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Research Article

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Local community beads: Representation to enhance learning about the Bohr structure in science

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ABSTRACT

This paper explored the ways learners respond to and express themselves while interacting with cultural artifacts or cultural realia, for instance, *beads*, that can be used to mediate the learning of physical science concepts. The study mandates that a culturally responsive pedagogy be used to teach indigenous learners to assist them in learning science concepts. Hence, the choice of beads, cultural artifacts found in learners' lived world as realia, creates an enabling context accessible to teachers and learners. Many learners from Namibian in under-resourced schools seem to find science concepts as abstract and difficult to learn. We assume this could be because science is decontextualized and not relevant to learners' everyday lives. It is against this background that this study explored the use of beads as models of representations to mediate learning of Bohr structure in a grade 8 physical science class. The interpretive paradigm informs it. Data was collected from 30 junior secondary school learners in grade 8 class at Ndambu-Kanyanga Combined School using brainstorming and reflections. The socio-cultural theory was used as a theoretical framework. The findings of this study revealed that models and representations enable learners to focus on different particles of the Bohr structure. The study thus recommends that teaching strategies in Namibia should encourage accommodation representations when teaching physical science.

Keywords: physical science, Bohr structure, models, beads, socio-cultural theory

INTRODUCTION

In teaching science, using models is essential for helping learners develop a strong understanding of concepts. In view of Vygotsky (1978) learning and teaching theory, humans are cultural beings and are creators of culture. Humans construct their physical, mental, and emotional being from their interconnections with their environment in the form of everyday knowledge (Chawla, 2020). In the classrooms, learners can co-create their lived experiences, and learning, as they relate to both teachers, learning agents such as instructional materials and cultural artifacts. To facilitate learning science, it is pertinent for teachers and learners to relate science to their lived world, or their cultural realia as Mhakure and Otulaja (2017) argue. This study aimed to present to learners to promote scientific knowledge building.

Galili (2022) alludes to culture as the lens through which learners process, interpret, and understand the subject matter, which in this case is science concepts. Learning in Indigenous learners is much more than just obtaining good marks in class; it is a way of life, of relating to each other and what is learned, for example, in science, to their environment, and for helping solve problems. Here, we present a robust representational artifact capable of producing insightful drawings and tangible models of abstract quantum phenomena. While this method may not be suitable for all types of abstract phenomena in physical science, it is particularly relevant to the important field of electron configuration information processing.

Models make it easy and affordable to create representations of concepts, providing learners with tangible versions of abstract ideas. The basis supporting this paper is the research done dealing with a model of representation and visualizations (Rangkuti & Karam, 2023), to adapt a curriculum so that it meets the conceptual needs of the learners (Mukwambo et al., 2018). The concept of the atom is fundamental to physical science and is a key component of science education (Makhmudov & Khudayberganov, 2023). As atoms and molecules are too small to be seen with the naked eye, models are necessary for describing and communicating the particles of atoms in matter (Tuzón & Solbes, 2024). Analogical models can be concrete, for instance, atoms represented as balls (Dahlkemper et al., 2022). We regard that models can only act as aids to understanding and recalling, explanatory tools, and learning devices if they are easily understood and remembered by learners.

The lack of use of models and practical activities with the meaning of the model is experienced not only by learners at Ndambu-Kanyanga Combined School but is also a phenomenon found in the entire country attributed to teachers not embracing models of representation and visualizations embracing cultural artefacts. This led to the engagement of learners in the mentioned circuit to develop a model of representation to mediate learning of Bohr structure in a grade 8 physical science class. Studies in chemistry education demonstrate the promise of hands-on models and are designed to serve as scaffolds for novice learners to develop representational competence when working with beads for representations in chemistry topics (Wang et al., 2021). There is a need to consider misconceptions in science classrooms as they can negatively interfere with the learning of scientific concepts (Pekmez, 2018). However, misconceptions on the other hand can stimulate learning (Crogman & Trebeau Crogman, 2018). As atoms and molecules are too small to be seen with the naked eye, models are necessary for describing and communicating the particles of atoms in matter (Netzell, 2015). For instance, associating familiar items in teaching learners about atomic structure could be the best idea for learners' conceptual development. The study thus sought to address the following research questions:

1. What are grade 8 physical science learners' views and know-how about learning atoms and atomic structure?
2. How do models of representations shift learners' meaning-making after they engage with the analogical bead model of the Bohr structure?

The ideas for this paper are contextualized within a larger research work on the possibilities of using beads as a place-based learning tool in the teaching and learning of physical science concepts. Both teachers and learners have universal curriculum resources at their disposal to construct teaching and learning experiences as will be revealed in the literature review to follow.

LITERATURE REVIEW

Beads Model as Culturally Responsive Pedagogy

In the notion of the study, we opt for beads that physical science teachers use as teaching and learning materials to mediate the learning of Bohr structures. Beads are the learners' cultural mediating artifacts and honor the community members' pride (Fakoyede & Otulaja, 2020). Ideally, we introduce a generalized readily local representation of the electron configuration of an element that describes how electrons are distributed in its atomic orbits. This is called the *beads* representation, which makes it possible to visualize arbitrary considerable states spontaneously and easily. At the same time, our representation is exact and objective. It bridges the gap between the highly abstract description of orbital phenomena and the mission to convey them in explicit terms of meaningful pictures and tangible models.

The bead is defined as a small, decorative object that is formed in a variety of shapes and sizes of material such as stone, bone, shell, glass, plastic, wood, or pearl and with a small hole for threading or stringing (Miller, 2019). **Figure 1** shows the plastic bead we sought necessary to represent electrons in each energy level, the orbits.

Figure 1. Plastic-beads learners used to make a Bohr model structure of the atom cell (Source: Authors' own elaboration)

Socially, beads such as nephrite, emerald, green jade, and Amazon stones symbolize lush vegetation, the rain that nourishes it, fertility in humans and animals (Leong et al., 2019), and strength more broadly. In science education, these beads are considered valuable in helping learners visualize tiny electrons orbiting their pathways, as well as protons and neutrons within the nucleus of an atom.

Bohr Structure and Its Representation

In this study, atomistic representation involves beads attached to a sphere of iron, which is then wrapped in copper wire. Through this approach, we present several examples of solving materials in science problems using deep learning (DL) methods within an atomistic framework. Learners can conceptualize each bead as representing a single atom of an element. The challenge arises when dealing with an arbitrary number of atoms and element types in a system, making traditional methods less effective for atomistic predictions.

DL-based techniques offer a promising solution to this issue (Choudhary et al., 2022). We align this representation with teaching by analogy, bridging theory and practice (Gray & Holyoak, 2021). Nkadimeng and Ankiewicz (2022) explored the potential of Minecraft Education as a game-based learning tool for teaching atomic structure in junior high science classes matrix (Raghunathan & Priyakumar, 2022). In our study, we engaged learners with a sociocultural artifact that holds social meaning and serves as a symbolic aid in learning the Bohr model in a rural school setting.

Learners' Knowledge of the Bohr Structure

Studies on learners' understanding of the atom often focus on atomic identity and behavior, while others, like the present study, examines how learners represent atomic structure. Research indicates that textual descriptions from learners reveal numerous misconceptions across various age groups (Abasseri et al, 2024). For instance, some learners mistakenly attribute macroscopic properties to atoms themselves, assuming that the properties of individual atoms match those of the substance such as oxygen atoms being in a gaseous state or iron atoms being in a solid state (Yaşar, 2024).

Other misconceptions arise from a lack of distinction between atoms and other entities, such as cells or molecules, leading learners to treat "atom" and "molecule" as synonyms. For example, some believe that water molecules consist of

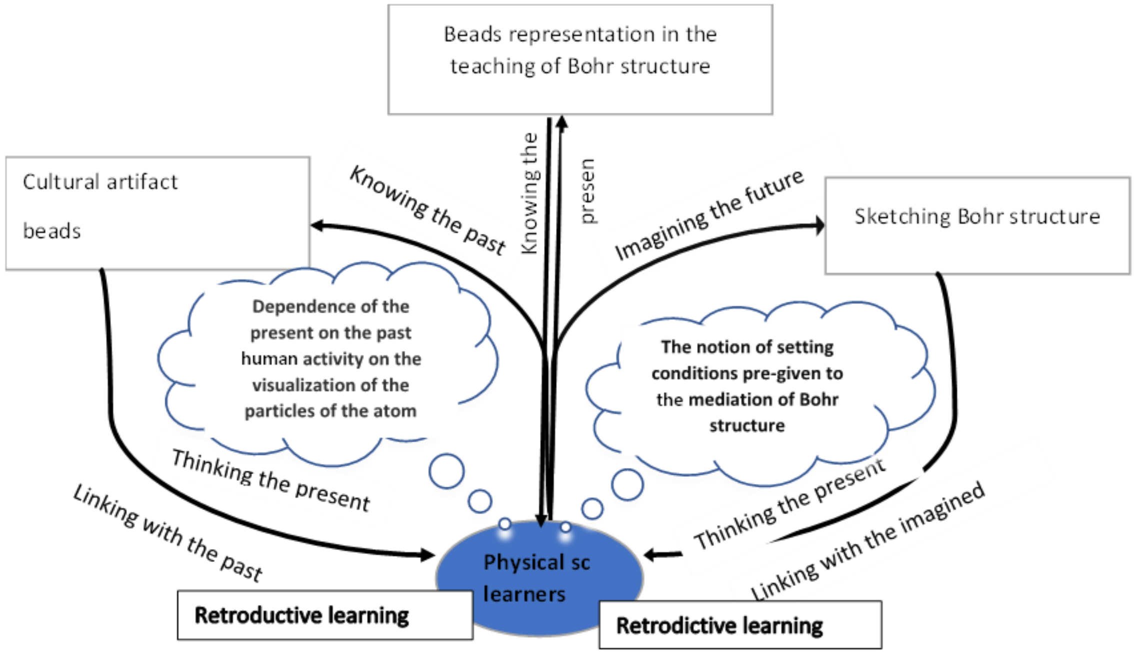

Figure 2. Learning process of integrating IK into science (Adapted from Chikamori et al., 2019, p. 9)

separate hydrogen and oxygen molecules, or use "molecule" and "atom" interchangeably (Zarkadis et al., 2020).

Learners' conceptions of atomic characteristics, including identity and behavior, significantly impact their mental models of atomic structure. A literature review reveals the general categories of these models, organized from simplest to most complexes (Zarkadis et al., 2020):

1. **Particle model:** Atoms are seen simply as particles without further detail.
2. **Atom cell model:** The atom is represented similarly to a cell.
3. **Solar system model:** Representations include electron orbits, with or without specified energy levels, resembling a solar system (Zarkadis et al., 2021).

Many physical science learners rely on the Bohr model to visualize and imagine the atom's invisible particles. For example, they may draw circles to represent electron orbits, though the electrons themselves remain invisible to their minds.

Textbook as Curriculum Resources

The textbook is a curriculum element used as a standard source of knowledge for the prescribed study of a subject and an instrument for teaching and learning (Pangestika et al., 2023). It should be considered as one of the numerous sources teachers can pull upon in constructing an effective lesson and may bid a framework of coordination and direction.

It is essential to highlight that there is no perfect textbook, perfect for every teacher, perfect for every group of learners, and perfect in every way of teaching (Gray & Holyoak, 2021). This brings the need to make a significant move away from prescriptive curriculum to enable learners' ways of understanding natural phenomena to be incorporated. Social interaction among individuals plays an integral part in how people teach (Chuang, 2021). Learner–learner and learner–teacher interactions are important ingredients of learning from a constructivist perspective. For Vygotsky (1978), cognitive development begins with an interaction between the child and a more knowledgeable other, and the social processes are then transformed into the child's internal mental schema as Piaget (1977) suggests. Thus, the bead cultural artifact represents a form of technological knowledge developed locally as an atom cell model.

CONCEPTUAL AND THEORETICAL FRAMEWORK

Conceptual Framework

The study was designed to address a research gap in teaching physical science, particularly in representing the Bohr model using beads in a rural Namibian school. This conceptual framework was designed in alignment with the research questions. For grade 8 physical science to reach optimum levels of critical thinking they must apply dialogical arguments in reaching decisions (Van Staden, 2023). In addition to the dialogical argumentation instructional model, the study was also informed by the transformational model of education for sustainable development (TMESD) framework, significant to which is designing, implementing, and improving indigenous knowledge (IK) integrated science teaching (Chikamori et al., 2019) (**Figure 2**).

Chikamori et al. (2019) explain that the TMESD framework consists of three learning interrelated sub-processes: '*knowing the present*', '*past-present relationships*' as well as the '*future-present*'. To these scholars, knowing or studying past-present relationships is referred to as *retroduction*. On the other hand, future-present relationships are referred to as *retrodiction*. In the study context, retroductive learning emphasizes hypothesizing the causes of observed effects. It encourages learners to identify and understand the foundational principles behind the Bohr model. This approach is often used to generate explanations by questioning and connecting evidence to the process of drawing the Bohr structure. In contrast, retrodictive focuses on reasoning backward from a known outcome to understand the sequence of decisions model that led to it.

In this study, this framework emphasizes reconstructing the steps that led to a particular understanding of electron configuration representation. Additionally, *retroductive* learning tends to be more theory-driven, while *retrodictive* learning usually has a practical focus, such as mapping out steps in electron orbitals which allows our beads model to complement *retrodictive* learning framework.

Theoretical Framework

This work is based on the idea that cultural artifacts serve as mediating tools for teaching and learning abstract science concepts in classrooms–Bohr structure. Vygotsky (1978) suggests that artifacts smoothen meaning making between subjects and objects. In this study, artifacts like beads, and learners' local languages serve as mediators, enhancing peer interactions in science classes.

A teacher is regarded as a knowledge broker (Rycroft-Smith, 2022), and uses cultural artefacts such as beads, and local languages to engage learners. Socio-cultural theory (SCT) was used as a theoretical framework in this study. Consequently, learners' negotiations of meaning and consensus building may adopt a cognitive stance that is most favorable or comfortable with their level of understanding. Through a case study, this paper highlights the use of new analytical methodologies for studying the content and patterns of learners' interactions and how these contribute to their construction of knowledge (Kumpulainen & Kajamaa, 2021). From Vygotsky's (1978) SCT, in this study, we used the following concepts from the SCT: mediation of learning, social interactions, zone of proximal development (ZPD), and self-regulation. Each of these concepts is discussed in the following sections.

Mediation of learning

Akhundi et al. (2019) identify two theories that emphasize a mediation approach to learning: Vygotsky's (1978) SCT and Feuerstein's theory of mediated learning experience (MLE) (Hong-Fen, 2022). Both SCT and MLE centered on the concept of mediation, examining how sociocultural influences and shape learners' development and understanding of concepts, such as Bohr's atomic structure in the context of this study. SCT focuses on mediation as a process where a novice learns with support from others.

Through mediation learning, teachers guide learners from familiar knowledge to new knowledge, often using artifacts (Álvarez, 2021). Mediation occurs between people with differing knowledge levels about the subject (Engeström & Sannino, 2021). Xi and Lantolf (2021) similarly describe learning mediation as a bridge between current mental development stages, achieved through ZPD (Stott & Hobden, 2019; Vygotsky, 1978).

Challenges in learning physical science concepts are linked to learners' cognitive inabilities, which may not be fully developed to connect representations to content knowledge (Jacob et al., 2020). McCarthy and McNamara (2023) argue that learning activities should progress from known to unknown or from simple to complex, building on prior knowledge. Models often serve as visual aids to represent objects that are too large or small to observe directly, helping learners visualize concepts (McCarthy & McNamara, 2023). In this study, "cognitive" refers to processes of perceiving, as cognitive scientists aim to understand mental functions like perception, thought, memory, language, and learning (Plebe & Perconti, 2022).

Social interactions

Vygotsky (1978) proposed that learning is a socially mediated process beginning at the social level, where learners engage with peers and more knowledgeable individuals. Rubtsov (2016) describes social interactions as a mechanism for sharing and understanding functions. Knowledge is thus seen as collectively constructed, rather than a matter of correct or incorrect individual possession. Vygotsky's (1978) theory served as a framework to explore how grade 8 physical science constructed knowledge and generated new ideas during the lessons.

Zone of proximal development

Vygotsky (1978) defined ZPD as the distance between a learner's current developmental level, demonstrated through independent problem-solving, and the potential developmental level achievable through collaborative problem-solving with more knowledgeable peers or adults. Vygotsky's (1978) observations revealed that learners perform better when working collaboratively than independently. Kim (2017). later viewed the multidimensional model of Vygotsky's (1978) ZPD as a valuable conceptual tool for enhancing learners' conceptual development.

In ZPD theory, "actual development" refers to a learner's independent capabilities, while "potential development" encompasses skills and understanding that are beyond the learner's unaided reach. ZPD-oriented assessments thus gauge both current achievements and future developmental potential (Vygotsky, 1978).

RESEARCH DESIGN

Methods

The study is grounded in the SCT of Vygotsky (1978) within a social constructivist framework, recognizing that science learning develops through social and collaborative interactions, promoting internalization and enhancing self-efficacy (Ngo, 2024). A case study underpinned by an interpretive paradigm (Rahi, 2017) was adopted and the unit of analysis was the conceptual development of the Bohr structure. Data were generated using the grade 8 learners' completed worksheets or tasks and reflective journals.

Participant and Data Collection Methods

The sample for the study comprised 38 grade 8 physical science learners at Ndambu Kanyanga Combined School (pseudonym) in the Kandjimi circuit of the Kavango West Region. At the time of this study, it was the first time the school offered grade 8 after the revised curriculum called the national curriculum for basic education 2016. Qualitative data collection encompassed the generation of qualitative data through classroom observation, learner interviews, and document analysis. In all, a sample of 15 learners was purposively selected from a pool of 38 learners who successfully participated and attended the physical science lessons since the school was the first to offer this grade 8. To facilitate this, the observation schedule devised by researchers was employed, encompassing the action and elements involved in learning the Bohr structure. The schedule comprised predefined criteria, which the researchers marked off while observing learners engaging in the lesson of the Bohr structure. Documents such as learners' exercise books, and diagnostic and summative tests were analyzed to evaluate the learners' conceptual development. To applaud the existing textual materials (Morgan, 2022b) recognize the purpose and recognition of its value and application of the document analysis approach. This approach has specific benefits when constraints such as limited resources address the ethical issues associated with other qualitative methods.

Data Analysis

As data was collected from multiple sources during the study, data analysis aligned well with such data collection tools. qualitative data analysis from classroom observations, transcribed teacher interviews, and document analysis. Thematic analysis, as described by Dawadi et al. (2021) and Eklund et al. (2019), was employed to systematically organize and interpret patterns of meaning in the data, confirming findings from the quantitative data. Thematic analysis, described as a theoretically informed and structured qualitative research method, was guided by a framework by Eklund et al. (2019) in the current study. Qualitative data emerged from classroom observations and interviews with 15 out of 38 physical science learners engaged in Bohr structure lessons and document analysis. The thematic analysis involves a series of steps that focus on identifying recurring themes or ideas in a textual data set (Castleberry & Nolen, 2018). Data were analyzed by following the six steps, as follows:

- **Step I.** Immersing oneself in the data. Equally, data involves transcribing audio and reading through initial notes to get familiar with it (Pokorny et al., 2018).
- **Step II.** We generate initial color-codes for the main themes.
- **Step III.** We searched for themes. Appropriate themes were searched for categorizing the data.
- **Step IV.** We reviewed themes. For the improvement of generated themes, a review process was done.
- **Step V.** We defined and named themes.
- **Step VI.** We produced the report. The report was based on the contents of the emerging themes (**Table 1**).

DISCUSSION

The research focused on exploring the use of beads as models to facilitate learning about the Bohr structure. This study is particularly significant as it addresses the need for effective teaching strategies in science education that foster conceptual understanding through cultural artifacts, such as bead models. The findings suggest that integrating IK into the teaching of the Bohr structure can significantly enhance learners' academic performance. For example, Freddo and Hyatt (2024) highlighted the link between learners' engagement with visualization and representation and their understanding of electronic structures. Similarly, Malone et al. (2020) and Ott et al. (2018) distinguished between heterogeneous and homogeneous multiple external representations.

Table 1. Themes emerging from semi-structured interviews

Themes	Theory	
	Literature	Theoretical framework
Using representation	Kumar and Reddy (2024)	CAT
Prior knowledge	Le Grange (2019)	African IK
Practical activities	Shrof et al. (2021)	Active learning

The data collected from interviews were organized into themes, as outlined in **Table 1**. During the interviews, grade 8 physical science learners shared their perspectives and experiences regarding the learning of electronic structures. A total of 15 learners were selected from the grade 8 physical science cohort for interviews, and the data were coded based on thematic categories. Three main themes emerged: representations, learners' prior knowledge, and practical activity. Learners were observed interacting with one another during the tasks and reviewing the teacher-created diagnostic test. Quantitative data were also gathered, with 38 individual learners assessed through the diagnostic test and the summative assessment. Each theme was analyzed with an individual theory.

Representation

It is important to recognize that there is no universal or ideal representations for effective learning in science education. This variability arises from the influence of personal and environmental factors, which can differ widely between individuals and contexts. Communication accommodation theory (CAT) provides a wide-ranging framework aimed at predicting and explaining many of the adjustments individuals make to create, maintain, or decrease the social distance in interaction.

It explores the different ways in which we accommodate our communication, our motivations for doing so, and the consequences. Learners observed manifesting collaboration when they were doing the task and constructing atomic structures of elements using beads and wire bid with copper wires to represent electrons of an atom. In this study engaging learners in creating visualizations can also provide complementary information alongside their verbal and written representations and hence be used to evaluate learners' understanding (Morgan, 2022a).

Learners' Prior Knowledge

Learners' ability to recognize beads and wire rings/loops can be viewed as prior knowledge. Initially familiar with metal rings, learners later understood them as shells, while beads are

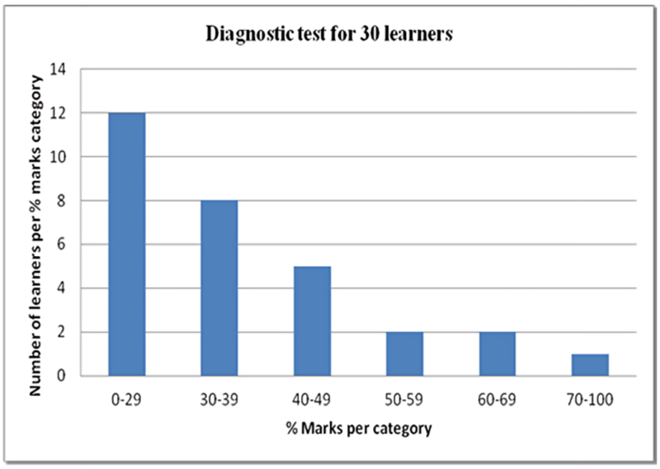

Figure 3. Diagnostic test results (for the 30 grade 8 class) (Source: Authors' own elaboration)

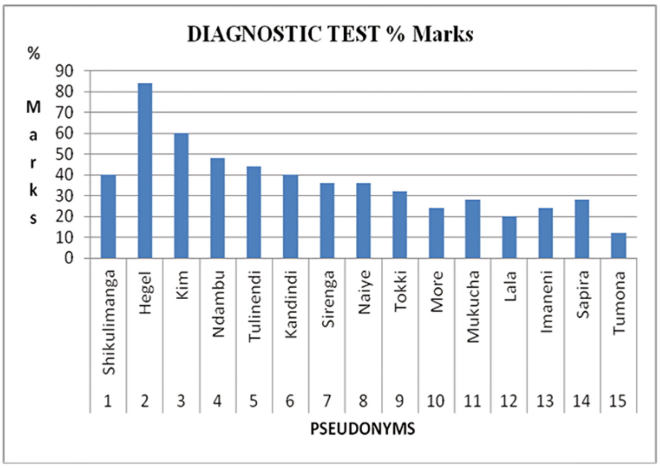

Figure 4. Diagnostic test results for the focus group members (Source: Authors' own elaboration)

introduced as representations of electrons. Beads, considered cultural artifacts, hold significance in various contexts, such as waist adornments for women or decorative elements in cultural attire.

Simonsmeier et al. (2022) highlight that prior knowledge enables learners to assess the credibility of sources and evaluate the plausibility of new information.in this study, learners accredit the beads and align with the feature of how electrons in the atom could behave. Learning by Africanisation- to decolonize curricula, enhances learning and the betterment of conceptual development (Le Grange, 2018).

Practical Activities

Practical activities in which learners were engaged to enhance the active learning instruction is a pedagogical approach that typically focuses on the reinforcement of higher-order cognitive skills that support DL and understanding (Kumar et al., 2022). In this study, grade 8 learners were engaged in the practical work of making a model of the atomic structure of some elements using beads. Learners were able to make use of these analogies in identifying the number of protons and electrons, the number of shells for a given element, and the number of beads [electrons] in each shell.

From the topic task given to the learners before being engaged in the making of bead models, most learners reported that they had no or little knowledge about the meaning of an atom and its particles, and below is the data that emerged in diagnostic assessment.

Figure 3 illustrates that only three out of the 30 learners achieved a score of 60% or higher on the diagnostic test. It is important to note that the minimum passing requirement for physical science in Namibia is 40% (equivalent to an E grade or better). A subset of 15 learners was selected for detailed analysis based on their performance in the diagnostic test.

Figure 4 presents the diagnostic test results for these 15 focus group learners. The data reveals that while some questions were answered well, others were poorly addressed or left unanswered by certain learners. The diagnostic test results for the focus group are ranked and displayed in **Figure 4**.

Based on the scores, the following learners were categorized as high achievers: Ndambu, Hegel, Tulinendi, and Kim. Meanwhile, Shikulimanga, Kandindi, Mukucha, More, Sirenga, Naiye, and Tokki were identified as average achievers, meeting the E grade standard according to Namibian benchmarks. Tumona, Lala, Imaneni, and Sapira were classified as low achievers. This composition highlights the heterogeneity of the focus group in terms of abilities.

Among the 15 learners, five (33%) were able to sketch the Bohr structure of a given element while 10 learners (67%) correctly identified the common term Bohr structure. Additionally, five learners (33%) provided the correct number of shells and the number of electrons in each shell of the element. Notably, 12 learners (80%) were able to identify the particles of atoms within an element.

However, after learners were engaged in models of representations, the study revealed that representations have the potential to support learners to focus on different characteristics of atoms and atomic structure. Learners were asked questions such as What is an atom? What are the three particles of the atom? Is the atom being seen with our own eyes? What is the pathway for electrons? During their group discussions, learners expressed that they cannot view atoms and their particles. Some learners had no idea about the meaning or its particles. Nevertheless, learners from the group expressed that *as small material we cannot touch or observe with our eyes*. Similarly, they demonstrated less knowledge in sketching the Bohr structure for a given atom of the element. **Figure 5** shows how a group of learners tried to sketch and/or draw the structure of an atom of a given element.

It has been demonstrated that active learning occurs when learners engage in collaboration and negotiations of meaning, consensus building, struggle resolution, and general social interaction. It revealed in their reflections that most learners particularly those who are doing grade 8 for the first time struggle to allocate and identify the exact numbers of electrons for each atom of the element.

For instance, a member from group 6 shared

Figure 5. Group of learners trying to draw the structure of the atom (Source: Authors' own elaboration)

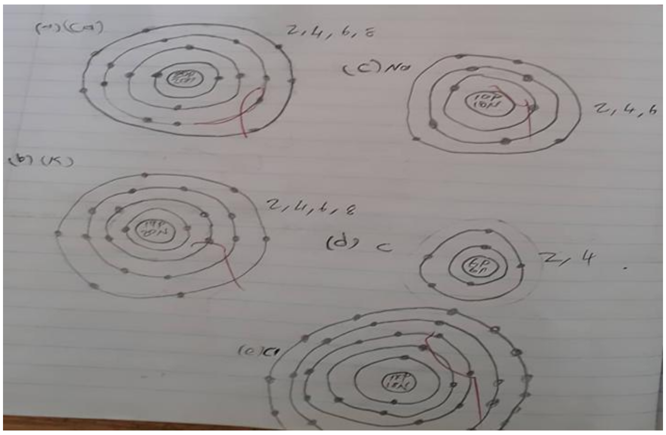

Figure 6. Abilities of learners in drawing Bohr structure of given elements (Source: Authors' own elaboration)

> "When I started drawing the atomic structure of an atom, I did not know how to draw it and could not imagine what electrons and shells look like".

After learners had done the group activity bellows were what learners had demonstrated without the aid of the models. **Figure 6** shows the abilities of learners in drawing Bohr structure of given elements.

Data was analyzed using the component of SCT: collaboration and negotiations of meanings, bellows are the reflections of learners in their works (task):

Group 1:

> "Before the models, we find the structure of the atom more challenging. Examples are shown in the textbook; however, we cannot make sense of it. The textbook states that electrons are tiny–very small and invisible so, drawing electrons was tough for our group since we cannot see how they are arranged".

Group 4:

> "We were inexperienced in drawing atomic structure. Made us draw an incorrect atomic structure, The textbook said a maximum of two electrons in the first shell and then a maximum of eight in the second shell, and so on. It is difficult to count things or objects which we cannot see with our eyes and/ or feel with hands".

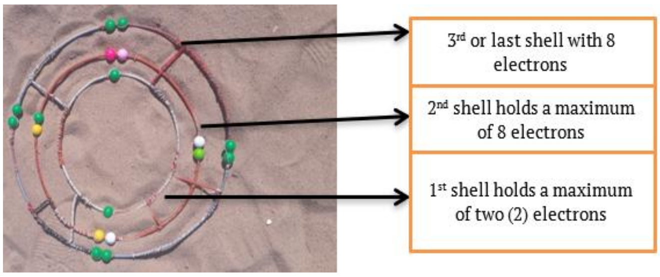

Figure 7. A model to represent the structure of Argon (Source: Authors' own elaboration)

However, learners did the tasks with limited views of scientific knowledge to follow the scientific method of drawing atoms of elements which promotes rote learning in our assumption. However, most of them managed to discuss collaboratively and solve the problem of drawing Bohr's structure.

Learners had an opportunity to share their experiences of interpreting models to understand the Bohr structure.

In their reflections group five has the following:

> "First, we collected the wire to represent the shell; secondly, we collected beads to represent the electrons. In the beginning, it was so difficult to make an atomic structure with a wire and beads. Count the beads and arrange it thereafter, tie or hock onto the wire ring. For instance, the structure of Argon must be made as two electrons in the first shell, eight electrons in the second shell, and the third shell holds a maximum of eight as well, since it has a total number of eighteen electrons".

Figure 7 shows a model to represent the structure of Argon.

Group 2 reflected that

> "beads made us construct an electron structure easier".

They further expressed that mud or pieces of reeds would be used if getting beads was expensive.

From this excerpt, it could be summarized that models of representations are part of the teaching and learning experience. In early learners' reflections, the study revealed that representations could cause learners to focus on different characteristics of atoms and atomic structure. Models created a great opportunity for learners to comprehend that electrons are exactly arranged in their shells as seen in beads fixed in rings of wire, as shown in **Figure 8**.

Collaborative interactions and meaning making among grade 8 physical science learners align with Vygotsky's (1978) assertion that learning is enhanced through social engagement. The models shown in **Figure 8** helped learners understand that the number of protons equals the number of electrons. Additionally, the bead colors used in the models had no impact on identifying the quantities of electrons, protons, and neutrons within the study's context. To evaluate the learners' conceptual development of Bohr atomic structure, a

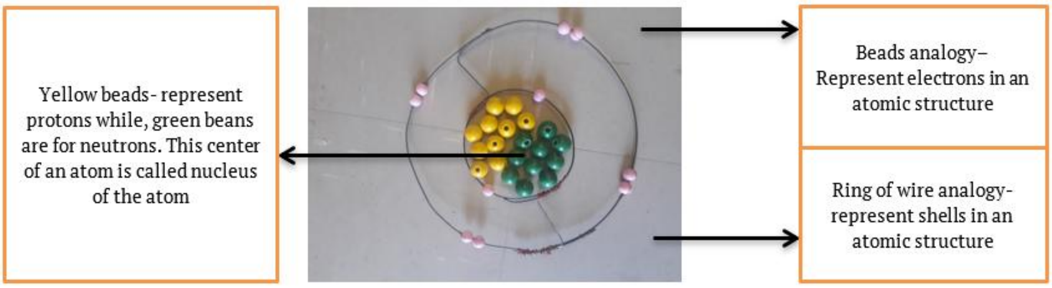

Figure 8. Representation of nucleus and the shells with electrons (Source: Authors' own elaboration)

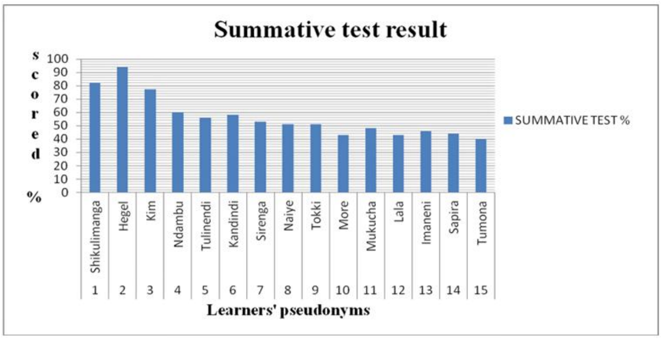

Figure 9. Summative test results for the focus group members (Source: Authors' own elaboration)

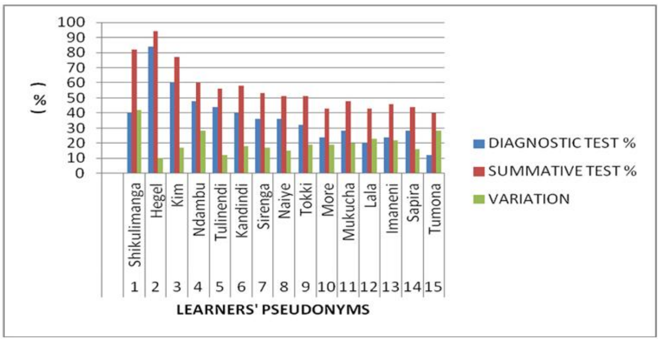

Figure 10. Diagnostic test and summative test scores (Source: Authors' own elaboration)

summative test was conducted following the intervention. The results of the focus group learners are presented in **Figure 9**.

The extent of variation in learners' performance was used to evaluate the effectiveness of the intervention and to select sample participants for interviews. Quantitative data from both the diagnostic and summative tests provided insights into how learners engaged with the collaborative learning process. These performance variations guided the selection of learners for individual interviews, ensuring a diverse representation through heterogeneous grouping.

Figure 10 highlights a consistent improvement in performance, as reflected in the diagnostic and summative test scores of the 15 focus group members.

Figure 10 illustrates a significant overall improvement in learners' performance. While all learners scored above 40%, only four achieved 60% or higher on the summative test. This outcome represents a substantial improvement compared to the diagnostic test, where 40% of the 15 focus group learners scored between 12% and 29%. Notably, learners like Lala and Tumona, initially identified as lower achievers during the study's initial sampling, also demonstrated marked progress. This improvement may be attributed to the integration of diverse mediational tools, such as the bead model, which served as an effective analogy for representing atomic particles.

CONCLUSION

Integrating analogies through models offers a valuable opportunity to enhance lessons on the Bohr atomic structure, serving as a powerful aid for learning in suitable contexts. For grade 8 physical science learners, addressing and correcting misconceptions is essential for fostering deeper conceptual understanding (Chauraya & Brodie, 2017). In this study, a diagnostic test was utilized to uncover learners' prior knowledge of atomic structure.

According to Reinhardt et al. (2018), assessments play a critical role in helping learners meet educational standards while improving the quality of teaching and learning through well-designed interventions.

To explore the potential of using model analogies effectively, we developed an assessment aimed at evaluating learners' understanding of atomic structure representations and related concepts. This research emphasizes the strategic use of models as a tool to elevate the quality and impact of science education nationwide

Recommendations

Based on the objectives and findings of this study, the following two key recommendations are proposed:

1. Higher education institutions, educational reforms, and teaching strategies in Namibia should actively encourage teachers to incorporate diverse representations in their practices.
2. Science teachers are encouraged to implement both diagnostic and summative assessments. These assessments play a crucial role in helping learners achieve required standards while enhancing the quality of teaching and learning through the effective design of targeted interventions.

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Declaration of interest: The authors declare that they have no competing interests.

Availability of data and materials: All data generated or analyzed during this study are available for sharing when appropriate request is directed to corresponding author.

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