Journal of Research Administration
Society of Research Administrators International

VISUALIZING SCIENCE: BRIDGING PEDAGOGY AND SEMIOTIC REASONING IN THE NATURAL SCIENCE CLASSROOM

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Abstract

There is an increased recognition of the significance of incorporating Visual semiotic models (VSMs) and scientific visual reasoning skills (VSR-skills) in Science disciplines. This qualitative study sought to explore the use of VSR-skills and VSMs in a Natural Science classroom to bridge pedagogy and semiotic reasoning in the Natural Science classroom. 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 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, observation protocol and a checklist. 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 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 models, visual semiotic reasoning, semiotics, pedagogical practices

I. Introduction

Background

1. Overview of the natural sciences classroom

Natural Sciences at the Senior Phase level serves as the foundation for continued study in more specialized Science fields such as Life Sciences, Physical Sciences, Earth Sciences, or Agricultural Sciences. It educates students for active engagement in a democratic society that honours' human rights and encourages environmental responsibility. Learners in Natural sciences are also prepared for economic activities and self-expression (CAPS, 2011). The curriculum is organized around four organizational tools of knowledge known as strands, which are meant to emphasize the connections learners must make with related topics in order to obtain a complete understanding of the nature and interconnectedness of Natural Sciences. These knowledge strands include Life and Living, which focuses on the biosphere biodiversity, Sexual Reproduction and Variation, and Matter and material, which focuses on the qualities of materials, sorting mixtures, introducing the periodic table of elements, and separating acids, bases, and neutrals. The topics of energy and change include energy sources, kinetic and potential energy, heat and energy transfer to the environment, insulation and energy conservation, and the national electrical supply system. The relationship between the Earth and the Sun, the Earth and the Moon, and the Earth's historical growth of astronomy are the main topics of Planet Earth and beyond.

Natural Science knowledge strands are abstract because they are concerned with complex systems that exist at numerous levels of organization simultaneously (Noroozi& Mulder, 2017). These organisational levels range from simple atoms to complex systems within an organism that leads to learning and teaching challenges such as learning difficulties experienced by learners, poor performance, poor content conceptualizing and poor conceptual reasoning due to a lack of depth of scientific knowledge and skills.

2. Increasing importance of effective pedagogical practices

The increasing importance of effective pedagogical practices is driven by various factors, reflecting a growing awareness of the critical role education plays in individual and societal development. The primary reasons why effective pedagogical practices are of importance are that learners have diverse learning styles, preferences, and needs. Effective pedagogy acknowledges and accommodates these differences, providing a more inclusive and personalized learning experience. Inclusion is a key focus in modern education, aiming to provide equitable opportunities for all learners, including those with diverse abilities, backgrounds, and learning needs. Effective pedagogical practices take into account the importance of inclusive education. Furthermore, there is a growing emphasis on learner-cantered learning, where learners actively engage in the learning process, take ownership of their education, and develop critical thinking skills. This allows the teacher to put emphasis on 21st-century skills, such as critical thinking, creativity, collaboration, and communication, which requires a shift in pedagogical approaches. Additionally; assessment practices are evolving to focus not only on evaluating learners but also on informing teaching and learning where emphasis is on reduction of summative assessments and creation of space for teaching and assessment of learners for learning and not of learning. Therefore, summative assessment strategies are increasingly integrated into effective pedagogy to provide timely feedback and support student progress.

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, UpmeierzuBelzen, 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". Deely and Semetsky (2017) define VSMs as the scientific model that communicate phenomenon that is spoken or unspoken using signs and/or symbols and contains spatial relationships in the external world whereas Visual Semiotic Reasoning (VSR) is the cognitive process of interpreting and building meaning from visual signals. It entails the ability to evaluate and comprehend the relationship between visual elements such as shapes, colours, lines, and symbols to derive meaning and draw conclusions.

B. Problem Statement

1. Identification of the challenges faced in natural sciences education

Grade 7 Natural Sciences education faces challenges such as abstract concepts, limited prior knowledge, language barriers, and a need for experiential learning. Integration of STEM subjects, teacher preparedness, student engagement, and inclusive perspectives pose additional difficulties. Resource constraints, assessment methods, and a lack of diverse representations further contribute to the challenges. Addressing these issues requires a comprehensive approach, including curriculum development, teacher training, resource allocation, and the promotion of an inclusive where VSMs are used to promote semiotic reasoning.

They may have challenges of "knowledge border crossing" where learners' border crossing indicates the process of learners' indigenous beliefs and practices prior knowledge to integrate it with Natural Sciences concepts and scientific culture learnt at school. These difficulties are portrayed in the high dropout rate in South Africa, low percentage of pupils studying science subjects, low scientific skills and knowledge levels among learners, low levels of learner engagement in schoolwork and poor performance of learners in international bench mark tests. One may perceive these as a poor academic level of teaching and learning in South Africa across all disciplines that is from teacher training institutions to primary schools (Fleisch, 2008; Michael, 2021; Spaull, 2013). These challenges may be also associated with the nature of VSMs used to teach, pedagogical practices that are used to present intricate abstract concepts to learners where there is a poor unfolding of content knowledge and delivery from a teacher to a learner which entails specific language of Sciences (semiotics). Alayrac et al. (2022) stated that the language used in the science discipline is characterized by intense use of metaphors, similes, anthropomorphisms, teleological expressions, scientific jargon, abbreviations, acronyms, and mathematical relations, which do not coincide with learners' daily language usage. This lack of everyday referents inhibits content misconceptions and misunderstandings that may arise from everyday meanings but creates difficulty for learners to conceptualise and visualise abstract phenomena.

2. Lack of emphasis on visual semiotic reasoning

There is a lack of research on instructional strategies using VSMs to develop scientific reasoning and VSR-skills, how do learners learn scientific reasoning and VSR-skills? How should scientific reasoning and VSR-skills be taught and assessed? Therefore, this emanates in a deficiency of research in investigating if there is any significance of using VSMs to enhance effective conception of Natural Sciences curricula and develop scientific reasoning and VSR-skills. This deficiency could be emanating from quantitative traditional assessment methods, where learners' achieved skills and knowledge are measured through quantitative teacher ratings, and controlled and uncontrolled tests. In which such do not necessarily measure reasoning skills achieved holistically. According to the curriculum assessment policy statement, high cognitive order questions that require high order skills are always assigned a low percentage (10 to 15%) from Grade four to Grade twelve in terms of competency cognitive levels (CAPS, 2011). This might make it difficult for a teacher to analyse and interpret learners achieved reasoning skills. On the contrary if one only responds successfully to high-order questions but not to middle and low-order questions they would have failed to achieve the aims and objectives of the assessment task

C. Significance of the Study

1. Addressing the gap in current pedagogical practices

While natural sciences pedagogical practices have evolved, some gaps still exist in effectively teaching and learning science. Identifying specific gaps in current pedagogical practices can be context-dependent and may vary across different educational systems, regions, and disciplines. However, some common gaps that are often discussed in the literature include lack of emphasis on inquiry based learning and teaching approaches where learners are not given adequate opportunities to explore scientific concepts through hands-on investigations, questioning, and experimentation. This goes hand in hand with inadequate use of educational technological devices such as simulations, virtual labs, and interactive software integrated into natural sciences pedagogy. Majority of the time these devices are used as teacher demonstrations which does not allow all the learners to engage with them and learn.

Furthermore, The Natural Sciences CAPS policy specifically aims at doing science, knowing the subject content and making connections and understanding the uses of science with a time allocation of ten weeks per term and three hours per week. This policy requires a flexible educator with strategic pedagogical practices. Looking at the work load in the Natural Sciences discipline the allocated time might not be enough to teach learners so that they can successfully conceptualise its content knowledge and Semiotic Reasoning in the Natural Sciences Classroom. This might indicate that there is a limited focus on the Natural Sciences pedagogy

Developing scientific literacy which includes the ability to critically evaluate scientific information has also portrayed some gaps as it is not always a focal point. There may be a gap in teaching learners how to analyse scientific claims, interpret data, and make informed decisions based on evidence. This might result in teachers facing challenges in staying abreast of the latest developments in Natural Sciences and effective pedagogical strategies. There may be a gap in providing ongoing professional development opportunities to enhance teachers' content knowledge and instructional skills.

To address these gaps an ongoing collaboration among educators, curriculum developers, policymakers, and researchers to promote evidence-based practices, continuous professional development, and a commitment to fostering a deep and meaningful understanding of natural sciences among learners is required.

2. Enhancing learners' conceptual understanding of Natural Sciences through visual reasoning

A learner needs to be motivated to be holistically engaged in any task. Motivation in a science class room can be induced by using VSMs that learners correspond to and enjoy working with. They also have to be given activities that enhance overlearning. Overlearning refers to practicing newly acquired skills beyond the point of initial mastery (Fan, Xiao &Su, 2015). Therefore, the activity should be challenging but manageable and intrinsically rewarding and have the ability to stimulate and exercise the brain of learners. On the other hand, "VSMs are capable of long attention span stimulation and endorse stimulus. They have the advantage of outlining information in a way that knowledge is more efficiently acquired and retained than when it is signified in a textual manner. Furthermore, VSMs enrich the withholding of information, increase problem-solving solving, scientific reasoning and promote the incorporation of new and prior knowledge (Cook, 2006 as cited in Taukobong, 2018 p. 15)."

Moreover, the VSMs utilised in a class must be interactive so that they can afford learners to visually explore scientific Natural science concepts in a virtual classroom, manipulate variables, observe the outcomes and draw conclusions from virtual experiments that are used. Additionally, learners' conceptual understanding of Natural Sciences through visual reasoning can be enhanced through integration of 5E instructional model adopted from (Açışlı, Yalçın& Turgut, 2011) can be utilised. The 5E instructional model is a framework for organizing and structuring teaching and learning activities in a way that promotes active engagement, exploration, and deeper understanding of concepts. The 5E model consists of five phases: Engage, Explore, Explain, Elaborate, and Evaluate. Each phase serves a specific purpose in guiding students through the learning process.

II. 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.

III. 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 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 were analysed.

IV. Results

The results indicate that the teachers experience challenges such as different visualization perspectives, lack of learning materials and resources, load shedding, time to set up VSMs and limited resources to teach. They further indicated that teachers and learners face challenges encountered on lack of emphasis on visual semiotic reasoning is miscommunication where significant features (colour, size, texture, lines) on the VSMs may cloud learners' focus and interpretation of VSMs used to represent certain phenomena. These factors are fundamentals for thorough conception and interpretation of VSMs and should be explicitly addressed to enhance the VSR and VSR-skills of our learners. A teacher can design tasks with the objective of reinforcing reasoning skills through using VSMs and learners' conceptual knowledge. However, learners' conceptual knowledge may result in misconceptions and misunderstanding of content due to multiple unintended meanings depicted by the VSMs.

The results elucidate that the teachers need to improve learners' scientific reasoning skills using different VSMs such as charts, puzzles, memory games, experiments, pictures and videos should incorporated in their pedagogical practices. Furthermore, the VSMs should be coupled with activities that have the same observations and administer spelling tests weekly. (See Table 1)

Table 1: Strategies and methodologies teachers utilize to develop and enhance scientific reasoning in NS classrooms.

Strategy and methodology

Usage of multimedia learning and integration of VSMs (charts, internet, models, videos, smart phone and real-life examples).
Ask scientific high-order questions and activities that enhance problem-solving skills
Use of the scientific method
Utilization of experiments and practical activities
Use of informal tasks to allow learners to state their hypothesis and explain how and why things work the way they do
Facilitate group work and co-operative learning
Allowing learners to freely give inputs and elaborate on their inputs
Repeat scientific terminologies
Use problem-based learning and debates by giving learners scenarios they can deliberate on
Build on learners' prior knowledge by using Inquiry-based learning
Use blooms taxonomy as part of the questioning technique

In terms of addressing the gap in current pedagogical practices the results indicated that there is a need to implement innovative pedagogical practices integrated with interactive and hands-on activities, real-world applications, and experiential learning to capture learners' interest and curiosity. This can make Natural Science classes more engaging for learners. Furthermore, interactive and inquiry-based learning approaches needs to be reinforced as they can contribute to better knowledge retention.

They further alluded that addressing gaps in pedagogical practices can foster a sense of scientific inquiry and curiosity among learners. Encouraging them to ask questions, explore topics independently, and conduct experiments can nurture a passion for the natural sciences. On the other hand teachers need to be supported with resources and innovative pedagogical practices development so that they can experience greater job satisfaction when they witness increased learner engagement and understanding. The support can make teaching more dynamic and fulfilling for instructors.

V. Discussion

Schönborn and Anderson (2009) stated that teachers should Discourse contextual factors that inhibit learners' ability to envision VSMs, Explicitly make conceptual knowledge illustrated by the VSMs unambiguous to learners, Scientific understanding of the semiotics and conventions used by VSMs must be explicitly communicated to learners, Equip learners with the scientific and VSR- skills required to process VSMs and learners should be notified of the restrictions and delimitations of the VSMs. When the teachers were observed, none of the teachers addressed the limitations of each VSMs used to represent phenomena. It was as if they assumed that learners knew that VSMs represent reality and are not reality and what each aspect of the VSM means in context.

The Natural Science Grade 7 teachers need training and development on the selection of relevant VSMs and how to teach and assess using VSMs to enhance VSRs of learners.According to Okai-Ugbaje (2021),developing a framework for integration of VSMs in Natural Science pedagogy requires a systematic approach that would encompass the diverse needs of learners, pedagogical practices and nature of VSMs. It is empirical to identify the VSMs, pedagogical practices and VSMs commonly used to teach and assess Natural Science. The scholars further stipulate that a framework for integration of VSMs in Natural Science pedagogy should incorporate the conceptualization of the nature of science, visual literacy, semiotics and how it relates to VSMs in scientific communication, design principles, pedagogical approaches, assessment strategies and professional development.

According to Qu (2016), there are some ways in which teachers can be supported and developed on how to integrate VSMs to enhance visual semiotic reasoning skills of the learners. The strategies are but not limited to providing professional development workshops, provide Resources, create Lesson Plans, encourage peer collaboration and provide constructive feedback

VI. Conclusion

To sum up, the use of visual components and semiotic reasoning in Natural Science classes is a revolutionary method of teaching that has enormous possibilities for teachers and students alike. Acknowledging the mutually beneficial connection between scientific comprehension and visual communication is essential in closing the gap in the methods of instruction used today. The instructional paradigm known as "Visualizing Science" recognizes that scientific notions are inherently visual and highlights the crucial role that semiotic reasoning plays in interpreting visual language.

Teachers can reap a multitude of benefits when they adopt the principles of scientific visualization. Increased engagement, better conceptual understanding, and the development of critical thinking abilities are all benefits that learners stand to receive. The incorporation of visual components opens up doors to the practical applications of scientific ideas in addition to making them more approachable. This method encourages kids to be curious, to conduct scientific research, and to have a lifetime love of learning.

Teachers themselves are essential in helping students visualize science. Initiatives for professional development can provide them with the skills and information required to slickly integrate semiotic reasoning and visual components into their teaching methods. In addition to immediately benefiting students, the dynamic interaction between semiotic thinking and pedagogy also makes educators happier in their work because they see the favourable effects on student learning outcomes.

The Visualizing Science framework has an impact on the wider educational scene in addition to the classroom. It starts conversations on how to further enhance the learning process through the use of technology, assessment techniques, and curriculum design. Essentially, Visualizing Science becomes a lighthouse for revolutionary teaching in the Natural Science classroom. It fills in the gaps in pedagogical methods that currently exist while also advancing scientific education into a field where visual and semiotic literacy are recognized as essential instruments for discovering the mysteries of nature. Visualizing Science acts as a beacon of guidance over the often confusing terrain of scientific knowledge, showing the way to more interesting, inclusive, and successful methods of teaching and learning about the natural sciences.

Implications for improving science education

Recommendations

1. Educators' Professional Development:

Put in place thorough professional development programs that give teachers the information and abilities they need to successfully incorporate semiotic reasoning and visual components into their lessons. Teachers can become more adept at navigating the subtleties of visual communication in the context of science education by participating in workshops, seminars, and continuous training sessions.

2. Cooperative Curriculum Development:

To create curricula that smoothly incorporate visual features, educators, curriculum designers, and experts in visual communication should collaborate. Curriculum that emphasizes Visualizing Science should be developed in accordance with academic standards and include creative teaching strategies that give priority to semiotic and visual literacy.

3. Development of Resources:

Build and maintain an extensive collection of visual aids for natural science instruction, such as pictures, charts, films, and interactive simulations. Give teachers quick access to these resources so they can improve their lesson plans and accommodate a range of learning preferences.

4. Techniques for Assessment:

Reconsider evaluation techniques to make them consistent with the Visualizing Science paradigm. Introduce formative tests that measure students' abilities in semiotic reasoning and visual literacy. Take into account project-based evaluations that let pupils illustrate their learning using imaginative visual aids.

5. Research and Evaluation:

Encourage research initiatives to assess the effectiveness of Visualizing Science in improving student outcomes. Conduct regular evaluations of the implemented strategies and gather feedback from educators, students, and parents to inform continuous improvement.

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