

## EXPLORING THE USE OF VISUAL SEMIOTIC REASONING SKILLS AND MODELS IN A NATURAL SCIENCE CLASSROOM

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### ABSTRACT

*Currently, there is an increased recognition of the significance of incorporating Visual semiotic models (VSMs) and scientific visual reasoning skills (VSR-skills) in Science, Technology, Engineering and Mathematics education. This qualitative study sought to explore the use of VSR-skills and VSMs in a Natural Science classroom to enhance learners' conceptualisation and engagement with scientific concepts. VSR-skills are abilities to interpret and construct meaning from VSMs such as diagrams, videos, graphs, models, and simulations to gain a deeper understanding of complex scientific concepts and processes as Natural Science concepts range from organisational levels that are from simple atoms to intricate systems. Therefore, integration of VSR-skills in the Natural Science classroom can foster critical thinking, problem-solving and communication skills which are some of the competent skills needed in the 21st century learning. A multiple case study method was executed at the research sites (schools) with Natural Sciences assessment tasks and the teachers who teach Natural Sciences as a subject with a minimum of two years' experience as sampled data sources. A non-probability sampling technique was adopted. Pedagogical practices, nature and quantity of VSMs used in Natural Science classrooms, verbs used to probe VSR-skills when teaching with VSM and VSR-skills needed to interpret the VSMs used in Natural Sciences pedagogy were identified using semi-structured interviews, lesson observations and document analysis. Collected data was analysed through Interpretative Phenomenological Analysis. The results elucidated that Grade 7 teachers lack practicality command of scientific understanding of visual semiotic reasoning hence they employ teacher-centred pedagogical practices that use a maximum of four VSMs when teaching. Furthermore, embedded in their pedagogical practices, the verbs associated with VSMs in the assessment tasks do not probe VSR-skills of learners. The study recommends that it is critical to find a balance between VSMs and hands-on experiences when implementing VSMs in Natural Science classes and a longitudinal research should be conducted that can look into the long-term effects of VSMs integration on VSR skill development.*

**Key Terms:** *Natural Sciences, Visual semiotic modules, visual semiotic reasoning, semiotics, pedagogical practices, assessment*

### INTRODUCTION

Imagine how intriguing and stimulating a Natural sciences classroom would be if all primary school teachers used pedagogical practices that incorporated visual semiotic reasoning skills and models in a Natural Science classroom . VSMs can enhance the VSR-skills and visual-spatial skills that will help learners reach a high cognitive level of scientific critical thinking and critical reasoning.

Having worked as a Natural Sciences teacher in an underprivileged Olievenhoutbosch primary school, where there is a dearth of scientific laboratories and crammed classrooms. I have personally seen how using visual semiotic models in a lesson can effectively induce a flow state in which certain brain regions (prefrontal cortex) deactivate to allow other regions responsible for knowledge retention to activate and improve VSR skills, conceptualize phenomena, and successfully complete assessments. In this sense, students get better at synthesizing scientific reasoning and developing scientific concepts. This experience demonstrated how well and efficiently VSMs can improve the ability to reason well and to conceptualize scientific ideas. Visual representations often make learning more engaging and enjoyable for students, VSMs can assist in developing problem-solving skills by visually breaking down complex problems into more manageable components.

In the Natural Sciences pedagogy, teaching a topic in such a way that the learner's conceptualisation of content knowledge and scientific reasoning skills are acquired has no specific procedure (Hartmann, Upmeyer zu Belzen, Krüger & Pant, 2015). Hence Natural Science teachers worldwide have different teaching strategies and teaching ideas they can employ even when they are teaching the same topic (Gess-Newsome *et al.*, 2019). This emanates in the use of different educational scientific visual semiotic models (VSMs) such as still or moving diagrams, physical models, videos, and computer simulations appears useful as learning and teaching resources (Mnguni, 2019).

According to Mnguni (2019), VSMs are “visual models that use discipline-specific semiotics to represent scientific phenomena for teaching and learning, research and/or convey meaning”. Their effectiveness may be questioned due to the abstractness of Natural Science concepts because they are concerned with complex systems that exist at numerous levels of organization simultaneously. Teachers' content knowledge, teachers understanding of content knowledge, pedagogical skills, and learners' potential lack of visual semiotic reasoning skills (VSR-skills) that are required to interpret these VSMs and respond to assessment tasks such as practical investigations, controlled tests and examinations. VSR-skills are skills that a learner applies through visualisation when deciphering and perceiving visual traits on the VSMs with their conceptual knowledge of relevance to the VSMs. Furthermore; learners experience difficulties in comprehending visual semiotic models due to lack of knowledge about the conventions of these models. Also, they do not know how to coordinate multiple scientific representations and are unable to construct their models (Cromley *et al.* 2016). Therefore, this study aims to explore the pedagogical practices and VSR-skills required in interpreting VSM used in Natural Sciences.

### **Problem Statement**

South African learners are still performing poorly in sciences. They find it difficult to link two dimensional (2D) diagrams and drawings with three dimensional (3D) models and real-life examples. Furthermore, they have a problem in realising that VSMs are not reality but represent reality by down scaling or up scaling it. The pedagogical practices and nature of VSMs that are being used in South African Natural Science classrooms enhance the conceptualisation of Sciences concept and however do not necessarily develop of VSR and VSR-skills. Secondly, the assessment

difficulties of the assessment tasks only promote learners' ability to do sciences in knowledge and application domain but not in reasoning domain. The assessments measure content knowledge, but not the application of VSR-skills.

In addition, science education depends on the assimilation of various channels of communication and uses multiple systems of VSMs to communicate. That is, in the Sciences textbook at least three visual semiotic graphics on a separate page may be utilised by authors. The graphics may be tables, charts, graphs, photographs, drawings, maps, and more specialized visual presentations. The problem is that not all learners can explicitly integrate all the different VSMs, shuffle to and from amongst them and visual-semiotically reason with complex combinations and communicate ideas and results.

It is therefore crucial for the researcher to investigate if the pedagogical practices and VSMs used in Natural Sciences develop and strengthen the VSR-skills by exploring the Visual-Semiotic Reasoning skills needed in Natural Sciences classrooms to successfully work with VSMs and respond to assessment tasks and have high learner retention of knowledge.

The manner in which the Natural Sciences curriculum is designed does not explicitly call for visual semiotic reasoning and scientific visual literacy development in its context. Therefore, the current study aims to explore the pedagogical practices and the VSR skills required to interpret VSMs used in Grade 7 Natural Science classes and ii) to develop a framework for the selection of VSMs that are used for teaching and assessing Natural Sciences. To venture into the exploration, the specific objectives of the current study are outlined below:

- a) To explore the pedagogical practices, quantity and nature of VSMs used in a Grade 7 Natural Sciences pedagogy to promote effective conception of Natural Science content.
- b) To explore the verbs used to probe VSR-skills when teaching with VSMs.

### **Rationale**

According to Arney (2012), it is important to teach learners the art of reading semiotic resources, because it equips them with visual scientific skills that help them understand the scientific language and scientific concepts as they are employed to create knowledge and mental models (Weliweriya, Sayre, & Zollman, 2018 in Mnguni, 2019). Furthermore; depending on how they are employed, they provide the capacity for learners to create the meaning of subject knowledge Van Leeuwen (2005) in Mnguni (2019). Lopez and Pinto, (2017) resonate well with the statements attested by the scholars above when they state that VSMs are capable of long attention span stimulation and endorse stimulus. They have the advantage of outlining information in a way that knowledge is efficiently acquired and retained than when it is signified in a textual manner. Moreover, VSMs enrich the withholding of information, increase problem-solving and promote the incorporation of new and prior knowledge.

Developing a framework for integrating VSMs, teaching and assessment in Natural Sciences might equipped our learners and teachers with 21st-century skills and prepare them to fully function in the digital world that is facing the 4IR. As a math, science and technology departmental head and teacher at a primary school I want to empower learners to use the languages of visual representation, the languages of mathematical symbolism, and the languages of experimental

operations in meaningful and appropriate ways. I also want to develop South Africans' personal interest in science by functionally integrating these languages into scientific activity. I want to conduct this study with Grade 7 Natural Sciences learners because the researcher teaches the subject and in the South African schooling system learners migrate to high school after completion of Grade 7 where they will choose subjects based on their career paths and these subjects are more outlined and in detail than in the lower grades. Conducting this study might be essential because research has revealed that there is little information available on learners learning Natural Sciences using visual semeiotics and VSMs to develop VSR-skills in South Africa.

### **Research Question**

The Main Research question that guided the study was “*Which pedagogical practices are used in the Natural Science classroom and the nature and quantity of VSMs used? The secondary research question that emerged was “Which verbs can be used to probe VSR-skills when teaching with VSMs?”*”. These problems directed the efforts toward uncovering the potential benefits, challenges, and implications associated with incorporating visual semiotics into science education.

### **Theoretical framework**

This studies theoretical framework is rooted in the theories of multimedia learning and cognitive constructivism. Cognitive constructivism is a notion that controls how people learn in science subjects. The theory stipulates that knowledge and skills through the use of visual cues cannot be directly transferred from a teacher to a learner's brain submissively through osmosis but through active practical involvement. According to the theories of multimedia learning and constructivism, the major components impacting learning are (vocabulary, pronunciation, spelling, morphology, syntax, and semantics) are learners' prior knowledge and holistic participation in visualisation process. Therefore, grouping learners during hands-on activities may assist learners in effectively interpreting VSMs and critically evaluating their strengths and limitations concerning its validity and reliability in representing a particular phenomenon or concept. However, such competency requires a learner to be multimodal fluent with skills to decode, encode and reason with VSMs. Kerracher and Kennedy (2017) define visualisation as a cognitive process that involves a variety of mental processes, as stated in the theory of multimedia learning.

According to this idea, VSMs first register in the cognitive system via sense organs such as the eyes and sense of hearing. The learner then concentrates on specific characteristics of the VSMs that emerge in the development of mental cues called mental visual images within working memory. Following the construction of pictorial mental pictures, the pictorial images are grouped into logical mental representations known as pictorial models. The process of arranging the mental pictorial images is referred to as visual-spatial thinking which involves the selection, organization, and assimilation of mental images. Finally, the learner engages in the mental integration of prior knowledge in the long-term memory and the pictorial mental images in the short-term memory (Mnguni, 2019). Mayer's (2003) cognitive theory of multimedia learning is compatible with cognitive constructivist learning epistemology.

According to cognitive constructivism, learners actively develop their own meaning of the external world rather than having meaning provided to them. Making one's own knowledge of the outside

world necessitates active participation in the visualization process rather than passively absorbing supplied information in its totality.

Learners do not enter a class room as an empty vessel, they possess prior knowledge from previous grades and indigenous scientific knowledge from their cultural backgrounds and they use this knowledge to conceptualize content. Prior information, however, affects perception and attention in addition to influencing subsequent conceptual learning. As a result, differences in how students understand VSMs are also primarily a result of their prior knowledge. To choose pertinent information from images, add information from their prior knowledge, and eventually construct a mental model, learners employ their prior knowledge (Mnguni, 2019). It is significant to highlight that learners frequently choose salient qualities (like color) that are simple to understand and handle cognitively as being significant during the cognitive processing of information (Lopez & Pinto, 2017).

Information-processing theories assume that learners have a limited working memory, and when it is overloaded with information, learning will be stalled. Predominantly, it is the prior knowledge of the learner that regulates the amount of information that can be retained concurrently in working memory. Working memory can accommodate more information when it is offered in both visual and aural modalities. Using several channels can help the brain process more information (Sweller, 2020). Multimedia learning instruction improves problem-solving abilities, reasoning or thinking abilities, including perception, memory, and language.

## **METHODOLOGY**

### **Research design and sampling**

The study was conducted within the context of the social constructivist research paradigm, a theoretical framework that advocates for the use of qualitative research methodologies to increase the validity and reliability of research findings and produce new knowledge (Creswell, 2014). In keeping with the social constructivist theory, a qualitative methodology is used in this investigation to explore the pedagogical practices and the VSR skills required for interpreting VSMs used in Grade 7 Natural Science classes. The rationale for using this approach is that it will assist the researcher in gaining an in-depth understanding of the implications behind the teachers' choice of pedagogical practices and VSMs used in Natural Science classrooms and the effect they have on learners' VSR-skills. The research design employed under the qualitative approach is a multiple case study design to empirically collect and analyse data. This design was used because this study is investigating several factors such as visual semiotic reasoning skills, Visual semiotic models, and pedagogical practices.

The sampled data sources were Natural Sciences assessment tasks and the teachers who teach Natural Sciences as a subject with a minimum of two years' experience. The type of sampling that was followed is non-probability sampling

### **Data collection and analysis**

Data was imperatively collected using, lesson observation, semi-structured interviews and document protocol analysis where semi-structured interviews with six Grade 7 Natural Science teachers were conducted first and four lesson observations with some of these teachers delivering

Natural Science pedagogical content knowledge and their Natural Science assessment tasks. Semi structured interviews were analysed using the Interpretative Phenomenological Analysis (IPA) system while the lesson observations were analysed using lesson observation protocol and document protocol analysis a check list was used.

## **RESULTS**

The interview results indicated that pedagogical methods used in a science class should be learner-centred, hand-on and allow learners to be innovative active critical thinkers who are active participants who are critical to information presented to them in any mode (verbal, textual and or visual). Verbs used to probe VSR-skills when teaching with VSMs were *Explain, differentiate, describe, recall, define, collect, investigate, conduct, collect, research, test, study, calculate, classify, design, compare, recommend, measure, experiment, rate and compile*.

The observation results indicated that the lesson was more of teacher centred rather than learner-centred and the VSMs modules used by the teacher during the lessons were mostly textbooks, learner workbooks, the chalkboard and one more VSM that differed across all four observations. The activities did not have verbs that probed VSR-skills

## **FINDINGS**

Natural Science Grade 7 teachers' pedagogical practices are mostly based on direct instruction (teacher-centred) and on average, Grade 7 Natural Science teachers use four VSMs during their lessons and the VSMs are chalkboards, textbooks, learners' book and charts. Furthermore, Natural Science teachers who participated in the interviews and lesson observations portrayed a comprehensive conceptualisation of visual semiotic reasoning and its skills.

The teachers attested that they use verbs to explore the VSR-skills of the learners. The assessment tasks that were analysed indicated that the teacher's questioning technique to explore reasoning skills based on a certain VSM's used verbs such as Classify, List, Identify, Supply, Provide, Explain, Study, Label, Draw, State, Discuss, Name and Support. Consequently during the interviews, the teachers alluded that they used verbs such as; "*Elaborate, discuss, explain, distinguish, Interpret, Organize and Classify, Define, Differentiate, Investigate, Identify, Summarize, Predict, Hypothesis, Design, Describe, Recall, Collect, Investigate, Conduct, Research, Test, Study, Calculate, Classify, Compare, Recommend, Measure, Experiment, Rate and Compile, Restate and Rephrase.*"

## **DISCUSSIONS**

The use of multiple VSMs can assist learners in building a deeper conceptualisation of scientific concepts and processes than the use of single VSMs (National Research Council, 2011 in Ainsworth, 2018). These multiple uses of VSMs is more effective and significant when the content presented is complex and interrelated in such a way that one concept builds on another concept as it is a prerequisite to understanding the complexity of the concepts therefore, multimodal VSMs help learners compare and contrast graphics on the VSMs to gain a deeper understanding (Ainsworth, 2018). However, not all the VSMs that the teachers mentioned in the interviews were used. Chalkboard, textbook and learner books were not mentioned yet but were frequently used by

the teachers during their lessons. Furthermore, power point slides and videos were never used during the lesson however they were mentioned that they were used during the interviews.

When comparing the verbs alluded from the empirically collected data (interviews) and Bloom taxonomy, the majority of the verbs mentioned reverberate with the verbs associated with Bloom's taxonomy level of analysis, synthesis and evaluation that are associated with high-order thinking skills that support visual semiotic reasoning skills. However, cognitive demand illustrated during lesson observations and assessment tasks analyzed was of a low order. The activities given during the lesson did not probe learners' visual semiotic reasoning skills as the majority of the verbs used resonated well with the verbs in the level of knowledge and comprehension in the bloom taxonomy which does not probe VSR-skills.

### **RECOMMENDATIONS**

It is critical to find a balance between VSMs and hands-on experiences when implementing VSMs in Natural Science classes. Teachers need to have a sound understanding of visual semiotic reasoning and verbs utilised to probe VSR-skills of learners using scaffolding and gradual release of responsibilities, explicitly explain VSR principles and visual language elements.

Learners must develop visual semiotic process skills to properly interpret Visual Science Models (VSMs) in Natural Sciences instruction. They should be able to examine visual components, interpret symbolic representations, comprehend context, make comparisons, draw conclusions and predictions, critically evaluate VSMs, express their interpretations, and reflect on their thought processes. For future research it is recommended that there should be a longitudinal research that can look into the long-term effects of VSM integration on VSR skill development.

### **RECOMMENDATIONS**

It is critical to find a balance between VSMs and hands-on experiences when implementing VSMs in Natural Science classes. VSMs should be introduced progressively, in alignment with learning objectives, and with context for real-world applications. Encourage active participation by asking questions and encouraging critical thinking. Using a range of VSMs, scaffolding interpretive skills, and encouraging student-generated models are all good ideas. Allow time for reflection and provide chances for professional development for instructors to use VSMs effectively. By following these guidelines, educators can improve student learning in Natural Science by making careful use of VSMs.

These ideas can help teachers support learners' knowledge of visual semiotic reasoning (VSR) and successfully probe their VSR skills. Using scaffolding and gradual release of responsibilities, explicitly explain VSR principles and visual language elements. Use a variety of probing verbs to elicit specific VSR skills from learners, thereby boosting higher-order thinking. To improve VSR skills, use a variety of visual stimuli, encourage teamwork, and add reflecting activities. Provide comments and assistance, create authentic assessments, and stimulate visual interpretation innovation. Finally, give chances for teachers to participate in professional development to expand their knowledge and pedagogical practices connected to VSR.

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