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Impact of Low-Cost Atomic Models on Upper Secondary School students' Comprehension of Electronic Configuration and Chemical Bond Concepts in Nyarugenge, Rwanda

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Abstract: This study sought to establish the impact of low-cost atomic models on secondary school students' comprehension of electronic configuration and chemical bond concepts in Nyarugenge, Rwanda through the quasi-experimental design. The researchers used achievement tests which had 20 marks, calculated in accordance with predetermined criteria. The pre-test evaluated students' prior knowledge while the post-test established whether their knowledge had increased after the intervention. An interview established the participants' perspectives, ideas and feelings. The study concluded that designed low-cost atomic models significantly affect the comprehension of electronic configuration and chemical bond concepts in the process of learning. The study therefore recommends that teachers of Chemistry should create and apply inexpensive atomic models to support the teaching and learning process so that learners can comprehend electronic configuration and chemical bond concepts in the process of learning.

Keywords: Students' performance; Low-cost atomic model; teaching and learning; atomic structure.

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Introduction

Studies on the teaching of chemistry have revealed that students find chemistry topics to be abstract, challenging and difficult to comprehend. For a better grasp of abstract concepts, it is crucial to create new materials and apply them in lessons. In this study, a teacher created affordable atomic/molecular models to instruct students about atomic structure and atomic stability.

Educators use instructional tools to engage students in the teaching and learning process. Instructional materials are tools that make the teaching and learning process more significant and clear (Aramide & Bolarinwa, 2010). A study found that teaching aids play an important role in teaching and learning and they improve students' memory. Using instructional materials improves students' rate of comprehension while also facilitating effective teaching and learning. Instructional materials create means of communication that support transactions between the teacher and the learner (Dhunpath & Samuel, 2009).

Instructional tools give pupils realistic experiences, which motivate them to take initiatives (Dhunpath & Samuel, 2009).While the use of teaching aids increases students' interest in subjects and enhances presentations (Hussain et al., 2022), models are useful teaching tools for science because they help students better grasp, communicate and investigate scientific phenomena (Harrison & Treagust, 2000). Models explain abstract concepts and portray elements of scientific experiments that are otherwise impossible to grasp. Additionally, models provide a means of increasing the authenticity of science instruction (Gilbert et al., 2004). Analogical models are those that share data with the fact that they represent one or more characteristics of objectives (Derman, 2017). Description of processes, such as chemical reactions, can also be done using models. Models appeal to kids because they convey abstract ideas in comfortable and visually attracting ways (Harrison & Treagust, 2000). Low-cost atomic/molecular models do help learners concretize what they study and they make learning interesting and active.

Atomic structure concepts are sometimes challenging and unclear to learners (Taber, 2003). (Üce & Ceyhan, 2019) present study findings Türkiye on conceptual understanding of bond polarity, molecular polarity, VSEPR theory, Lewis structure and molecular structure. In this study, secondary school students were unable to recognize the connection between bond polarity and molecular polarity. They failed to distinguish between polar and non-polar molecules and they believed that lone pair electrons had no impact on the molecular geometry of molecules.

In Sweden, (Kuzu et al., 2002) found a number of misconceptions in their study on the influence of chemical bonding on molecule stability where students believed that the carbon dioxide molecule was polar. In another study on covalent bonds, (Musa, 2015) revealed that students believed that HCl was an ionic compound despite the fact that the chemical bond in hydrogen chloride is either an ionic bond or hydrogen bond.

Transfer of electrons between two nonmetals creates covalent bonds. Molecules with nonpolar covalent bonds are neutral, whereas those with polar covalent bonds are charged. Compounds are the smallest units made up of various atoms bonded together via ionic bonds; the hydroxide ion should have a double covalent bond between oxygen and hydrogen atoms. Additionally, the high cost of atomic modelling kits and the lack of such kits on the open market have made it difficult for students to master chemical concepts linked to the spatial arrangement of molecules (Wijayawardana & Kaumal, 2017). This study sought establish the impact of low-cost atomic model on students' academic performance in Rwanda.

Literature Review

This section reports the literature review on variables in this study.

Atomic and Molecular Models

A molecular model is a tangible representation of an atomistic system that includes molecules and the processes they go through. They are vital in comprehending chemistry and in creating and evaluating hypotheses (Polik, 2006).

The atom's Historical Models

Atoms were thought to be straightforward spheres. Midway through, Thomson discovered the electron in the nineteenth century (Fredriksson et al., 2012). He deduced that the atom must be composed of electrons buried in a positively charged mass because he was aware that the electron was negatively charged and that the atom was neutral. The "plum-pudding-model" of the atom is a term that has been used to describe this line of thought.

Atomic Description and Representation

Models are required to describe and communicate changes in matters at the particle level because atoms and molecules are too tiny to observe (Harrison & Treagust, 2000). However, learners may find it challenging in studying electronic configuration and chemical bonding due to the abundance and variety of metaphors and analogies used to explain atomic processes.

Model-based Instruction

The model-based teaching and learning theory serves as the foundation for the theory we use (Buckley et al., 2004). Model-based learning is predicated on the idea that understanding needs building mental models of the events being studied, and that all subsequent problem solving, inferencing or reasoning is done by manipulating or "running" these mental models. As internal, cognitive representations are used in many types of thinking, we see mental models. Like prior knowledge, mental models have an impact on how we perceive things and how we understand ideas. Interactions influence our mental models by interaction with phenomena and representations) (Moray, 1999).

Importance of Models in Teaching

Models are effective teaching tools for science because they help learners understand, communicate and establish scientific phenomena(Harrison & Treagust, 2000). Models illustrate components of scientific experiments that are impractical to carry out in a classroom environment and to explain abstract notions that cannot be expressed in words. Additionally, using models improves the authenticity of science instruction (Gilbert et al., 2004). Analogical models are those that contain information similar to that of the thing they describe. They depict a single or a number of target's characteristics (Derman, 2017). They can be more physical like scale models or more abstract like an atomic scientific model (Harrison & Treagust, 2000).

Methodology

This section presents the methodology that guided the study. Particularly, it addresses the design, population and sampling, instruments used, validity and reliability and statistical treatment of data.

Research Design

The study used the descriptive design. It combined both quantitative and qualitative data for comprehensive results.

Population and Sampling

Population is a set of units to whom the results of study should be applied (Casteel & Bridier, 2021). In this study, 640 students and 18 chemistry teachers from 4 schools within the Nyarugenge District in Rwanda constituted the study's population. Through simple random sampling, 128 students and 6 teachers made up the sample.

Instrument

The researchers used achievement tests to establish students' conceptual comprehension and knowledge level. The tests had 20 marks, calculated in accordance with predetermined criteria. The researchers use the pre- and post-tests collected data from the control and experimental groups for analysis. The pre-test evaluated students' prior knowledge while the post-test established whether their knowledge had increased after the intervention. An interview established the participants' perspectives, ideas and feelings.

Validity and Reliability

In order to ensure content validity, a team of research experts from the University of Rwanda reviewed and approved the instruments before data collection took place. The researchers piloted the study's test items with 30 senior fourth chemistry students in a school from the Nyarugenge District, which was not part of the sampled schools. A reliability coefficient was calculated using the Split Half approach, which yielded the Cronbach's Alpha of 0.745. Data triangulation enhanced the reliability

Statistical Treatment of Data

The researchers analyzed data through t-test and thematic approach to answer the guiding research questions.

Results and Discussion

This section presents the results, guided by research questions. To determine the impact of low-cost atomic models on students' academic performance, the researchers conducted pre and post-tests to the control and the experimental groups.

Pre-test Results

Before using the designed low-cost atomic model, students of both groups (control and the experimental) did a pre-test to determine their prior comprehension of electronic configuration and chemical bond concepts. The pretest results appear in table 1:

Table 1: Independent Sample Pre-test Results

Pre-test Score	Group	N	Mean	Std. Deviation	T	Df	Sig. (2-tailed)
	Control	64	12.2120	2.5380	-0.067	126	0.712
	Experimental	64	13.4610	2.4245			

T-value significant at p > 0.05

Figure 1: **Student designing the electronic arrangement of a nitrogen atom**

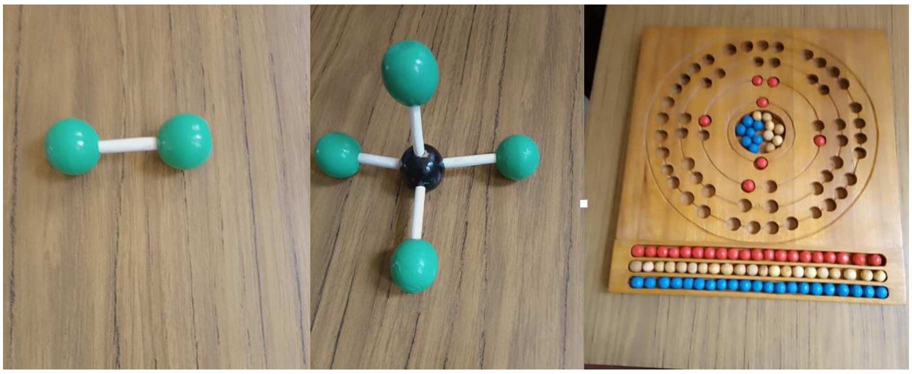

Figure 2: Different electronic structures designed by students

Table 2: Independent Sample Post-test Results

Post-test	Group	N	Mean	SD	T	Df	*Sig. (2-tailed)*
	Control	64	15.4563	2.4321	-5.530	126	0.001
	Experimental	64	18.9861	2.6510			

T-value significant at p < 0.05

Results in table 1 show that the mean score of the control group was 12.2120 while the mean score for the experimental group was 13.4610. The p-value was 0.712, which is greater than the critical value. This signifies that the mean scores of the two groups were not significantly different. It also suggests that the respondents in both groups had similar levels of comprehending concepts.

Intervention

The intervention involved teaching the experimental group using designed low-cost atomic models. Students in the control group learnt by using traditional methods of teaching, without the use of the designed low-cost atomic models. Figure 1 and Figure 2 indicate the use of the designed low-cost atomic models, which actively engaged learners in the experimental group during the process of teaching.

Post-test Results

As seen in table 2, after using the designed low-cost atomic model with the experimental group, students in both control and the experimental groups did a post-test to determine their final comprehension of electronic configuration and chemical bond concepts.

From table 2, the mean score for the control group was 15.4563 while that for the experimental group was 18.9861. The p-value is 0.001, which is lesser than the critical value, signifying that the mean scores between the control and the experimental groups are significantly different. The experimental group, which was taught through designed low-cost atomic models significantly, outperformed the control group, taught through the conventional approaches of teaching and learning.

From the interview, teachers indicated that students actively participated when studying using low-cost atomic models than when using conventional methods. Some teachers used drawing as interventional strategies while others used atomic model kits while teaching atomic structures. Teachers confessed that the use of low-cost atomic models is easy to design through available materials. The experience eradicated students' misconceptions, stimulated interest, motivated students' interest and increased students' performance. Furthermore, the use of low-cost atomic models helped students to comprehend abstract concepts of chemical bonding.

Students confessed that the use of a low-cost atomic model increased their level of understanding of electron structure. One students said, "This atomic model helps me to understand well the atomic structure of different elements in terms of electron arrangement and component of atoms." All interviewed students reported that they were motivated when they learnt atomic structure by using low-cost atomic/molecular models. All students reported that the designed models helped them to explain reality and to reduce the abstractness in chemistry.

This indicates that the low-cost atomic model has a significant effect on students' performance in electronic configuration and chemical bond concepts than using the traditional method. This also means that using low-cost atomic models increases students' performance in electronic configuration and chemical bond concepts. A study by Wijayawardana and Kaumal (2017) about designing and using low-cost atomic models from waste materials found that *the* use of low-cost atomic model kits increases students' performance. Another study shows that teachers had positive reflection on the use atomic models which improved the teaching and learning of atomic structure (Wiener, 2020).

Conclusion and recommendations

Conclusion

Since the experimental group students that used the designed low-cost atomic models outperformed the control group students who learned through traditional approaches, the study concluded that designed low-cost atomic models significantly affect the comprehension of electronic configuration and chemical bond concepts in the process of learning. The study therefore recommends that teachers of Chemistry should create and apply inexpensive atomic models to support the teaching and learning process so that learners can comprehend electronic configuration and chemical bond concepts in the process of learning. This will encourage learners to study electronic structure because these methods remove misconceptions found in chemistry.

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