Meaning Making in Science Classrooms: Orchestrating Multiple Modes of Representations

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Abstract. Students improve their understanding of science through mean making in science classrooms. Considering the multimodality of science and the cognitive benefits of the use of multimodal communication, science educators commonly use multiple representations for teaching and learning science. In this article, I introduce a draw-to-learn approach as a potential pedagogy which can prompt students' meaning making by translating from verbal mode to visual mode and vice versa and orchestrating multiple representations together. I then discuss how this multimodal representational practice can be meaningful for students in terms of a chain of meaning across modes of representation.

Keywords: Meaning making · multiple representations · science classrooms · draw-to-learn

1 Introduction

Meaning making, which indicates constructing the meaning of scientific concepts, has long been not only a crucial component of science classrooms but also regarded as a goal of science education [1]. In science classrooms, students are able to improve their understanding of the targeted scientific concepts through various meaning making activities such as doing investigations and constructing explanations. These are regarded as part of crucial scientific practices in the Next Generation Science Standard (NGSS) of the U.S and are taking place essentially in science classrooms [2]. In this regard, how to support students' meaning making has been a critical pedagogical question among science educators.

2 Multiple Representations in Science Classrooms

The use of multiple representations, such as written text, diagrams, animations, and graphics, is a prevailing phenomenon in science classrooms [3]. Although the development of Internet and Communications Technology (ICT) may accelerate the broader use of multiple representations, the underlying reason can be theoretically explained by two

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well-established research fields: (1) cognitive theory of multimedia learning (CTML) and (2) multimodality. Research in CTML provides a theoretical account of how humans process information in terms of different channels related to perceptual senses [4], while multimodality in this area of research grounds associated with the nature of science communication and concepts [5, 6].

2.1 Cognitive Theory of Multimedia Learning

From the point of view of CTML, human information processing involves two different channels (i.e., verbal/auditory channel and visual/pictorial channel) that is related to the structure of the human mind. Most studies of this research area [4, 7] grounds this theoretical assumption of information processing. Based on this dual channel assumption, there are several basic principles for providing multiple representations in multimedia learning. I will illustrate human's dual channels in processing information first and then two contiguity principles in organising multiple representations, which can enhance information processing given multiple representations for students' meaningful learning.

2.1.1 Dual Channel in Processing Information

A dual channel in processing information implies a way of increasing the capacity of receiving information related to human working memory [8]. Human information processing has verbal/auditory and visual/pictorial channels, which are assumed to have a particular amount of working memory capacity at a time. It means that the use of both channels at the same has a more significant amount of information processing than that of a single channel. Hence, if the information is given through pictures and words, it is more likely to be efficient in processing information than giving only pictures or words [4].

The underlying assumption of the dual channel theory is that pictures and words convey qualitatively different information. Hence, it allows the process of information simultaneously through the other channels. For example, we can easily imagine a situation that someone explains how to get to a destination using a map. In this context, the map provides distances, relational locations, directions, and paths, as a reduced scale, which are visual resources. At the same time, someone's talk would be about the sequences of paths involving textual information to get to the destination. Processing visual information represented in the map through the visual channel and textual information represented in the talk through the auditory channel would be much more efficient than just using one channel.

2.1.2 Spatial and Temporal Contiguity Principles

To convey more meaningful information effectively, CTML provides two basic principles in organising multiple representations such as pictures, words, mathematical equations and etc.: The spatial contiguity principle and temporal contiguity principle [4, 7]. The spatial contiguity principle is that learners will have better learn when providing pictures and words in neighbouring than providing them apart (See Fig. 1).

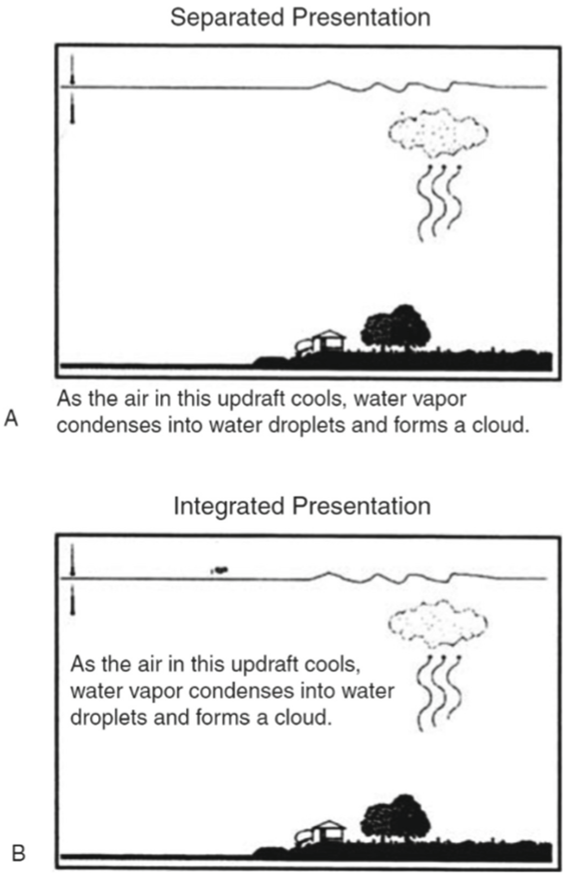

Fig. 1. Example frames from (A) separated and (B) integrated presentations (Mayer, p. 140).

It implies that educators may need to consider integrating multiple representations to provide them contiguously.

The temporal contiguity principle is that learners can do better learn when providing pictures and words simultaneously than successively [7]. In the previous map example, we would have a better understanding when we are listening to the explanation and seeing the map at the same time than doing them in sequential order. As these two contiguity principles can facilitate students' learning, educators may need to consider organising and providing various resources in actual science classrooms [9].

2.2 Multiple-Layered Representations

There is another strong necessity for the use of multiple representations in educational settings, which is related to a multi-layered nature that is multimodality [5, 6] and multiple levels of representations [10, 11]. I will provide a brief overview of multi-layered representations.

2.2.1 Multiple Modes of Representation

Science content cannot be communicated with only talks and words, which are verbal modes, because it inherently involves multiple modes of representations, including visual mode, to convey their meanings. This is about the representational nature of science content. For example, when describing Ideal gas law involving changes in conditions, we may need not only words but also a diagram or a graph. In general, these are the most common classifications, which are verbal and visual modes, respectively. Teachers and students in science classrooms also use multiple modes of representation for teaching and learning science. To illustrate more specific meanings of modes and their affordances, we can categorise five significant modes of representation in science classrooms [12]:

- Verbal-linguistic: the use of written and spoken language in the forms of words.
- Visual-graphical: the use of something that conveys image information which can be two-dimensional, or three-dimensional such as diagrams, graphics, flowcharts, and photographs.
- Mathematical-symbolic: the use of scientific and mathematical notation systems such as equations, formulae, and numbers.
- Gestural-kinaesthetic: the use of hand and body movement to represent or support something
- Material-operational: the use of physical objects related to practical work

These five modes of representation have distinct affordances. According to social semiotics [13], for example, verbal-linguistic mode affords typological meanings which involve the categorisation of words, such as increase/decrease and solid/liquid/gas. On the other hand, the visual-graphical mode affords topological meanings, which is about spatial information such as location, arrangement or the degree of meaning such as size, direction and length [5].

2.2.2 Multiple Levels of Representation

In teaching and learning science, teachers and students may inquire about the natural world and scientific knowledge, which mostly involve three levels [10]: A *macro* level, what we can observe *microscopic* level, what we cannot see by the naked eye without any aids and a *symbolic* level which is the use of symbols to represent particular entities, such as atoms. For example, in illustrating the Ideal gas law and its phenomena, if an explanation provides a descriptive account of observation of the change of volume, it is a macro level. If the explanation depicts the collisions or movement of the particles inside of the container with a diagram, it is at a microscopic level. On the other hand, if there is the equation to represent this phenomenon with $PV = nRT$ (Note: P is pressure, V is volume, n is the amount of substance, R is the ideal gas constant, and T is temperature), it is at a symbolic level.

Although this triadic classification has generally been perceived in science education since it originally stemmed from chemistry, there are some different levels in biology and physics education. There are two additional distinctive levels to represent unique biological phenomena: the cellular level illustrates cell structures, the molecular level involves biochemicals and DNA, while macro and symbolic levels are the same [14]. In physics education, there is an additional level representing non-substance entities, such as forces, which involve interactions between substances, and energy which is operationally defined in physics [11].

3 Draw-To-Learn in Science Classrooms

Draw-to-learn approach has widely been used in various disciplines including science [15, 16]. As illustrated above, it is necessary to use multimodal representations in communicating scientific content because of its nature [17]. Draw-to-learn can prompt the use of multiple representations by students.

3.1 Utilisation of Drawing Diagrams

There can be several cases for utilising drawing diagrams in learning science. (1) When inquiring about phenomena as objects, the phenomena may be described verbally and visually, which may involve drawings by students. (2) When constructing an explanation, a diagram would be needed to provide a causal explanation if the phenomenon involves visual content [11]. On the other hand, (3) when solving problems, students may draw to visualise the problem context and brainstorm to plan how to solve the problem using drawings [18]. Beyond the above exemplary cases, various contexts would involve drawings in learning science based on its substantial benefits.

3.2 Benefits of (Co-)representation of Scientific Diagram

Drawing diagrams can be a powerful approach to learning science with four significant advantages. (1) It prompts orchestrating multiple modes of representation in representing scientific ideas [19]. Many scientists rely on not only verbal text but also visual diagrams in developing and representing their ideas, which is a natural phenomenon given multimodality; likewise, when students draw diagrams, they will be facilitated to integrate multimodal resources (e.g., verbal and gestural representations) to refine and clarify their idea progress [20]. (2) It also allows students to encourage scientific reasoning. Each mode of representation has different affordances, as described above. When multiple modes of representation are involved, it is not merely adding the meaning of the other modes but multiplying their meaning, which denotes that they play complementary roles of one another [5]. Hence, when students construct a visual diagram as an explanation, they will face a need to make more meaningful connections between verbal and visual reasoning together [21].

(3) It arouses students' communication. Drawing diagrams is an activity which creates a social space to interact with peers, teachers and even oneself [22]. Therefore, they can communicate using partial or complete diagrams or plans for drawing. This is because they play a role which are idea recourses for discussions and idea development. (4) A drawn diagram can be a significant assessment tool for capturing students' thinking and understanding, including visual reasoning [23]. Since students can easily use their visual conventions to represent their ideas, it is helpful for teachers to identify students' understanding and progress.

If students can construct diagrams together, the benefits will be even more potential in utilising the draw-to-learn approach [20]. For example, students can do joint reasoning which reflects on the current model of scientific practices [19]. In addition, it also enhances integral multiple modes of representation. If students draw diagrams individually, they only interact with their metal models of targeted concepts and draw visual diagrams. However, if they co-construct a diagram together, they would develop their diagram while talking a lot in a way involving multimodal discourse (i.e., spoken language, visual diagram, and gestures) [24].

4 Intertextulity in Meaning Making

When students construct their scientific ideas or explanations through multimodal discourse, they may make meaning across various modes of representations, including drawn diagrams, written texts, talks, gestures, and even manipulated or observed materials. According to Bakhtin's dialogism [25], every single external representation should be understood in terms of a chain of connected meanings, which means that texts rely on other texts. This concept in linguistics is called intertextuality [26]. From this perspective, drawn diagrams are not merely final products but the established products in the history of using talks, written texts, labels, and gestures across multiple modes of representation [24]. In a closer view, when students translate their talk into a diagram, the meaning constructed in the talks will partially remain while some new meanings afforded by the visual mode would be added and refined, which can be seen as developmental progress across the two modes [20]. Science teachers therefore may need to support their students sufficiently in terms of providing appropriate multimodal resources and giving opportunities to generate their scientific understanding using multiple modes of representation.

5 Conclusion

Meaning making in science classrooms is a crucial activity which mostly involves the use of multiple modes of representation. Within the mind of constructivism, students will be able to improve their understanding of science by generating their own representations and revising them to refine their ideas. Since there are various merits to the use of multiple modes of representation, it would be helpful for students to experience and be given multi-layered representations. Draw-to-learn approach can be an integrative strategy to encourage students to orchestrate multiple modes of representation which will enrich their understanding related to multi-facet of science content. Supported by teachers' sufficient and appropriate guidance, students will progress in their meaning making of science in science classrooms.

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