DEVELOPING PRE-SERVICE SCIENCE TEACHERS' PEDAGOGY IN AN INQUIRY-BASED CLASSROOM: EXAMINING THEIR REPRESENTATIONAL COMPETENCE AND FLUENCY

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ABSTRACT: The manner in which science is communicated is important to the way in which concepts are understood by the recipient. Multiple representations involving verbal, graphical, symbolic or experimental modes can help students to better understand science phenomena. In this study the representational competence and fluency of pre-service science teachers (N=82), who were paired to present a model that illustrates series or parallel circuits, were analysed. In addition, the extent to which simulations constrain or afford understanding in the domain was also examined. The results indicate that 56% of pre-service science teachers use simulations to afford a better understanding of electric circuits while 59% can construct an appropriate model to demonstrate concepts in direct-current electricity. However, only 7% incorporate symbolic representations to show an enhanced understanding. There is also a need for students to improve their verbal skills to better explain concepts. Some implications of this study are outlined.

Keywords: multiple representations; competence; simulations; inquiry-based science teaching

INTRODUCTION

Science teaching involves an array of strategies or methods to convey the meaning of concepts or phenomena, whilst science learning entails the development of a common, shared understanding of scientific concepts. Daniel, Bucklin, Leone and Idema (2018, p.3) posited that "in science, representations are used to display data, organize complex information, and promote a shared understanding of scientific phenomena". These representations involve verbal communication, graphical and tabular displays, diagrams, models, equations, or simulations of the concepts.

In this paper we explore the representational competence and fluency of pre-service science teachers as they develop their pedagogy in science education. In particular, we examine how students enrolled in a Natural Sciences module in a Bachelor of Education programme use multiple representations (MRs) to represent concepts relating to direct-current electricity. These students will ultimately teach Natural Sciences in the Senior Phase (Grade 7 – 9) and would need to develop their skills as they engage with the curriculum in an inquiry-based science teaching classroom. All of this is neatly encapsulated in the notion of Pedagogical Content Knowledge (PCK) as espoused by Shulman (1986, p.9):

"… I include, for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations- in a word, the ways of representing and formulating the subject that make it comprehensible to others".

Multiple representations are therefore key to the development of the science teacher's pedagogical repertoire to promote understanding of subject disciplinary knowledge.

THEORETICAL BACKGROUND

Inquiry-based Science Teaching (IBST)

In this study, Inquiry-based Science Teaching is characteristic of teachers who "structure science activities so that students are required to explain and justify their understanding, argue from data and defend their conclusions" (National Research Council, 1996, p.50). Constantinou, Tsivitanidou and Rybska (2018) advocated that pre-service and in-service science teachers be given opportunities to familiarise themselves with various inquiry-based approaches. This pedagogical approach must be infused in the classroom and the research evidence produced can inform reform efforts in science education (Buck, Latta & Leslie-Pelecky, 2007). The latter found that there is a need to enhance our efforts to ensure science teachers have the content knowledge necessary to facilitate inquiry-based learning. These classroom strategies allow pre-service science teachers to explore the complexity of teaching science through inquiry in a controlled, nonthreatening environment (Qablan & DeBaz, 2015).

Ireland et al. (2014) proposed that there is evidence to suggest that Inquiry Teaching can lead to strong learning outcomes for students which include developing accurate scientific knowledge and skills, understanding and content knowledge of science. When learners are exposed to an IBST and learning environment they are also able to link phenomena to their everyday experiences (Constantinou et al., 2018). Primary school teachers have difficulties in being effective inquiry-based science teachers because they tend to lack knowledge concerning how science inquiry works and, particularly, how to implement inquiry-based teaching in their classrooms (Alake-Tuenter et al., 2012). This serves as further motivation to engage pre-service science teachers in IBST and learning activities to empower them as future facilitators of such activities.

Multiple representations in science education

According to Tang, Degado and Moje (2014, p.306) “representations are artefacts that symbolize an idea or concept in science (e.g., force, energy, chemical bonding) and can take the form of analogies, verbal explanations, written texts, diagrams, graphs, and simulations”. The different forms are used to communicate science in a visual way and depend on the receiver’s ability to make sense of it which is consistent with scientific thinking (Daniel et al., 2018). It is often the case that some phenomena are visible at a macroscopic level, but in order to understand it requires a visual representation to explain what happens at a microscopic level. For example, in redox chemistry we can observe that zinc metal immersed in a solution of copper sulphate has a deposit that forms on it as shown in Figure 1. The explanation for this phenomenon requires visualisation of atoms and ions that are not visible to the naked eye.

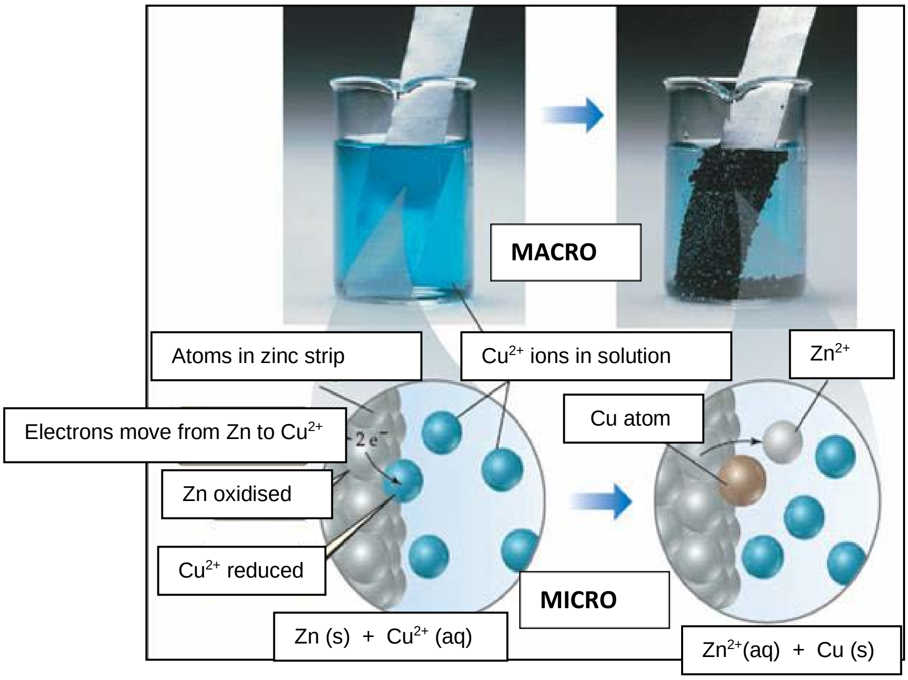

Figure 1: Macroscopic and microscopic representation of zinc metal reacting with a solution of copper sulphate

Multiple representations refer to the practice of re-representing the same concept through different forms, including verbal, graphic, and numerical modes, as well as repeated student exposures to the same concept (Prain & Waldrip, 2006). An important aspect is the ability of the student to interact between the different modes and to translate from one mode to another. The challenge is to create a teaching and learning environment which is conducive to such interactions. There is a growing body of evidence to support the value of student-generated representations in promoting learning (Waldrip & Prain, 2012). This is also underpinned by a strong pedagogical justification as students learn more effectively when they use appropriate representations. The focus of this study is on the representational competence and fluency of students as they build a model to illustrate direct-current electric circuits, and explain their observations using different modes. We also examine the use of simulations as an affordance or constraining representational mode in this disciplinary context.

Representational competence is a way of describing how a person uses a variety of perceptions of reality to make sense of and communicate understandings, whereas representational fluency is the process of translating and moving within and between representations to understand a concept (Daniel et al., 2018). The former is static and refers to the student's ability to use representations while the latter is a dynamic process of navigating between representations. The types of representations are illustrated in Figure 2.

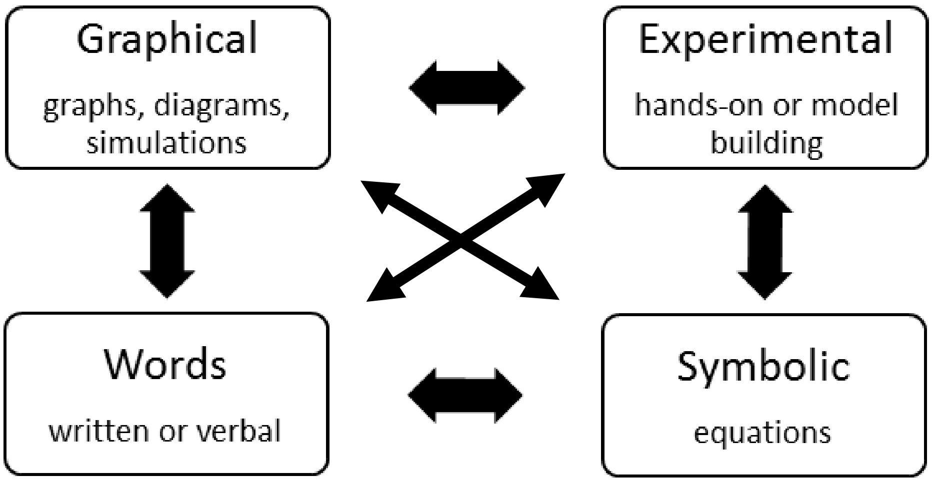

Figure 2: A representation model indicating categories of competence and fluency (adapted from Lesh & Doerr, 2003)

Various studies have attempted to measure students' representational competence (Kozma & Russell, 2005; Halverson & Friedrichsen, 2013; Mishra et al., 2018). These are all context specific such as in chemical education, biological education, etc. Students need to be able to select the appropriate representation according to a need to achieve a particular purpose (Prain & Tyler, 2013). Daniel et al. (2018, p.4) have argued that "to determine students' representational competence, representational fluency must also be addressed".

In this study a framework has been developed to measure students' representational competence and fluency as shown in Table 1.

The following research questions are addressed in this study:

1. What is the representational competence and fluency of pre-service science teachers in the domain of direct-current electricity?
2. To what extent do simulations afford or constrain pre-service science teachers' understanding of concepts in direct-current electricity?

RESEARCH METHODOLOGY

A quantitative research methodology was used which essentially allows for numerical data to be collected (Mertens, 2009). A group of second year pre-service science teachers (N=82) were paired in a Natural Sciences Education module in an IBST classroom at a South African university. They had to complete a project on electrical circuits at the end of a unit on current electricity. The model that they built had to illustrate how series or parallel electrical circuits work. They also had to explain what was observed using different representations, but importantly a simulation was required. All of this was video-recorded and later analysed according to the levels in Table 1.

Each representation mode was coded and captured in a spreadsheet. No attempt at any representation was indicated as zero (0). The frequency of each level for a particular representation was tallied and expressed as a percentage as shown in Table 2.

Table 1: Representational competency and fluency levels

	Competency & fluency		
Representation	**Low-level (1)**	**Medium-level (2)**	**High-level (3)**
Graphical (Graphs / Diagrams/ Simulations)	**Inappropriate** graphical illustration that is **not linked** to the experimental, symbolic or word representation modes. Student demonstrates **incorrect** scientific understanding of concepts.	**Partially appropriate** graphical illustration that is **partially linked** to the experimental, symbolic or word representation modes. Student demonstrates **partially correct** scientific understanding of concepts.	**Appropriate** graphical illustration that is **linked** to the experimental, symbolic or word representation modes. Student demonstrates **correct** scientific understanding of concepts.
Experimental (Hands-on/model building)	**Inappropriate** experimental illustration that is **not linked** to the graphical, symbolic or word representation modes. Student demonstrates **incorrect** scientific understanding of concepts.	**Partially appropriate** experimental illustration that is **partially linked** to the graphical, symbolic or word representation modes. Student demonstrates **partially correct** scientific understanding of concepts.	**Appropriate** experimental illustration that is **linked** to the graphical, symbolic or word representation modes. Student demonstrates **correct** scientific understanding of concepts.
Symbolic (mathematical equations/ formulae)	**Inappropriate** symbolic illustration that is **not linked** to the experimental, graphical or word representation modes. Student demonstrates **incorrect** scientific understanding of concepts.	**Partially appropriate** symbolic illustration that is **partially linked** to the experimental, graphical or word representation modes. Student demonstrates **partially correct** scientific understanding of concepts.	**Appropriate** symbolic illustration that is **linked** to the experimental, graphical or word representation modes. Student demonstrates **correct** scientific understanding of concepts.
Words (verbal/written text)	**Inappropriate** use of words that is **not linked** to the experimental, symbolic or graphical representation modes. Student demonstrates **incorrect** scientific understanding of concepts.	**Partially appropriate** use of words that is **partially linked** to the experimental, symbolic or graphical representation modes. Student demonstrates **partially correct** scientific understanding of concepts.	**Appropriate** use of words that is **linked** to the experimental, symbolic or graphical representation modes. Student demonstrates **correct** scientific understanding of concepts.

RESULTS

Table 2: Percentage representational competence and fluency at each level for pre-service science teachers

	Graphical (Graphs / Diagrams/ Simulations)	**Experimental** (Hands-on/model building)	**Symbolic** (mathematical equations/ formulae)	**Words** (verbal/written text)
No attempt	12%	5%	90%	5%
low-level	0%	5%	0%	2%
medium-level	32%	32%	2%	46%
high-level	56%	59%	7%	46%

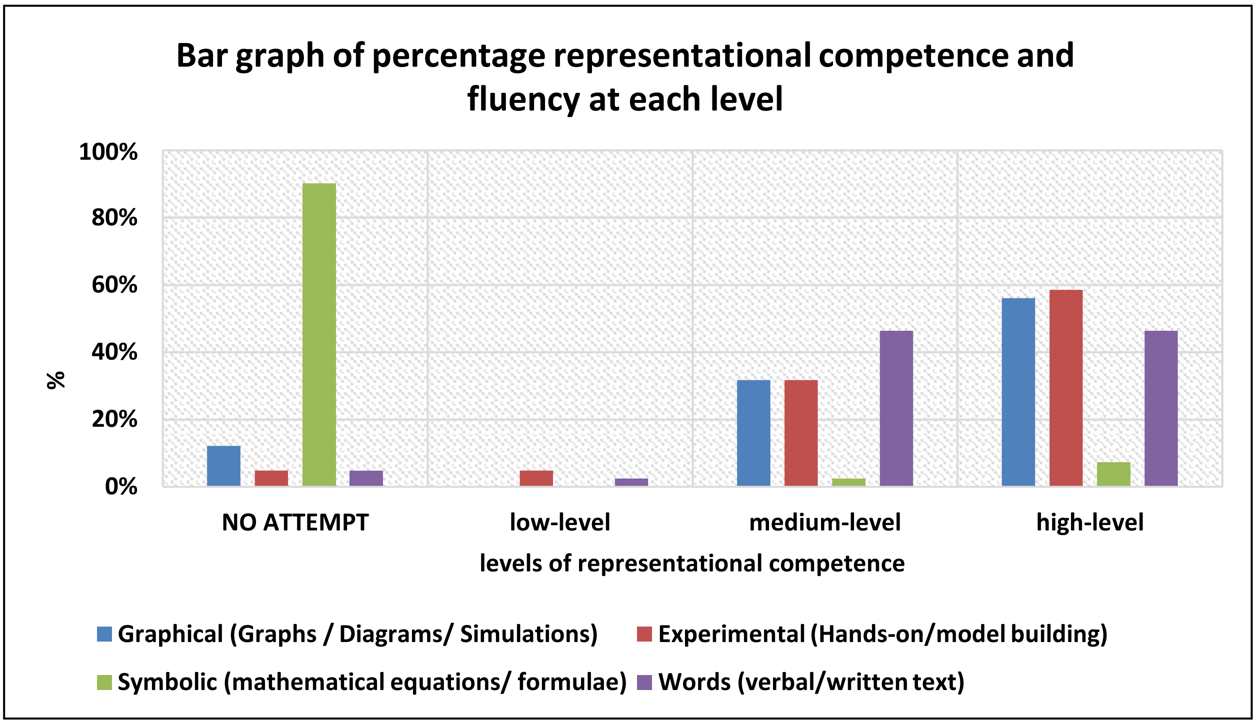

Figure 3: Bar graph of percentage representational competence and fluency for pre-service science teachers

DISCUSSION OF RESULTS

It is evident that 90% of the groups did not indicate any symbolic representation because the main focus was on the use of simulations. The 7% who used equations enhanced their explanation and made clear links between the different modes of representation. Twelve percent of the students did not attempt to use simulations or diagrams to explain their circuit while 32% and 56% were at the medium and high level respectively. This means that they were able to make partial or appropriate links by using simulations. This also shows that simulations do afford rather than constrain students' understanding of concepts in direct-current electricity.

It is noteworthy that 59% of the models were appropriate, but students' ability to explain concepts verbally using scientific language is still problematic.

CONCLUSION

It has been shown in this study that by providing students an opportunity to develop their skills through inquiry they are able to formulate explanations using different representations. This also allows them to link the science concepts to their everyday experiences such as current electricity. The value of student-generated representations depends on how they manage to internalise these artefacts that represent a concept in science. The representational competence and fluency of 56% of pre-service science teachers is at a high-level when it comes to using simulations to explain concepts in direct-current electricity, and 59% are competent at building a model. This indicates that simulations help to promote understanding in the domain.

It is recommended that students get more explicit instructions to incorporate symbolic representations in their explanations as well as opportunities to hone their argumentation skills.

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