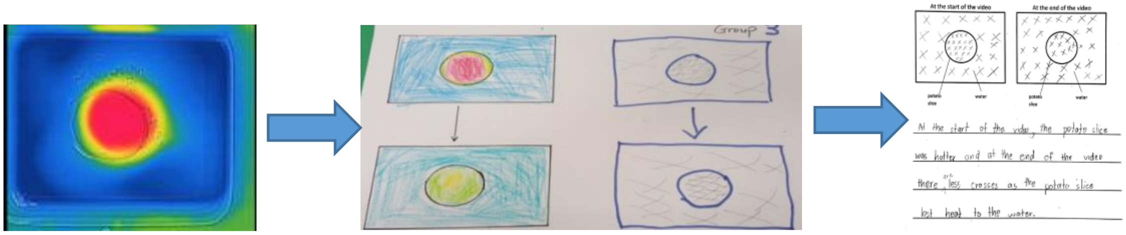


Figure 1. Activity sequence for the teaching of “heat”

This paper focused on the sequence of learning events after students had created their energy diagrams (second picture of Figure 1) and the written explanation (last picture of Figure 1). In an earlier research cycle, we found that teachers seldom supported students in making use of their models to explain the phenomenon. Instead, they merely attributed the change to “heat” by giving the students the definition directly, with little or no reference to the models students created. At the start of this cycle, we provided professional development on how teachers could work on and with student-generated models, but the teachers were free to decide on the semiotic choices.

Research design

We employed a case study approach (Merriam, 1998; Stake, 2000) to examine how a teacher made use of visual representations to help students come to understand the concept of “heat”. An in-depth examination into a teacher’s semiotic practices would allow a comprehensive understanding of the interplay of variables, namely the conceptual, pedagogical, and epistemological meanings, with the teacher’s orchestration of the semiotic modes selected and used in realising the concept of “heat”. As a design research, the rich and descriptive account yielded from a case study can inform the sufficiency of the teacher professional development provided, as well as anyfurther supports teachers might need to carry out the I2W approach better.

Our teacher participant, Mr N, was a Head of Department (HOD) of Science in his school, with 16 years of experience teaching primary science. Although he had taught the topic of Heat and Temperature before, he was using the image-to-writing approach for the first time after attending workshops on this approach. The students in Mr N's class were Grade 4 boys and girls in (age 9 - 10 years old), described by Mr N to be of middle- to high-achieving in science. The students were of different races which is typical of multi-racial Singapore. Ethics clearance was obtained from Nanyang Technological University (IRB–2016-01-041). Participation in the study was voluntary and written consent from school leaders as well as participants and their parents were obtained.

Data sources and analysis

Data sources for this study included video and audio recordings of lesson, with particular focus on the multimodal use by the teacher, and audio recordings of stimulated recall interview to determine what the teacher considered in his selection and use of modes in the lesson. The purpose of each data source in answering the research questions are summarised in Table 1.

Research questions	Data source	Purpose
1. What was the sequence of modes used by the teacher in supporting primary school students in learning the concept of "heat"?	Teacher's semiotic practices in supporting students in realising the meaning of "heat", and his students' responses captured through video and audio recordings	Video recordings of the lesson allows multiple modes (particularly, visual, audio, written and gestural) of representations that are typically used in a science lesson to be captured. Audio recording was also captured to ensure clarity of audio data.
2. How did the sequence of modes used by the teacher support primary school students in learning the concept of "heat"?		

3. What were some considerations made by the teacher in the selection and use of these modes?	Teacher's verbal reflection of his lessons, captured through audio recordings	Audio recording alone was sufficient for the interview data since it was expected that the reflection would be mainly conversational, and hence textual in its mode.

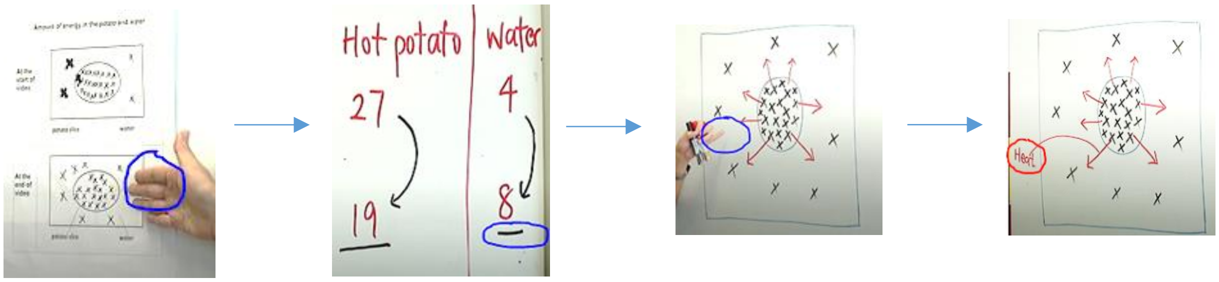
Our multimodal perspective of teaching and learning demanded that the transcript of the video data to be produced should include the various modes used by the teacher. Following the conventions of Kress, Jewitt, Ogborn, and Tsatsarelis (2001), the transcript captured not only the verbal discourse but also the images, gestures and other modes of communication that operate alongside to make meaning, recorded using time as an anchor (Bezemer & Mavers, 2011). As the focus on this study was on the disciplinary and pedagogical aspects of meanings rather than the interpersonal dimension, the transcription did not include facial expression, gaze and eye movement. As the interest of this study was on the teacher's orchestration of ensembles of modes in realising the meaning of "heat", the transcription highlights the transduction/transformation of these ensembles that advanced meaning-making (Kress et al., 2001). In short, the multimodal transcript captured a series of ensemble of modes that collectively realise the meaning of "heat". Each modal ensemble consisted of the various modes that were used to bring across a particular meaning associated with the concept of "heat". In other words, each ensemble of modes form the unit of analysis in this study.

Analysis of the first two research questions was guided by the three meta-functions – conceptual, pedagogical and epistemological. The modes used in each modal ensemble were firstly identified, then the meanings construed by each mode were determined along the three meta-functions, where applicable. The combined meaning produced by the modes was then analysed in order to understand how the modes interacted to realise the meanings, and thereafter, how the sequence of modal ensembles advanced the conceptual meanings and construed the nature of scientific knowledge, pedagogically and socially.

For research question 3, we produced a textual transcript of the interview and categorised Mr N's responses to the interview questions according to the various considerations made by the teacher in his choice and use of modes in the learning segment – conceptual, pedagogical and epistemological.

Findings and Discussion

The analysis focused on the teaching segment after students had generated their energy diagrams. Prior to the generation of energy diagrams, Mr N had noticed that students had associated "heat" with absolute temperature rather than changes in temperature. In this segment, he made use of a sequence of visual representations (refer to Figure 2) to help his students use the energy diagrams to construct a definition of "heat". Used in conjunction with verbal text and gestures, each forms a modal ensemble that were translated from one form to another. In the following sub-sections, we describe how each ensemble of modes and its translation supported students in realising the definition of "heat" and the teacher's considerations in his choice and use of the modes.



(a) Energy diagram (pictorial mode)

(b) Table of amount of energy (tabular mode)

(c) Use of arrow (pictorial mode)

(d) Specialised word (textual representation)

Figure 2. The sequence of visual representations used to realise the definition of "heat"

Students-produced energy diagram: Uncovering meanings made by students through questioning

As per the activity designed based on the image-to-writing approach (refer to Authors), students were instructed to create energy diagrams (using crosses or otherwise) so that they could use them to think and reason what might be happening in terms of energies when two objects of different temperatures were in contact. In line with the macroscopic view of heat advocated by the local primary science syllabus' objective (MOE, 2013), the energy diagrams are based on a macroscopic caloric view that Millar (2005) believes would help to bridge between young children's everyday knowledge and a more precise understanding of these ideas introduced at a later stage. While the disciplinary representation of energy is by means of numerical quantity, the energy diagram that made use of crosses functioned as an informal symbol to indicate the amount of energy possessed by a body (i.e., more crosses represent more energy possessed by a body) inferred from comparing a body's temperature at different time interval. In other words, these energy diagrams serve as a semiotic-material that allows its manipulability (Gilbert & Justi, 2016), which will otherwise be impossible for a formless, abstract idea. Figure 2a shows the energy diagrams drawn by one group of students.

After the students had completed their energy diagrams, Mr N was observed to select one group's models and embark on a series of questions to understand the conceptual meanings that students had imbued in their drawings with these eliciting questions: "can you tell us why did you draw like this" as he pointed at the crosses drawn inside the potato; and "what about the water?" as he gestured at the crosses drawn inside the water; as well as epistemological ones like "X means what?". The students responded that "the potato is hot so means more crosses", "the water is cold so there is less" (referring to the energy diagram at the top) and "(X means) the energy in the potato" respectively. Hence, with the verbal questions asked in respect to the energy diagrams, Mr N found out the conceptual and epistemological meanings made by the students with their energy diagrams.

Accounting for his pedagogical actions with the energy diagrams, Mr N explained that "because if (*sic*) they draw crosses, they may not mean anything to them". Mr N's explanation suggests his awareness that as a symbolic image, there is a convention by which the crosses were to be used. This convention is not evident from the image itself. Therefore, verbal questioning was necessary for the teacher to assess students' understanding of the target concepts (Chang & Yao, 2014). According to Kress and van Leeuwen (2006), images such as drawings are useful resources to construe spatial (e.g., position, location, shape and direction) meanings. However, their potential for producing conceptual reasoning might be limited. So, the verbal mode serves the pedagogical function of uncovering the cognitive work that went into the construction of the energy diagram. This episode indicates the need for teachers to be aware of the affordances and constraints of visual representations (Eilam & Gilbert, 2014). They also need to spend time and effort talking through the meanings of the images they and their students produce (Coleman, McTigue, & Smolkin, 2011) and not assume that everyone is making the same meaning.

From energy diagram to table – From "more/less crosses" to "increase/decrease in energy"

Following the questioning around the energy diagrams, Mr N drew a table to re-represent the levels of energy depicted in each of the objects at the start and end of the video (Figure 2(b)). He did this by using the responses given by students to these eliciting questions – "how many crosses did you draw for the potato … (at the start) and "at the end?", "the hot potato?", and "what about water?".

When the table shown in Figure 2(b) was constructed, Mr N directed students' attention at the change in the number of crosses for each object before and end of experiment by drawing an arrow from one number to another. Prompting the students to identify "so now, there is an increase/decrease of?", a mix of responses – "crosses", "energy" were obtained. Emphasizing that "we are using crosses to represent energy", he started to make references to these numbers as "energy" (e.g., "what is happening here is that energy from the hot potato is not going to stay here"). In this episode, we see first a transduction of modes from drawings to table, after which the arrows drawn into the table highlighted the comparison of numbers placed vertically (start and end of experiment), which successfully elicited a chorus response that there is a change in quantity. From a multimodality point of view, the transduction from drawings of iconic objects to a table of numbers removes from the phenomenon the spatial meanings of potato and water, highlighting the key physical entities and their quantitative attributes (amount of energy) against temporal factors of the phenomenon. By re-representing the amount of energy from pictorial crosses to a numerical representation, it also removes the semiotic concreteness initially used to represent magnitude. With the transduction to a conceptual visual representation (i.e., table), we also observed a shift in the reference of the image of “crosses” as “energy”. At the same time, description of quantities “more/less crosses” was revoiced with a more scientific description of “increase/decrease energy” to emphasize change.

Explaining the shift towards the use of table, Mr N explained that students “need to know that for the hot potato, there is a decrease, and decrease what does it mean. And for water, there is an increase, so what does it mean?”. His questions seeking to find out if his students knew what the changes in numbers represent indicated his awareness that his students might have the difficulty of recognizing the abstract entity signified in perceptual-based energy diagrams (Voisnaidu, 2010). The use of a table helps to do this in two ways. First, its construction shifts focus on the quantitative attributes of energy in each object at different time by removing extraneous meanings (e.g., shape, location, relative positions) conveyed by the energy diagram. We note that Mr N engaged the students in constructing the table through an interactive question-and-answer discourse. As a visual resource that organizes meanings with its own set of grammar that students might be unfamiliar (Lemke, 1998), we think that the question-and-answer sequences can help students see how meanings get translated from a topographical organisation to a topological one. Second, in translating the energy diagrams into a table, the quantitative meanings conveyed by pictorial crosses was re-represented by numbers. The teacher then ensured that the students associated the numbers with the conceptual idea of “energy”.

Back to the energy diagram – energy “starts to flow” and “this is what I call … heat”

After helping students to notice that energy for each object had increased/decreased over time, Mr N told them that “this energy from the potato is not going to stay here”. At this point, he redrew Figure 2(a) on the board and added in arrows directed out of the circle (potato) in all directions (see Figure 2(c)). The action of drawing the arrows prompted one student to describe the movement of the energy as "spread out". However, Mr N declared that "we don't use the word spread because the scientific word we use is start to flow", which is "what I call heat". At this point, Mr N labelled the arrow with the word "heat" (Figure 2(d)).

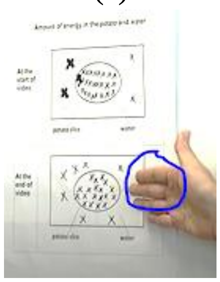
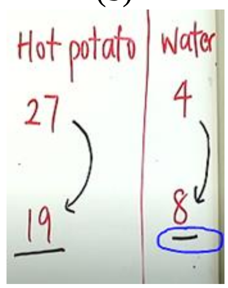
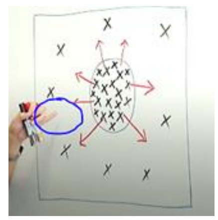
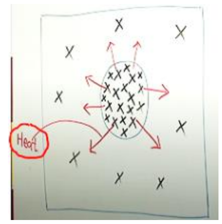
Explaining the shift back to the use of energy diagram, Mr N said that "there is actually an interaction between the potato and water, … and that is where I teach the concept to the students", indicating his awareness of the affordance of a perceptual image (e.g., energy diagram) and the constraint of a conceptual visual representation (e.g., table) to construe spatial meanings during an interaction. Redrawing the energy diagram, the spatial location of the objects are remade, which allows the spatial meanings of *from* the potato *to* water during the process of "starts to flow" to be made visually clear to the students. The arrows drawn indicate that the flow is multi-directional. In this sense, the spatial direction of "heat" as energy flowing *from* a hotter object *to* a colder object is realised visually.

In this episode, we also observed Mr N making reference to the objects by their relative temperature as he prompted students to describe that heat will flow from *"hotter"* to *"colder"* object with the questions "so it must start from?", "it will flow from this part here is?", and "now heat flows from hotter to?". After he is satisfied that the key technical words were introduced, he asked the students to form a definition for heat.

Implication and Conclusion

In this study, we sought to find out what visual modes were used by a teacher to support students in explaining a thermal phenomenon and realising the conceptual meaning of "heat", and how. We also sought to find out the considerations made by the teacher in his selection and use of representations. Our study shows the following key findings and summarized in Table 2.

Table 2. Summary of meanings construed by the sequence of modal ensemble

	(a)	(b)	(c)	(d)
				
Conceptual	Reasoning – linking hot/cold with number of crosses (e.g., “potato is hot so means more crosses”; “water is cold (so fewer crosses)” Identification – what X represent (e.g., “X represents energy”)	Attributive – changes in energy level for each object over time (there is an increase/ decrease of … energy”) Identification – “we are using crosses to represent energy)	Process and spatial meanings – energy “starts to flow”; arrows to show direction of flow	Identification – “what I call heat”
Epistemological	[use of semiotic resources to “stand-in” for a concept]	Table are semiotic tools for presenting, communicating and analyzing data		From specific to generalisation
Pedagogical	Use of visual crosses to provide semiotic visibility to an abstract concept of energy.	Table removes the extraneous meanings, highlighting the key aspects of the phenomenon	Use of arrows as a way of visualizing the directions of flow of energy	Use of label to indicate which part of the energy diagram refers to “heat”.

	Use of verbal questioning to find out the meanings made by the students with the energy diagrams.	Numbers help to address a substance-concept of energy		

(1) A sequence of visual ensemble ranging from energy diagrams (refer to (a)), using crosses as an informal symbol of energy possessed by each object at different times, to tabular representation of the energy diagram using numerical symbols to re-represent amount of energy signified by crosses and their differences at different times (refer to (b)), to the use of arrows to show the process of energy transfer between objects (refer to (c)), and finally to the introduction of the textual representation "heat" as a way to label the arrow representing the transfer of energy between objects. The sequence of visual modes needed to realise the meaning of "heat" shows that a visual model like the energy diagram is not an alternative form of the same concept as traditionally conceived, but a multimodal endeavor (Tang, Delgado, & Moje, 2014). Rather representational work has to be done to transform the visual model from one mode to another in order to realise its abstract meaning. In other words, using visual representations to realise abstract scientific concepts from empirical data will require a coordination and transformation of a sequence of (visual) modes of representations, which Latour (1999) refer to as a series of representational passes. This finding affirms the need for teachers to provide support to students in using visual representations in meaning making, instead of assuming that students are able to do it themselves or that visual representations are merely an alternative inscription of the scientific concept.

(2) A closer examination of the modes of representations used shows the importance of considering what the modes can or cannot do in realising the intended meanings of science

when selecting them. For example, the crosses in the energy diagrams have the affordance to make "visible" the energy level of each object, the specific quantitative amount and differences in energy level of each object might not be obvious. Instead the table re-represents the energy diagrams by highlighting the specific quantitative amount of energy using numerical symbols so that their differences can be worked out. The return to the energy diagrams thereafter allows for processes happening between the two objects to be hypothesized. This finding shows that the selection of modes cannot be arbitrary but consciously considered to be apt in realising the intended meanings. However, Krajcik and Varelas (2006) reported that unlike expert who are better able to coordinate features within and across multiple representations to explain and develop underlying concepts, novice learners tend to have difficulty interpreting visual representations in ways intended by their teacher and using multiple representations to connect with the visual mode to realise scientific meanings. This difficulty of students might explain why the teacher had used a more authoritative stance in modeling how the energy diagram could be used to explain the thermal phenomenon and to realise the concept of "heat".

(3) This study also demonstrates how visual representations can function as epistemic objects (Evagorou, Erduran, &Mantyla, 2015). In this respect, we identified instances of visual mode portrayed how scientists use different visual representations to aid their knowledge building process. For example, the use of crosses in the energy diagrams as early symbols to think about energy levels in the objects before formalized idea of "heat" is made is similar to how Michael Faraday drew lines to help him contemplate on the notion of magnetic field before the concept was formalized (Gooding, 2004). Kozma and Russell (2005) consider such imaginary-based representations as necessary epistemic objects providing the necessary pathway for the development of concrete ideas to theoretical ones.

Another example of the epistemic function of a visual representation is the table (refer to (b)). Tables are commonly used in scientific inquiry to present and communicate data, as well as to aid analysis (Kress & van Leeuwen, 2006; Lemke, 1998). In this case, while it was not used to record empirical data (temperature), it organized theoretical inferences (energy level) based on the energy diagrams created so that patterns of changes were made more prominent. In other words, there is an emerging potential of its use in this segment in demonstrating one aspect of scientific practices. However, we note this was not one of the consideration in Mr N's choice of mode, indicating that his unawareness of its potential epistemological function. This might explain why teachers in Coleman, McTigue, & Smolkin's (2011) study were found to do very little to build students' ability to interpret and produce these communicative skills when using graphical representations, indicating an area that should be included in teachers' professional development.

(4) Our findings also showed that the use of visual representations for science learning requires pedagogical considerations. As mentioned a couple of times by Mr N, students may not be aware of the features of the given visual representations and affordance for advancing meanings. As demonstrated by Mr N through the use of questioning, teachers need to actively promote students awareness of such features to avoid erroneous interpretations of visual representations (Eilam, 2012). In other words, while visual representations may promote students' understanding of abstract ideas, the quality of teaching and learning is determined by the complex interactions between the teaching approach, students' characteristics and the visual representations used in realising the meanings of the abstract scientific concepts. This further supports the importance of developing pedagogical-representational-content knowledge as claimed by Eilam and Gilbert (2014).

In short, while there may be lists of guidelines on what teachers should do when using visual representations to teach science, the micro analysis of a teacher's use of visual representations made these guidelines clearer. In mindfully selecting visual representations to facilitate students' gains (Eilam & Gilbert, 2014), this study show that one needs to consider the aptness of the representations in making the meanings intended. Careful design of interventions (e.g, Klopfer, 2003; Slotta & Chi, 2006; Wilensky & Reisman, 2006) would then involve examining what, and how, ensemble of multiple representations can realise the meanings, as well as to consider the pedagogical strategies (e.g., questioning, formative assessment, teacher-centredness vs student-centredness) that should go alongside the ensemble of multiple representations. As students, particularly elementary students are nonetheless novices in the knowledge work of science, it is also necessary to model and talk about how the various representations can be used for meaning-making. This is something we do not see the teacher in the study doing much of.

While this study is based on one case, it nonetheless illustrates the importance of teachers' role in mediating between visual representations, contents and students' learning in the use of visualisation for concept learning. Presently, teachers' professional development programs are generally deficient in the opportunities and experiences they provide to teachers to develop such representational competences for teaching and learning, resulting in teachers' lacking expertise in the utilization of visual representations. Just as teachers develop pedagogical content knowledge for teaching different content (Shulman 1986), so too must teachers develop pedagogical-visual-content-knowledge (Eilam 2012) for the apt selection and effective use of visual representations for specific students, for teaching a particular content, in a certain milieu. Future research could expand on the narratives of teachers' use of multimodality in their science classroom teaching in order to identify further considerations in its selection and use in science classrooms in general and for various learning purposes.

As an exploratory study, the findings reported here are merely scratching at the tip of the ice-berg. The teacher's explanation, reasoning and justification for his use of different modes of visual representations could be more extensively captured to compare between his planned and enacted actions. More extensive study into teachers' PVCK in the context of teachers' professional knowledge and PCK could be another line of research in the future.

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