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Multimodality in science education as productive pedagogy in a PGCE programme

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Initial teacher education programmes such as the Postgraduate Certificate in Education (PGCE) in South Africa are undergoing significant changes with the introduction of a new policy regime. This paper briefly outlines the policy changes advanced for teacher education programmes in South Africa. It examines productive pedagogies as a conceptual framework to underpin such a restructured programme. It then proposes that multiple representations can serve as a productive pedagogy of enactment in the science classroom because it engages the student with higher-order thinking skills, connects them with the world beyond the classroom in a supportive environment, and values difference by affording students multiple opportunities to develop a deep understanding of concepts. Some examples are given and the broader implications for classroom practice are discussed.

Keywords: Productive pedagogies, teacher education, multimodality, science education

Introduction

Unless initial teacher education can prepare beginning teachers to learn to do much more thoughtful and challenging work, and unless ways can be found, through professional development, to help teachers to sustain such work, traditional instruction is likely to persist in frustrating educational reform, and reformers' visions are likely to continue not to permeate practice broadly or deeply.

(Ball & Cohen, 1999: 6)

In post-apartheid South Africa, reform efforts in education have been characterised by curriculum change with little emphasis being placed on the professional development of the teacher. The breadth and scope of these curriculum

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changes necessitate a broadening of the teachers' subject knowledge as well as pedagogy to improve the teaching and learning process. Science and mathematics teaching, in particular, have borne the brunt of criticism as learners' achievements have been less than desirable in these disciplines. The country has to produce more scientists and engineers in a globally competitive environment while the declining uptake of students into these disciplines at tertiary level should be addressed as a matter of urgency. Even though the reasons for this decline are multifaceted, there is no doubt that the teacher plays a crucial role in motivating students and inculcating a positive attitude towards the subject. Ball and Cohen's concern about traditional instruction frustrating reform efforts would ring true unless teachers adapt their pedagogical practices.

The extant literature on the content knowledge of South African teachers reveals that many have not mastered the curricula they are expected to teach (Spaull, 2013: 25). Garbett (2011: 36) also argued that "teaching science effectively in primary schools is dependent upon understanding the complex relationship between learners' prior understanding, science content, teaching approaches, and pedagogical content knowledge". These sentiments resonate with the Department of Higher Education and Training's (DHET, 2011: 53) minimum set of competences required of newly qualified teachers, one of which is that they "must be able to reflect critically, in theoretically informed ways and together with their professional community of colleagues, on their own practice in order to constantly improve it and adapt it to evolving circumstances". How this will translate in reality remains a moot point as it could also be argued that the new Curriculum Assessment Policy Statement (CAPS) for Grades R-12 is very prescriptive and leaves little to the imagination of the teacher.

In this conceptual paper I address the following questions:

1. What are the policy changes that are proposed for teacher education in South Africa, particularly in relation to the Postgraduate Certificate in Education (PGCE)?
2. Is the productive pedagogies conceptual framework appropriate for a new PGCE programme?
3. How does the notion of multimodality in science education fit in with the productive pedagogies framework?

In the next section I examine the policy changes advocated for initial teacher education programmes.

Policy changes in teacher education in South Africa

Teacher education programmes in South Africa underwent a comprehensive review process for accreditation purposes from 2006 onwards. The Council on Higher Education (CHE, 2010: 48) national review report on teacher education programmes highlighted the challenges faced by the PGCE programmes in general:

- Students' undergraduate majors are no guarantee to sufficient disciplinary knowledge to build pedagogical content knowledge (PCK).
- Time constraints lead to cramming within the one-year programme.
- It is sometimes difficult to foster a common understanding with part-time staff to achieve a unity of purpose and coherence within the programme.

An external evaluation report on the Higher Education Quality Committee (HEQC) of the CHE (2009: 14) further stated that transformation is not just about the demographics of students and staff, but also the changing of teaching and learning practices. The HEQC made certain recommendations after the review in relation to these programmes. Thus, these teacher education programmes are being reconceptualised in the light of the Minimum Requirements for Teacher Education Qualifications (DHET, 2011) policy document which must have been implemented by 2015. The policy which acquired the acronym MRTEQ:

> *requires all teacher education programmes to address the critical challenges facing education in South Africa today – especially the poor content and conceptual knowledge found amongst teachers, as well as the legacies of apartheid, by incorporating situational and contextual elements that assist teachers in developing competences that enable them to deal with diversity and transformation (DHET, 2011: 6-7).*

The MRTEQ policy document outlines various type of knowledge that teachers need in order to practise effectively. Five different types of learning are proposed for the acquisition of knowledge for teaching purposes:

- Disciplinary learning refers to subject matter knowledge.
- Pedagogical learning includes general pedagogical knowledge and pedagogical content knowledge.
- Practical learning incorporates learning in and from practice.
- Fundamental learning refers to language competence, use of technology and academic literacy.
- Situational learning refers to the various contexts and environments in which learning takes place, especially the diverse challenges in the South African context such as HIV/AIDS.

The PGCE programme offers graduates in different disciplines an opportunity to develop skills and competences as teachers in specialist areas. This qualification can be phase specific from the Foundation Phase (Grades R-3) to the Further Education and Training phase Grades 10-12). It is important that students gain the necessary subject matter knowledge from their undergraduate degree so that the focus can be on the five areas of learning outlined above. Teacher educators also identify the socialising effects of school cultures as one of the external factors that undermine their best efforts (Gore, Griffiths & Ladwig, 2004: 375). It is against this background that the productive pedagogies framework is outlined in the next section and proposed as a conceptual framework for teacher education.

Productive pedagogies

Lingard, Hayes, Mills and Christie (2003: 3-4) suggested that the most significant contributor to student achievement is the teacher's classroom practice through the alignment of the curriculum, pedagogy and assessment. These Australian researchers advocated the notion of "productive pedagogies" and "productive assessment" from their Queensland School Reform Longitudinal Study (QSRLS). They stated that "the concept of productive pedagogies is intentionally postmodernist in its engagement with the difference dimension, and in its broader assumption that productive pedagogies can be manifested in multiple ways in the classroom" (Lingard et al., 2003: 7).

The concept of productive pedagogies derived from the QSRLS and examined teachers' classroom practices from a sociological perspective. It included a literature review of, among others things, "school effectiveness and school improvement research, sociocultural approaches, learning communities and constructivism, critical pedagogies, along with Freirean, indigenous, post-colonial and feminist pedagogies" (Lingard, 2010:172). The term "productive" was used because teachers' classroom work produces particular outcomes (Lingard et al., 2003: 9). These practices are intellectually demanding, connected to the world, supportive in a demanding way, and engage productively with differences. It also recognises "the epistemological doubt about knowledge forms, yet still works with a positive thesis about what teachers and schools can achieve" (Lingard et al., 2003: 7).

Lingard (2010: 72) also avers that the construction of a progressive pedagogy "was evident in the emphasis upon the constructed nature of knowledge and multiple perspectives on things and also in the constructivist and collectivist approach to learning". Bourdieu's notion of "cultural capital" was taken account of, but with the emphasis placed on providing all students with the necessary capital to navigate through their schooling. At the core was a concern about classroom practices that make a difference to student learning, particularly those from marginalised backgrounds. The 20 elements of productive pedagogies were categorised under four dimensions: intellectual quality, connectedness, supportiveness, and engagement with, and valuing of difference. These are shown in table 1 along with the productive assessment.

About 1 000 classroom observations were conducted in 24 case study schools over three years (1998-2000) and about 250 teachers were each observed four times. The findings indicated that:

> *there was a high degree of support for students (although very few opportunities for them to affect the direction of activities in the classroom), but not enough intellectual demandingness, connectedness to the world or engagement with, and valuing of, difference (Lingard, 2010: 173-174).*

The author refers to these as "pedagogies of indifference".

The dimension of intellectual quality looked at higher-order thinking and the ability of students to manipulate information and ideas through synthesis, explanation or interpretation. The depth of knowledge considered central ideas and the extent to which relatively complex relations were established. Students' depth of understanding was demonstrated through their ability to solve problems and draw conclusions. The notion of substantive conversation examined the extent of teacher–student interaction in the classroom to promote coherent understanding. Metalanguage is a reflection of whether aspects of language, grammar and technical vocabulary are foregrounded in the classroom. Hayes, Mills, Christie and Lingard (2006: 46) concluded from their findings that students benefit from activities that require them to be actively engaged in the construction of knowledge. Put differently, students who apply higher-order thinking engage with deep learning rather than surface learning; they also engage in dialogue in the classroom and see knowledge as a social construction which is subject to change. Dooly (2008: 22) accentuated the fact that students' interest in learning increases when they work collaboratively by exchanging and debating ideas within their groups. The notion of cooperative learning helps students develop a better attitude towards the subject, develop better social skills, become more articulate, and end up respecting differing viewpoints more than when they are taught in the traditional teaching modes (Herreid, 2007: 127).

The dimension of connectedness examined knowledge integration across subject areas, the students' background knowledge linking to their cultural, linguistic and everyday experiences, and the larger social context in which they live. Another aspect of this dimension involves a focus on a problem-based curriculum in which students solve a specific practical or hypothetical set of problems. In contrast, the dimension of a supportive classroom environment considers the academic engagement of students, the implicit and self-regulatory or explicit direction of their behaviour, and whether criteria for judging student performances are made explicit.

The last dimension of working with and valuing difference observed the valuing of the non-dominant culture's beliefs, languages, practices and ways of knowing, as well as the inclusion through participation of students from diverse backgrounds. The style of teaching was identified as narrative when there was an emphasis in teaching and in student responses on form and structure. Another element within this dimension "emphasises the need for schools to create learning communities in which difference and group identities are positively recognised and developed within a collaborative and supportive classroom community" (Hayes et al., 2006: 69). The last element of active citizenship recognises the right of an individual in a democratic society to participate in all the practices and institutions within that society.

Table 1 ***Relationships between productive pedagogies and productive assessment***

	Classroom practices	
Dimensions	***Productive pedagogies***	***Productive assessment***
Intellectual quality	Problematic knowledge Higher-order thinking Depth of knowledge Depth of students' understanding Substantive conversation Metalanguage	Problematic knowledge: construction of knowledge Problematic knowledge: consideration of alternatives Higher-order thinking Depth of knowledge: disciplinary content Depth of knowledge: disciplinary processes Elaborated written communication Metalanguage
Connectedness	Connectedness to the world beyond the classroom Knowledge integration Background knowledge Problem-based curriculum	Connectedness: problem connected to the world beyond the classroom Knowledge integration Link to background knowledge Problem-based curriculum Connectedness: audience beyond school
Supportiveness classroom environment	Students' direction Explicit quality performance criteria Social support Academic engagement Student self-regulation	Students' direction Explicit quality performance criteria
Engagement with and valuing of difference	Cultural knowledges Active citizenship Narrative Group identities in learning communities Representation	Cultural knowledges Active citizenship Group identities in learning communities

Source: Lingard (2010: 173)

It is evident from the productive pedagogies framework that the different dimensions address all the areas that the MRTEQ policy proposes within an initial teacher education such as the PGCE programme. There is an emphasis on quality and depth of knowledge and an awareness of the different contexts within which learning takes place. In the South African context diversity plays such an important role that the teacher must consciously cultivate and promote respect and tolerance for the views of others within the classroom. More importantly, the teacher must strive for excellence in every context to promote deep learning.

In the following section multimodality in science education is examined in detail as a productive pedagogy of enactment in the classroom.

Multimodality as a productive pedagogy of enactment in the science classroom

Developing the students' conceptual understanding in science entails a plethora of representations that allow the student to engage with disciplinary knowledge. The role that language and text plays in the process of communicating this knowledge by the teacher cannot be discounted. In adopting various pedagogical strategies within different contexts, the science teacher uses a multiplicity of modes which Airey and Linder (2009: 40, 42) term a "critical constellation of modes" in physics. The authors propose that multimodal teaching has the potential to lead to better and more comprehensive outcomes, and research should be carried out "into which constellation of modes best opens up the possibility for experiencing each of the particular ways of knowing of physics". Van Heuvelen (1991: 891) argued that student solutions are devoid of any qualitative understanding whereas physicists rely on qualitative analysis and representation.

In this section the concept of multimodal representations in science education is explored as fundamental to developing the students' conceptual understanding in science. It is also underpinned by a constructivist approach as it affords the student multiple opportunities to construct knowledge in the science classroom. In physics this was proposed as a pedagogical technique when Van Heuvelen (1991: 896) stated that "multiple exposures to skills and concepts over extended time intervals can assist in making these permanent". These tie in with the view of Lingard (2010) quoted earlier where he argued that a progressive pedagogy is evident when there are multiple perspectives on things and a constructivist and collectivist approach to learning.

Prain and Waldrip (2006: 1843-1844) highlighted the fact that learning concepts and methods in science entail understanding and conceptually linking different representational forms. This focus on multimodal representations is also consistent with the nature of scientific discourse. According to these authors, the following definitions are useful:

- "Mode" refers to the type of representation entailed in the resource (visual, experiential, 3-D written, graphic, numerical).

- “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.
- “Multi-modal” refers to the integration in science discourse of different modes to represent scientific reasoning and findings.

An important aspect is the ability of the student to interact between the different modes and to be able to translate from one mode to the other. The challenge is to develop a teaching and learning environment that allows for this type of interaction, and which caters for the different learning styles and abilities of the students. The different representational forms include such categories as descriptive (verbal, graphic, tabular), experimental, mathematical, figurative (pictorial, analogous and metaphoric), and kinaesthetic or embodied gestural understandings or representations of the same concept or process (Prain & Waldrip, 2006: 1844). In current electricity, for example, the students can engage with scientific investigations, computer simulations, 3-D models, diagrams, graphs, verbal accounts, etc.

In their exploratory study, Prain and Waldrip (2006: 1843) aimed at identifying initial beliefs and practices of a group of teachers and students (years 4-6) in Australia when the students engaged with multiple representations of the same science concepts. A multi-site case-study approach was employed with qualitative and quantitative methods; they found that while teachers used various modes to engage students and assess learning, they were not systematic in their focus on student integration and translation across modes. The study also established that various factors affected students’ understanding of different modes, and that students who recognised relationships between modes demonstrated better conceptual understanding than students who lacked this knowledge. Tytler and Prain (2010: 2075) cite Reif and Larkin (1991) who argued that understanding a concept in science involves being able to operate flexibly and coherently with a range of associated representations, and this process will involve both deductive and inductive logical modes, and non-formal personal and perceptual associations.

Tang, Chee and Yeo (2011: 1776) cite Yore and Treagust (2006) who posit the view that there is a general lack of a multi-representational framework that investigates how various representations and representational transformations (from one mode to another) promote conceptual understanding. There is also a need to conduct empirical research to show how multiple modes of representations can be used to support science achievement. Congruent with the outline above, Tang et al. (2011) define an instructional representation as a particular form of expression such as a written text, analogy, equation, table, graph, diagram, and simulation. A mode of representation, or modality, is a semiotic (meaning-making) resource system moulded and repeatedly used over time in a community. An important point of departure is that no two different representations are equivalent, and translations between representations are not as unproblematic as many would assume.

The question which they pose is how are appropriate meanings constructed through the use of any kind of representation (or combination of representations) rather than which is the right representation to use. The results of the study of the role of multimodalities in representing the work-energy concept with Grade 9 physics students showed that the thematic integration of multimodalities is both difficult and necessary for students in order to construct a scientific understanding that is congruent with the physics curriculum.

> *Positioning multiple representations, multiple modality, and textual, semiotic and symbolic modes within the larger framework of science literacy for all, can be seen by realizing that these modes and their use in science play roles in both the understanding of science and the fundamental literacy in science that allow scientists and students to construct understandings and to report and argue these ideas with others (Yore & Hand, 2010: 94).*

A further consideration of multimodal representations locates it within the broader framework of scientific literacy. Whether it is fundamental literacy or the level at which scientists engage with research and interrogate ideas in order to establish scientific knowledge, the role of multimodalities is important. Yore and Hand (2010: 96) argue further that the embeddedness of representations, experience, argument, and printed words appears to be an indicator of successful integration of mental images, conceptual understanding, and stored meaningful knowledge.

The focus on multiple representations of science concepts is consistent with a constructivist approach to learning science which is less restrictive than a traditional textbook approach. A review of the research has the following implications for teaching:

1. It is important for teachers to use multiple and multimodal representations to enhance student learning.
2. It is important for teachers to assist students in scaffolding their understandings using multiple and multimodal representations.
3. Multiple and multimodal representations need to be carefully planned into the teaching and learning material.

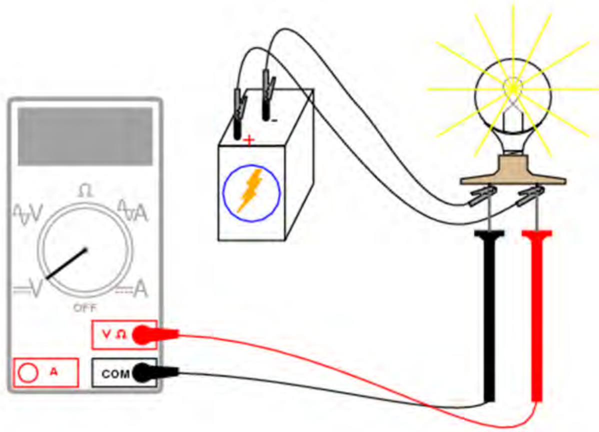
Recent research in physics education research has also highlighted the importance of multiple representations within the discipline:

- Unpacking representations is a vital aspect of coming to appreciate the disciplinary affordances of representations of attaining a more comprehensive access to the disciplinary knowledge (Fredlund, Linder, Airey & Linder, 2014: 9).
- In a case study which focused on how a particular set of representations facilitated meaning making in small-group discussions, it was found that representation affordance is critically related to how the representations get situated in a learning environment (Enghag, Forsman, Linder, MacKinnon & Moons, 2013: 643).

- For the teaching and learning of science a productive way of thinking about the signification of the representations used is in terms of their affordance which is the inherent potential of that representation to provide access to disciplinary knowledge. It is the collective disciplinary affordance that underpins appropriate holistic meaning-making (Linder, 2013: 44).

Some examples of how multimodality in the science classroom can fit in with the notion of productive pedagogies are illustrated below.

Example 1: In this example pre-service science teachers are engaged in the experimental mode (figure 1) in groups at different workstations. The students are discussing in groups of their own choice which encourages inclusiveness without anyone being allowed to dominate. This also extends the notion of a supportive classroom environment.



Observations and readings relating to current and potential difference for light bulbs connected in parallel and in series are recorded on a worksheet as shown in figure 2. The translation is from a 3-D experimental mode to written text. The use of the ammeter and voltmeter were meant to help students develop an appreciation of how the current divides in parallel while the potential difference is the same. The current reading is also associated with the relative brightness of the light bulbs. Students should recognise that the removal of a light bulb in parallel still allows the current to flow, but affects the relative brightness. This extends their knowledge beyond the classroom, because this is the way in which schools and homes are commonly connected.

Make sure that the circuit is complete and make the following observations:

A. *the brightness of the lightbulbs.*
B. *reading on ammeters.*
C. *potential difference across A, B and C (use multimeter in position as indicated).*
D. *the brightness of lightbulbs B and C when A is unscrewed (please screw back into position).*

A. The lightbulbs in parallel, A & B, are dim but of equal dimness. The lightbulb in series, however, is very bright.
B. The ammeter reading in series is 0,28 Amps. (bulb in series) and the ammeter reading in parallel is also 0,28 amps.
C. The potential difference across C is 3,6V. The potential difference across both B and C is 0,9V.
D. B and C are of equal brightness but C has become less bright than the original and B has become more bright than the original.

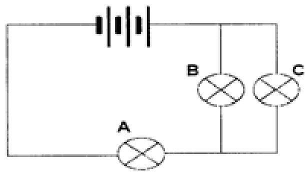
Figure 2: Experimental observations at workstation 1

Students write a test later in which the questions simulate the experimental set up. Individual answers are recorded on the sheet as in figure 3. In this multiple-choice type question the correct answer must be provided as well as justification for the answer. This links to the dimension of intellectual quality and engages students' higher-order thinking skills. They are solving a problem and drawing conclusions based on sound reasoning to substantiate their answer.

Three identical bulbs, A, B and C, are connected to a battery. Assume the battery has negligible internal resistance.

Watter EEN van die volgende kombinasies is die korrekte voorstelling van die helderheid van gloeilampe A en B, in vergelyking met hulle oorspronklike helderheid, as gloeilamp C verwyder word?

Which ONE of the following combinations correctly represents the brightness of bulbs A and B, compared to their original brightness, if bulb C is removed?



	Nuwe helderheid van gloeilamp A ***New brightness of bulb A***	**Nuwe helderheid van gloeilamp B** ***New brightness of bulb B***
A	dowwer / *dimmer*	Helderder / *brighter*
B	Helderder / *brighter*	dowwer / *dimmer*
C	Helderder / *brighter*	Helderder / *brighter*
D	dowwer / *dimmer*	dowwer / *dimmer*

3

A: B will become brighter because the current no longer "splits" and more current will be flowing through B than before. Bulb A will become dimmer because there is more resistance present as one bulb in parallel is disconnected. (3)

Figure 3: Answer to a theoretical question which simulates the experimental set up of workstation 1

At another workstation the students record the data and plot a graph of the relationship between potential difference and current for two different types of conductors. A conclusion must be written from the graph which shows a translation from the graphical to the descriptive (verbal) or mathematical as shown below in figure 4. Students are meant to make inferences about the fact that the potential difference is directly proportional to the current (written mode), V□ I (mathematical mode); the steeper gradient for Nichrome implies it has greater resistance, and the type of metal thus affects resistance.

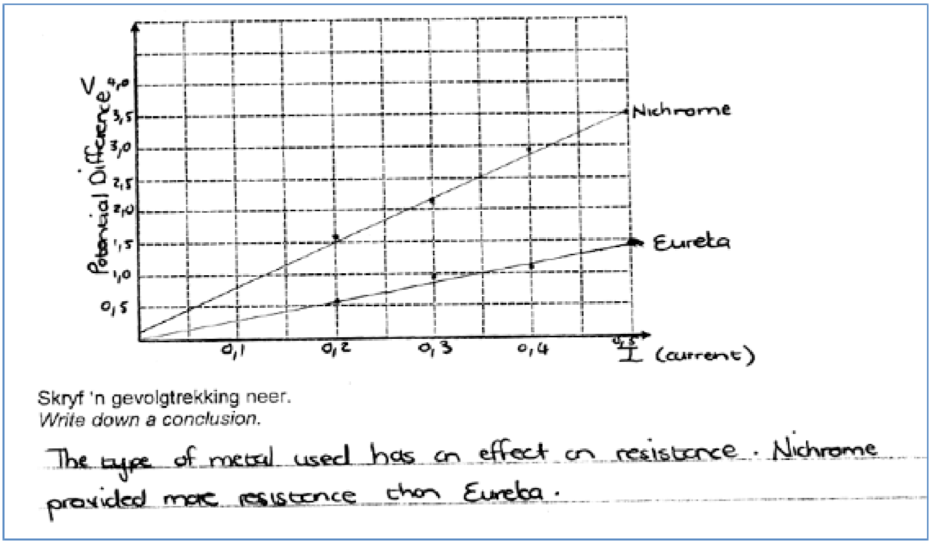
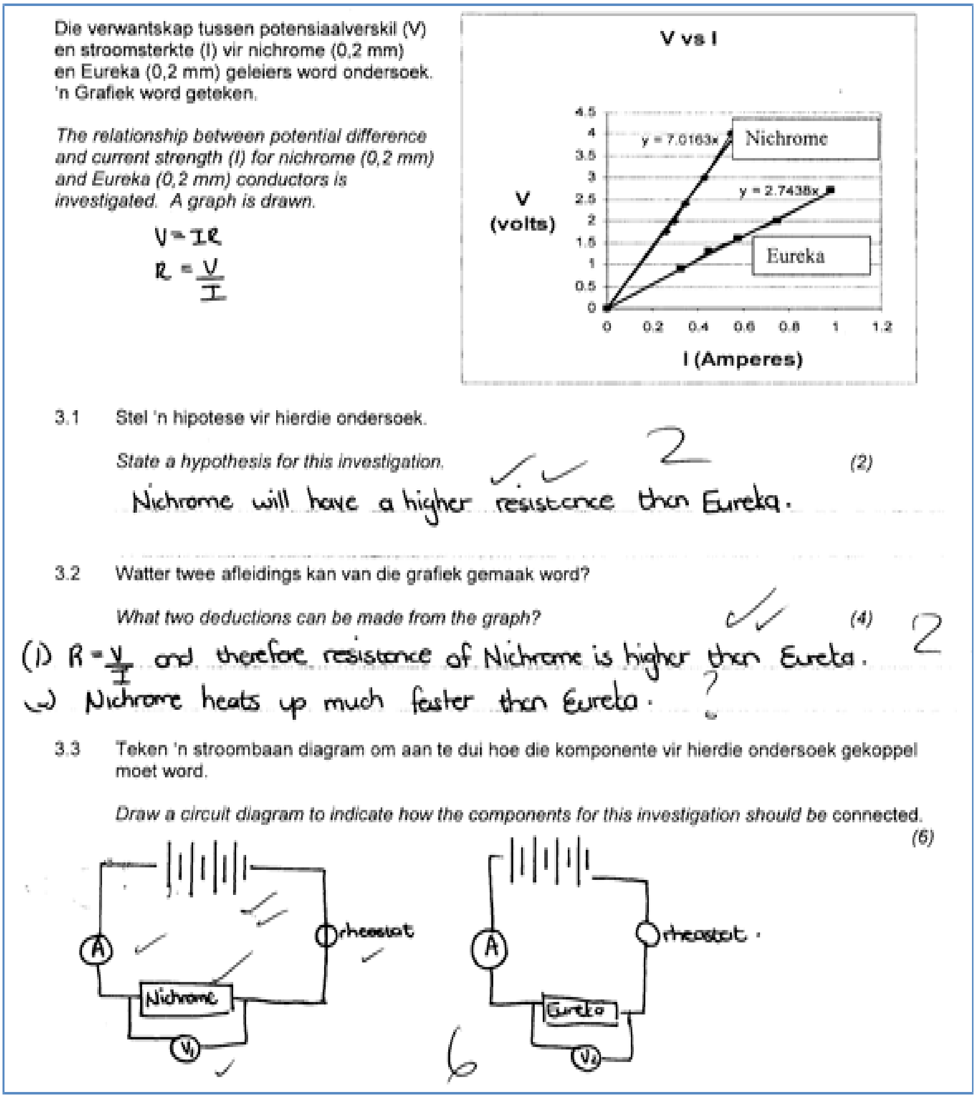


Figure 4: Experimental data are obtained to plot a graph at workstation 2

In the test that followed one of the questions has a graph which the students must use to answer related questions. This involves translation into a hypothesis, deductions and diagrammatic representation of the investigation as shown in figure 5. This encompasses a range of representations such as written, mathematical and visual.



Die verwantskap tussen potensiaalverskil (V) en stroomsterkte (I) vir nichrome (0,2 mm) en Eureka (0,2 mm) geleiers word ondersoek. 'n Grafiek word geteken.

The relationship between potential difference and current strength (I) for nichrome (0,2 mm) and Eureka (0,2 mm) conductors is investigated. A graph is drawn.

V = IR
R = V/I

3.1 Stel 'n hipotese vir hierdie ondersoek.

State a hypothesis for this investigation. (2)

Nichrome will have a higher resistance than Eureka.

2

3.2 Watter twee afleidings kan van die grafiek gemaak word?

What two deductions can be made from the graph? (4)

(1) R = V/I and therefore resistance of Nichrome is higher than Eureka.
(2) Nichrome heats up much faster than Eureka. ?

2

3.3 Teken 'n stroombaan diagram om aan te dui hoe die komponente vir hierdie ondersoek gekoppel moet word.

Draw a circuit diagram to indicate how the components for this investigation should be connected. (6)

Figure 5: ***Theoretical question which simulates the experimental set up at workstation 2***

Example 2: In this example students build a 3-D model that exhibits the principles of electricity that they have learnt in class over a six-week period. They work in groups of up to three and must demonstrate that the model works and explain the principles involved. A transcript of the explanation (verbal mode) provided by two students for their model in figure 6 follows below.

Figure 6: Students demonstrate their model to the class

Student A: "We have a series connection from this side. Then in series the resistance is much more. The potential difference of this component and that component is the same. You must also observe that the motor is moving very fast ... yes."

Student B: "The circuit is connected from the positive to the negative side where the red wire from the battery is the positive. The black wire then is the negative. As soon as I connect another component such as a light bulb in parallel, the other components such as the motor will run slower because the current must be divided. And if I connect another light bulb, it will also stop and turn much less. So the resistance decreases in the parallel connection and the current strength increases across the parallel components. What I want to add is that in most circuits a series and parallel connection is used and in this case the motor and LED are in series and the light bulbs are in parallel."

The two students demonstrated that they could translate their understanding of parallel and series combinations to a model that works. However, some parts of their argument are unsound. For example, student A refers to the potential difference across two different components connected in series as the same. Student B shows evidence of using her knowledge about parallel combinations acquired earlier to explain what happens to the effective resistance.

Discussion

Prain and Waldrip (2006: 1853) have presented the different representational modes in a case study of electricity. The pre-service science teachers were exposed to all of the modes during their six-week study of electricity in the initial teacher education programme. In example 1 the students are exposed to hands-on activities to engage with the concepts in electricity. This signifies a particular mode of representation, but it has considerable potential to be translated into other forms. The observations made and the data obtained can be translated into graphs, mathematical equations, diagrams, models and verbal descriptions.

From the evidence presented in this article, students' conceptual understanding can be scaffolded and their scientific reasoning can be cultivated by adopting a non-formulaic approach to teaching electricity. When exposed to hands-on investigations about series and parallel combinations of light bulbs, the qualitative understanding acquired during this particular representational mode can be translated into the written mode such as a worksheet. Students are also able to interpret formal representations such as graphs and translate to a written or visual mode such as a diagram to develop their conceptual understanding.

Sampson and Clark (2011: 67) have argued that, before students can explain a phenomenon, they must first make sense of it, and the explanation must then be consistent and justifiable with what is valued and appropriate in science. Osborne (2007: 179-180) proposed that students engage in dialogic interaction to construct meaning as they present their arguments with the necessary evidence. In example 2 the 3-D model has to be translated into a verbal mode when the students explain how it works. While they were not 100% correct, I would argue that it introduces them to the disciplinary ways of knowing in science. In order to develop their understanding they need to subject their arguments to their peers.

Students come from a variety of backgrounds when they enter teacher education. Some do not have the necessary background to do science education. In preparing them for the world of teaching, the development of their pedagogical content knowledge is critical. Multimodal representations function within a constructivist environment as the student assimilates their extant knowledge with new ideas to create understanding. The capacity of the student to translate between modes depends on their cognate ability. Repeated exposure to the different modalities can help in constructing appropriate meanings.

Conclusion

In positing the view that multimodal representations in science can serve as a productive pedagogy of enactment in the classroom, I want to conclude by stating to what extent it links with each of the dimensions. It is evident that students are required to engage higher-order thinking to manipulate information through analysis and interpretation. They had to demonstrate their depth of understanding by solving problems and drawing conclusions. When demonstrating their model they were actively involved in knowledge construction in front of their peers by engaging in dialogue. The collaborative efforts within the group context also develop better learning and a respect for other viewpoints (Dooly, 2008; Herreid, 2007).

There is definite knowledge integration with mathematics when dealing with graphs and calculations as well as technology when they build a model. This also allows connections with their everyday experiences of electricity when they are presented with a practical problem. Students are supported in the classroom when doing problem solving and when they are busy building their models. To an extent self-regulated behaviour is promoted, because the model constructions take place outside of class time. The criteria for assessment are also explicit because a rubric is given to the students. Students from diverse backgrounds are entering the programmes. When presenting their projects many students are unable to express themselves adequately in English. Language is not used to judge the presentation as this would prejudice these students. This speaks to the dimension of working with and valuing difference.

I have shown that productive pedagogies have the potential to serve as a powerful conceptual framework to underpin an initial teacher education programme. In South Africa there are huge challenges with regard to science education. Students would benefit from exposure to multiple representations of concepts in science which can be enacted as a productive pedagogy in the classroom.

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