Embodied learning and multimodality in science education:

teachers' perceptions of teaching electrical circuits, their diagrammatic symbols, physical components and functions through multisensory approach

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ABSTRACT

This small case-study discusses a specific science teaching strategy that has been developed through a multimodal and socio-semiotic lens while drawing on embodied cognition as a pedagogical tool for designing a learning journey to engage students in learning about electric circuits. I have worked with pre-service teachers (PSTs) to use this strategy in their classroom to allow their students to use different senses and modes of communication to engage in knowledge acquisition. The use of movement, sound, imagery and other resources is then linked with real objects and tasks in the science classroom. This type of pedagogical strategy has potential implications for sciences teaching and learning which are explored in this piece. I draw on self-reported answers and semi-structured interviews with PSTs and other former PSTs from our institution who have used this strategy in real classrooms environments. Results show that this strategy has had important impact on PSTs' perceptions about teaching and learning and pedagogical understanding, as well as achieving a more meaningful engagement of students during and after the lesson, in particular if the teacher is also actively involved in doing the task with the students.

KEYWORDS

EMBODIED COGNITION

MULTIMODALITY

SCIENCE EDUCATION

ELECTRIC CIRCUIT SYMBOLS

INTRODUCTION

Teaching and learning science in secondary school has many challenges. It starts when teachers and students are faced with a predetermined list of 'canonical' subject knowledge, that must be understood and is often taught in specific and 'established' ways (Aikenhead 2006). Canonical subject knowledge usually comes from both national curricula and/or course-adopted textbooks that end up becoming 'official knowledge' (Apple 2013). The content is then interpreted and translated into actual teaching by science teachers in an attempt to engage learners in developing their knowledge, skills and competencies. This process relies on teachers' in-depth understanding of their own pedagogical content knowledge (PCK) (Shulman 1987) in order to transform subject knowledge into meaningful learning experiences using varied pedagogical tools and strategies. However, hundreds of observations of science teaching in my capacity as a mentor and a teacher educator in the last five years have shown me that textbook and curriculum knowledge are often directly reproduced by teachers.

It is understood that foundational knowledge is a critical component for future learning (Willingham 2009), and Young et al.'s (2014) concept of 'powerful knowledge' consolidates the importance of teachers to consider what might be selected as specialised and 'canonical' knowledge in order to enable students to later access additional layers of knowledge and enter other sociocultural institutions within a given society. However, what this paper addresses is the manner in which this knowledge is 'imparted'. As with any other subject, science (and in particular physics) has its own language and meanings which, in turn, makes learning science a challenging task (Wellington & Osborn 2001). In many instances, the language of science is the same as ordinary spoken language, albeit with very technical and different denotations (eg force, energy, power, field, resistance, current). In order to overcome these barriers across many different concepts, science teachers and educators have developed a range of strategies to support science teaching and learning in the classroom: modelling, animations, stop-motion animations, role-play, creative writing, drawing/painting and songs are some of the myriad of pedagogical tools physics teachers have at their disposal to support learning within their classroom.

However, effectively implementing these varied modes of instruction relies on science teachers' pedagogical understandings of science teaching and learning (ie how to turn content knowledge into teachable moments through the use of such pedagogical teaching tools), their epistemological beliefs about the constructions and purposes of science knowledge (ie how a teacher understands the role of science, its meanings and inner workings) and their confidence and willingness to explore new avenues of thinking about physics education (ie their sense of openness to teaching strategies). All this must happen while at the same time understanding how designing specific learning episodes might support students' cognitive development in understanding scientific concepts to increase learning opportunities and outcomes of students, allowing teachers to 'exploit the specific perceptual and cognitive strengths of different individuals' (Pashler et al. 2008: 109 in Sankey et al. 2010: 854).

Many of these alternative teaching strategies encourage instructional and subject knowledge elements to be presented in more than one sensory mode (writing, visual, oral, touch, smell, etc) and often in a 'cohesive and synchronous' manner (Walsh 2010: 213). In turn, materials that are presented in a variety of modes may lead to students perceiving learning differently and thus, potentially, lead to improved learning performance, in particular for lower-achieving students. This is a key assumption of this paper, which draws on the idea of multimodality and multisensory pedagogical tools. Importantly, this notion is not new. Dewey had already argued that schools that provide opportunities for students to engage in conjoint activities would allow students to 'acquire a social sense of their own powers and of the materials and appliances used' (Dewey 1916:40). Prather et al. (2009) have argued further that 'it is the [effective and meaningful] implementation of interactive learning strategies that is key to achieving higher gains in student achievement' (p. 329), while research on literacy highlights the important role which imaginative, interpretive and interactive features of communication can play in learning (Coiro et al. 2008).

This paper explores how a multimodal strategy can be used to teach electric circuits and its components, as well as how pre-service teachers' (PSTs') perceptions of using a multimodal strategy in their classroom can be developed. I approached this topic by using an image–movement–sound–recognition sequence – dubbed 'Kung Fu electrical circuit' symbols – in which all students actively participate, as well as the teacher. It draws on some of the conceptual ideas and on the theoretical frameworks of multimodality and social semiotics proposed by Kress et al. (2014), as well as the notion of embodied cognition learning, particularly that presented by Stolz (2015) and Wilson (2002). I pull these ideas together to present an alternative, purposeful and structured way of thinking about science teaching.

RETHINKING SCIENCE TEACHING: SOCIAL SEMIOTICS, MULTIMODALITY AND EMBODIED COGNITION

Socio-semiotics

When interpreting science teaching and learning through a socio-semiotic lens, it becomes important to develop an understanding of the relationship between form (sign) and meaning (signifier) as it becomes key to unlocking science teachers' pedagogical content knowledge. In socio-semiotics, both form and meaning are created and shared within specific communities. Moreover, since the link between the two is never arbitrary, but 'it is always motivated by the interests of the maker of the sign to find the best possible, the most plausible form for the expression of the meaning that s(he) wishes to express' (Kress et al. 2014: 5), science teaching often relies on the science teacher as the sign-maker (Fredlund 2013). Thus, for any particular science teacher, their choice of form (sign) with which to express scientific meaning (signifier) is rooted in their epistemological and pedagogical beliefs about science teaching and learning, regardless of their scientific (and most likely canonical) conceptual understanding of scientific knowledge. A science teacher's choice is limited by their own spectrum of ideas about the meaning of how science knowledge is conceived and their own pedagogical understanding of learning.

Therefore, the sign-making and signified concept is only a 'partial representation of the object represented since it represents the interest of the sign-maker when choosing to make the sign, and the signmaker's interest is always partial' (Kress et al. 2014: 6). Therefore, teachers must be acutely aware of their sign-maker bias when making representational choices to teach given subjects. Further still, socio-semiotics argues that meaning-making in school goes beyond textual and verbal representations of reality. Students and teachers make meaning in an active process where multiple modes of representation are shared (and/or learnt) and help the process of meaning-making by teachers and students (eg Lemke 1998; Jewitt 2008).

Multimodality

An important contribution to the role of multimodal and multisensory learning is the work of Gunther Kress and colleagues who have done an in-depth analysis of classroom practice and argued that 'learning can no longer be treated as a process which depends on language centrally, or even dominantly. Meaning is made in all modes separately, and at the same time, that meaning is an effect of all modes of acting jointly. Learning happens through all modes as a complex activity in which speech or writing are involved among a number of modes' (Kress et al. 2014: 1). In order to take this initial standpoint of multimodal learning from a science education perspective we must break down the traditional assumption that scientific knowledge is only valid when rationally communicated through words (either written or spoken). Acknowledging the science classroom as a multisensory, multimodal and dynamic environment for teaching and learning also requires science teachers to reflect both on their epistemological beliefs about scientific knowledge as well as their pedagogical understanding of teaching and learning. This is because how a teacher conceives and learns scientific knowledge influences their decision-making processes in how learning experiences are organised as well as how they deliver and convey this knowledge to learners.

Jewitt & Kress (2003) argue that modalities of learning tend to occur together as a combination of meaning-making signals which are distributed across specific modes in distinctive ways at different times according to social contexts and purposes. Further still, these modes of representation constantly interact with a variety of media, and shape both what is represented as well as learners' internalisation of those representations. Arguably, science education relies significantly on the use of models and analogies (forms) in order to facilitate representation and communication of conceptual understanding (meanings) of very abstract ideas. These choices are made by science educators who all have different ways of looking at the world.

Firstly, representation focuses on what an individual teacher wishes to represent about 'the thing' represented. This involves the teachers' choice of models for demonstrations, and how scientific concepts can be visualised and translated into teachable lessons. Secondly, communication focuses on how that is done in the environment of making that representation suitable for specific 'others', a particular audience: for example, a teacher's choice of mode(s) (language, writing, sound, imagery, smells, touching, etc) to convey such model or scientific concept. Multimodality argues that our choices of the ways in which we are able to represent and communicate knowledge have the potential to enrich the curriculum content as well as how we interact with it (eg Hasset & Curwood 2009). Moreover, 'the ways in which something is represented [and communicated] shape both what is to be learned, that is, the curriculum content, and how it is to be learned' (Jewitt 2008: 241). Ultimately, multimodality promotes an alternative way of thinking about science pedagogy (Bonner 2014) to support the development of varied multimodal strategies because it is essential to 'explore the ways in which representations in all modes feature in the classroom' (Jewitt 2008: 241).

Embodied learning

Until recently, our description of learning has been guided by theoretical constructs developed by cognitive psychology and behavioural experimentation about the processes that might take place during learning. Albeit the notion of social constructivism has taken a theoretical and experimental root of its own since the classic works of Piaget and Vygotsky, the constructs of many learning theories have remained largely disembodied (Kelan 2010). This implies that the human body is often thought of not as an active, cognitive part for learning, but rather as only an interface for communication with the outside world: for example, as per a 'Piagetian notion of a sensory-motor system for the development of abstract concepts' (Amin et al. 2015: 746) or a Vygotskyan symbolic interaction with the physical world. However, Carr (1994) argues, their description of cognitive learning portrays a linear understanding of learning 'as if they are events in a "causal relationship" that can be explained somehow with "laws established on the basis of observation and experiment"' (p. 39) (in Stolz 2015: 475).

Several researchers have brought to light the proposition that cognition is also embodied. For example, Wilson (2002) has captured a theoretical framework in which embodied cognition plays a significant role in learning. Recent work in psycholinguists, neuroscience, gesture analysis and cognitive psychology has uncovered tantalising links that abstract conceptualisations of reality rely on sensorimotor experiences and 'image schemas' stored in the visual-spatial mechanism in the brain (ie Gibbs 2005; Nunez & Sweetser 2006). Additionally, Stolz (2015: 475) argues that embodied cognition is 'an alternative or challenger to traditional cognitive science due to its reluctance to conceive of cognition as computational'. Recent research shows that 'cognition is embodied and involves a deep connection between perception and action' (Stolz 2015: 476), and Stolz goes on to argue that learning is deeply connected to how we explore the world and its intrinsic relationships while embodied learning allows students to understand the significance of the 'phenomenal' body and how it meaningfully experiences the world.

In the classroom, the translation of these ideas into meaningful learning experiences for students depends on teachers' pedagogical intentions and how teachers explore the use of the 'phenomenal body' within their classrooms, especially as it now recognised that our bodies are able to mediate cognitive learning and that cognitive learning impacts our bodies, in all spheres of life, including academic knowledge (Kahneman 2011).

Purposeful, embodied and multimodal teaching and learning: developing the Kung Fu electrical circuit routine

Thinking and practice of embodied learning in the science classroom is not new. Science teachers have been trying to convey difficult concepts to students in a variety of ways. Gestures, sounds and touch have always played a part in teaching, and current research suggests that they are a very powerful tool in helping children's conceptual understanding. In this activity it is the students who are performing the gestures, sounds and touching physical objects. In addition, the gestures are purposeful, with each combination of gesture and sound (forms) having a shared meaning between teachers and students. Kress et al. (2014) argue that 'the body is central to understanding the meaning of action. In this way, the process of action can be understood as "bringing action into being" rather than as translating meaning into action'. (p. 85). At the same time, a purposeful multimodal approach to science teaching can bring scientific entities into being: it can 'make ideas seem real, create involvement, construct fact and convey the realism of scientific truth' (Kress et al. 2014: 115). Therefore, these social-semiotic and multimodal systems and learning tasks must be:

- Purposeful: non-spontaneous, pre-developed and/or co-developed by teachers and shared with participants during the lesson
- Outcome-focused: linked to specific learning outcomes and actively used tasks
- Action-based: a unique choice is made by teachers where actions (forms) have a specific meaning that shapes the knowledge to be acquired (non-behaviourist nor idiosyncratic)

The key assumption here is that it is the multisensory exploration of knowledge for meaning-making that is particularly effective in supporting meaningful learning. It is the conscious, purposeful and explicit effort to connect knowledge with semiotic meanings along with multimodal experiences that reinforces the learning experience, (re)shaping knowledge acquisition and contributing to a higher student engagement and achievement.

THE ELECTRIC CIRCUITS KUNG FU

The principal goal of the learning task researched for this paper was to recognise electric circuit symbols, their meaning and their function through multisensory representations and then to be able to accurately draw the symbols individually, predict a particular outcome from a drawn electric circuit, build an actual electrical circuit and understand the functions of its components. The task has been designed with the following sequence; this happened for individual electrical components, in turn.

1. Manipulate physical objects [electric components] (tact) without the teacher telling students what they are
2. Show pictorial representation (visual) associated with the physical object and then draw it (movement, visual)
3. Act this pictorial representation (motor + sound) with the teacher to associate object, pictorial representation with an action (see: https://youtube/ex7xwaPha2I)
4. Link action with function when the component is shown working in an electric circuit (use of technical vocabulary, knowledge)

   This is then repeated for a certain number of electrical components as chosen by the teacher depending on the level of attainment of the class.
5. Building own circuit based on a complete circuit diagram (visual + tact + motor + knowledge) and any additional consolidation tasks

METHODOLOGY AND DATA ANALYSIS

As an exploratory study, the methodology employed relies on a qualitative data collection through teachers' and PSTs' own self-reflective notes of the outcomes of this task which they chose to do in their lessons. The data collected for this project happened over a period of three years and relied on three separate strands. The first was the self-selection of teachers wishing to take part in the project and thus making personal use of this learning strategy. Secondly, I have collected self-reported accounts from teachers and PSTs who have used this learning strategy in their own classroom. This is likely to have inherent bias from the teachers as they have already self-selected to attempt the task in their own classroom. Nevertheless, this self-selection and self-reporting tries to capture a snapshot of what might be possible when teachers are enthusiastic and encouraged to attempt multimodal tasks.

A total of 82 PSTs from across the science teacher education course (biology, chemistry and physics) were involved in the instruction period of the task during their university-based training. All were invited to participate in the research if and when they were teaching electricity at their school placement, either at Key Stage 3 (age 13–14) or Key Stage 4 (aged 14–16). Overall, a total of 17 PSTs took part in the study, independently chose to participate and sent their written reports/ field notes on how they conducted the task as well as their report of student learning. PSTs were also interviewed on the outcome of the task, and the interview also served to double-check their field notes. Instead of analysing teachers' actual multimodal actions in the classroom, this exploratory work delves into PSTs' perceptions of using a multimodal strategy in their classroom and their students' responses.

The first theme that emerged from analysing their answers was how it appears that there is a 'higher student engagement in lessons'. Pre-service teachers reported

> *'the class was very receptive, with all kids enjoying the activity... and even the "too cool for school" pupils really got into it!'* (Carl, Physics PST)

> *'next lesson students wanted to "play the game" and looked forward to the start of the lesson'* (Ama, Chemistry PST)

> *'it went well, most took part enthusiastically and, importantly, they talked about it (and the symbols) at the next lesson, two days later!'* (Doug, Biology PST)

> *'it was a great success, it really got them engaged and they accidentally forgot they were learning [electric circuit] symbols and how they worked'* (Andy, Physics PST)

The discourse used is encouraging, with PSTs describing how they think students may have perceived this strategy in their classrooms. The idea that students were receptive, enthusiastic and used the knowledge acquired in subsequent lessons provides us with an insight into the expectations of teachers. When first introduced to the task, PSTs were decidedly sceptical about how it would be received in their own classroom. PSTs reported that students were both more engaged and motivated by the task. The nature of the task, where students have to actively get involved in the learning through movement, sound and, may have played a role in this. There is also the novelty factor. Students may have had previous routine experiences in science lessons of either sitting down doing work, observing demos or doing practical work. Nevertheless, students' written, verbal and physical expressions can be considered an insight into how they interacted with the acquisition of new content and may be a way to understand new learning (Kress et al. 2014). Moreover, some teachers went further in providing classroom evidence:

> *'we revised the symbols in the next lesson and I saw students acting the moves and laughing, enjoying themselves... it seemed to help and prompt them... ultimately it was also great for building rapport with the students and it was fun!'* (Andy, Physics PST)

> *'I felt it was very successful and greatly improved pupil involvement in the activity... it was memorable and exciting... it generated a great deal of interest in what would otherwise have been a tedious rote learning activity'* (Simon, Physics PST)

These brief accounts by PSTs demonstrate how a multimodal approach to learning may have the potential to increase the level of engagement of students in lessons. However, it is still debatable whether meaningful learning has taken place, as this paper focuses on the reports of teachers rather than data collection from their individual assessment tasks. Teachers' self-response indicates that this is the case, but no actual measure has been devised in this study.

An important sub-theme within this 'engagement' is the way this task allowed disenfranchised and disaffected students to become involved in lessons. PSTs reported:

> *'the activity got an SEN [special educational needs] student who often feels marginalised to volunteer to lead the activity at one point, illustrating its potential as something that can be used to foster greater student integration'* (Dimash, Biology PST)

> *'I have one student who is selectively mute and generally disengaged, and although he was not willing to perform the actions, he was happy watching his classmates, however, I did see him sneak some moves in quietly on his own!'* (Robert, Physics PST)

Students who may not be academically inclined and who find it difficult to retain concentration for long periods of time may benefit from a more dynamic, fast-paced style of teaching and learning which relies on multimodal events that might happen either simultaneously or concurrently. At the same time, students who may perceive themselves as quiet and shy might find it difficult to get physically involved in activities within a science lesson. Nevertheless, the reports above are encouraging and teachers may be able to modify the task to suit their students' needs while permitting multiple outcomes for different students. Additionally, this is the beginning of a journey into purposeful multimodal design with promising reports from PSTs. Although currently there is no evidence for increased academic grades as a result of a multimodal practice, teachers do report increased levels of recall and understanding by their students.

> *'it certainly helped them label and describe the parts correctly... and most were able to fully recall the symbols during the next task'* (Veronica, Physics PST)

> *'students were able to recall them in the topic test at the end, they told me it immediately stuck in their heads more than just copying or matching exercises (which we also did)'* (Jamal, Physics PST)

'they would refer back to actions in later lessons when they needed to recall which symbol was which and were able to explain their function more easily' (Hannah, Chemistry PST)

'students were successfully able to match up symbols to the component after this activity, throughout the unit, they were able to refer to the Kung-Fu symbols when creating their circuits and helped each other out if they had forgotten by making reference [to the movement]' (Dani, Physics PST)

DISCUSSION AND IMPLICATIONS FOR TEACHER EDUCATION

The self-reported data above indicates that purposeful and multimodal tasks may be able to support students' progress in developing basic knowledge acquisition and develop meaningful understanding of specific scientific concepts and ideas in science. There is a growing body of evidence on purposeful, multimodal and embodied learning tasks that promote learning. For example, it has been demonstrated how both verbal and movement registers (ie gestures) are essential to the development of students' understanding of scientific ideas (Roth & Welzel 2001; Givry & Roth 2006). Enyedy et al. (2012), in their research on a Learning Physics through Play (LPTP) project, have found evidence that 'embodied actions laminated with symbols invented by our students were used as a key resource to ground abstract aspects of the students' models of force and motion' (p. 375), which led to students being able to develop better conceptual understandings of those physics ideas. Tang et al. (2011) also took a socio-semiotic and multimodal perspective to study students' conceptual understanding of work–energy and 'recommend that teachers spend time in class highlighting these multimodal connections explicitly and helping students use these connections to build the thematic meaning of the scientific concept' (p. 1800). Prain et al.'s (2009) research on representations of the concept of evaporation suggests that when teacher help to negotiate both meaning and representation of specific constructs, multiple modes of accounting for knowledge acquisition may enable both better conceptual understanding and teacher insight into students' way of thinking about specific concepts.

Additionally, even at university level Huang & Roth (2011) assert that the 'professor's practical engagement in the world (e.g. inscriptions) centrally constitutes the power to communicate concepts in physics lectures. What makes physics lectures different from reading a physics book consists in the communicative capacities involved in the professor's working act' (p. 470). This implies that even when students passively watch a lecture, a teacher's multimodal representations of constructs are more powerful than a lecture from behind a podium. Thus, a better understanding of multimodality and embodied cognition is critical for classroom pedagogy to move forward, particularly when a multimodal and embodied strategy is purposefully planned and sequenced in advance by the teacher.

This argument translated into the idea of a purposeful design, with semiotic devices that are consciously shared during classroom teaching to support learning. Teachers often make spontaneous gestures when teaching. Many of the gestures used are now commonly accepted within schools. For example, 'when a teacher puts their hand up to ask for silence, all students put their hands up and fall silent' is an accepted socio-semiotic and embodied device used by many teachers in the classroom to convey a specific meaning such as 'silence, please'. The key difference here lies in the preparing specific learning sequences which elaborate and develop concepts and constructs we wish our students to acquire and understand. These gestures must be shared with students, and must be followed up with a structured task to assess the acquisition of meaning and then used the meaning in a new situation. Teachers can also work together with students to allow them to develop their own multimodal and embodied devices to complement instruction and augment understanding. Thus, constructs and concepts no longer lie embedded in a text or in verbal communication. This specific way of approaching pedagogical thinking asks teachers and students to reimagine the possibilities for teaching and learning. It requires us to ask two key questions for future research:

a) Which modes are more relevant to convey different scientific concepts? How should teachers and students interact with i) the concept/construct ii) the mode of instruction?

When making a decision on taking a multimodal approach in their classrooms, teachers must ensure they have an excellent understanding of the concept to be taught in order to prepare strategies on how scientific concepts may be translated into these modes as well as the different avenues of understanding that such modes afford for students. Students' interpretation of the knowledge acquired by these modes must be fully assessed post-instruction as well as exploring whether they are able to use them in new and different situations.

b) How can students intellectually and physically engage with multiple modes to acquire knowledge and apply their understanding?

Ultimately, as teachers our critical approach to understanding both teaching and learning as well as human cognition is a key part of our job description. While we may have our own preferred way of engaging with conceptual understanding, imposing our own way into our students' only serves to reproduce what we think is appropriate rather than providing a platform for experimentation, questioning and problem-solving that might differ from our own. ■

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