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Developing the Culturally Relevant Analogies to Enhance the Teaching and Learning of Electricity and D.C Circuits in High School Physics

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Abstract: Researchers were convinced that developing culturally relevant analogies will improve the teaching and learning of Electricity and Direct Current Circuits, a challenging topic in Physics. The study sought to determine abstract concepts within the physics curriculum that pose teaching and learning difficulties and to create culturally relevant analogies to enhance the teaching and learning of Electricity and Direct Current Circuits. A mixed methods approach was used. Questionnaires and interviews were used to identify abstract concepts in physics and subsequently develop contextually appropriate physics analogies for use in Electricity and Direct Current Circuits in High School physics instruction. Findings have shown that Quantum Physics, Thermodynamics, Ideal Gases, Particle and Nuclear Physics, Astronomy and Cosmology, and Electricity and Direct Current Circuits are more abstract and difficult to teach and learn while Work, Energy and Power, Dynamics, Density and Pressure, Kinematics, and Physical Quantities and Units are easier. As a result, a meticulous effort was made to identify and formulate Zimbabwean analogies that are contextually relevant and relatable, specifically tailored for teaching Electricity and Direct Current Circuits.

Keywords: Physics education, Contextual analogies, Electricity, D.C Circuits, Zimbabwe

INTRODUCTION

Learner conception of ideas is influenced by background and heritage. Like any other subject, there are abstract concepts in Physics which could be understood easily when context specific analogies are used. Researchers were convinced of the pertinence of developing culturally relevant analogies to improve the teaching and learning of Physics in Zimbabwean Schools. This study used a mixed approach in which questionnaires and interviews were used to identify abstract and difficult to teach concepts. Zimbabwean contextually appropriate physics analogies were then developed for use in high school physics instruction. An advisory text was then generated which intended to assist teachers improve students' comprehension of difficult physics concepts by making them more relatable and simpler to understand.

Experience has taught researchers that thorough preparation is quintessential in the delivery of a successful lesson. And, in some instances, after gathering all the apparatus for an experiment still learners could not comprehend certain concepts under Electricity and Direct Current (D. C) Circuits. Consequently, there has been a call for educators to improvise and use heritage based instructional methods. It wasn't accidental that one of the researchers discovered that when she was teaching some concepts using an analogy to teach a concept, Physics learners would be more engaged. Upon sharing, researchers found out that colleagues also use various other analogies when teaching various other topics in High School Physics. As a result, researchers developed a lasting idea that if all these analogies could be gathered and documented, Electricity and D.C circuits could be more relatable, understood and locally applied. It is on record that analogies are key elements in shaping the way one views everyday life (Brown & Salter, 2010).

Anyway, developing analogies relevant to the teaching and learning of Electricity and D.C Circuits only was not enough for the researchers. The idea of a longitudinal research to be conducted across Zimbabwe was then conceived. Despite the size of the sample, a profound idea of engaging experienced educators in order to gather culturally appropriate analogies which could mitigate the abstractness in the identified topics in this longitudinal study was appealing. Justifiably, it was revealed that Physics students faced conceptual challenges in various grade levels due to lack of knowledge, misconceptions and difficulty in understanding abstract concepts (Ayktulu, Bezen, & Bayrak, 2015). And, developing these analogies was aimed at helping make otherwise abstract concepts more relatable, thus enabling learning by connecting prior knowledge to new concepts. It is documented that an analogy compares familiar and unfamiliar domains of knowledge, with the familiar being identified as the base domain and the unfamiliar being the target domain (Orgill & Bodner, 2004).

While researchers acknowledge that analogies play a vital role in the teaching and learning of Electricity and D.C Circuits as they assist in conceptualising otherwise difficult subject content, it is important to note that they can be a source of misconceptions. A study revealed that while some Afrocentric analogies were found in some curriculum materials for schools in the SADC, they failed to help learners overcome misconstructions, thus creating a misunderstanding of concepts. One of the major causes of this was inadequate adaptation by teachers who did consider cultural backgrounds (Mukwambo, Ramasike, & Ngcoza, 2018). As a result, it was imperative for researchers to develop appropriate analogies that are relevant to the teaching and learning of Electricity and D.C. Circuits targeted for High School Physics since this topic had motivated the researchers from the onset.

Statement of the problem

The teaching and learning of High School Physics in Zimbabwean Schools is often limited by the use of analogies that are not culturally relevant to the student heritage. This has led to a lack of understanding and engagement with the subject content, and ultimately, a lower level of knowledge, understanding and comprehension. With the advent of Education 5.0, this research was aimed at creating culturally relevant analogies to improve the teaching and learning of Electricity and D.C Circuits in High School Physics.

Main Research Question

The main research question guiding this study was what context specific analogies could be developed to enhance the teaching and learning of abstract concepts in Electricity and D.C Circuits for High School Physics?

Sub-Research Questions:

- What are the most challenging topics/concepts in Physics that need to be taught in the Zimbabwean context?
- Which contextually appropriate analogies can be developed to explain the concepts in Electricity and D.C Circuits for High School Physics in the Zimbabwean Context?

Significance of the Study

A text with contextually appropriate analogies for use in Zimbabwean high school physics instruction, will contribute to the body of literature on culturally and contextually relevant teaching materials in physics education. Besides, the text will assist in the comprehension of Electricity and D.C Circuit concepts, making Physics more accessible to learners by relating subject content to their experiences. In the face of a heritage based model of Education 5.0, our contribution serves as a model for future research and development of culturally relevant teaching and learning resources in physics education.

Delimitations of the Study

The research is constricted from Ordinary to Advanced level Physics in the Zimbabwean curricula. Although the study comprised a sample of experienced teachers from Zimbabwe's education system, the selection criterion was based on researchers’ knowledge of participant physics teachers.

The Concept of Analogies in Physics Education

Until now, we have been emphasising the use of contextualised analogies in the teaching and learning of Electricity and D.C Circuits without defining them. And, it is not by coincidence that the Zimbabwean curriculum is heritage based, which command that educators cogitate and ruminate the cultural and environmental factors distressing an individual learner during the teaching and learning process. At their face value, analogies are simply comparisons between two things, situations or ideas. In the present study, researchers emphasise academic analogies that transfer familiar situations into conceptual grasp of abstract topics in High School Physics. Arguably, researchers observed when two or more things or situations are comparable in at least some way, the analogical thinking allows learners to draw valid conclusions about unknown factors on the bases of resemblance to a known situation.

Several papers written on the use of analogies in teaching and learning have cautioned against the use of analogies which represent things or situations unknown to the learner (Glynn, 2008; Cruz-Hastenreiter, 2014). In the face of Education 5.0, learners can not be constantly fed with swirling and intermingling physics concepts that do not at least relate to their heritage. One of the analogies that have withstood the test of time is the Thompson’s plum pudding model that describes the model of an atom. The plum pudding model postulated that atoms were positively charged spherical matter that contained negatively charged electrons dotted across the positive matter. One of the researchers discovered that mostly male learners could not relate the plum pudding analogy to the structure of the atom because they were not sure of what a plum pudding was. Upon quizzing the class on the nature of the plum pudding, only a female learner could explain to the whole class because it is deep rooted in the Zimbabwean culture that females prepare meals for the families. Fortunately, after the explanation by the female student, male learners were able to relate and discover the context of the plum pudding concept thereof. Although the plum pudding model was disproved, similar analogies have been used to describe scientific discoveries for centuries (Orgill & Bodner, 2004). Guided by this discovery learning, we proceeded to develop culturally relevant analogies to activate analogical reasoning, organise abstract physics concepts, and develop cognitive competences of innovation and industrialisation in High School Physics.

A study conducted in Lincoln, England explained the didactic purpose of analogies in the

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teaching and learning of physics. Learner reasoning of the base domain (known situation) is compared with the target domain (the unknown abstract concept) (Fotou & Abrahams, 2020). While our paper builds on previous researches (Glynn, 1991; Fotou & Abrahams, 2020), our study is unique in that it is aimed at developing analogies to enhance the teaching and learning of abstract concepts in Electricity and D.C Circuits for High School Physics while other papers where theorising the applicability of these analogies in Physics education.

THEORETICAL FRAMEWORK

Our study was based on social constructivism theory which registers that learners have prior knowledge and effectual lessons should build upon that pre-existing knowledge. Experience has taught researchers that, it is easier to teach newer situations using similar and relatable past experiences and knowledge (Taber, 2013). And this prior knowledge is gained from their experiences and reflections on the experiences. Constructivism dispels the idea that learners take in new information passively (Ayktulu, Bezen, & Bayrak, 2015). The theory states that 'language and culture are frameworks through which humans experience, communicate and understand reality' (Akpan, Igwe, Mpamah, & Okoro, 2020).

Arguably, the teaching and learning of Physics in Zimbabwean schools is heavily influenced by the history and socio-economic factors of the country. Firstly, there is a significant colonial influence in the country's educational system which has greatly affected the teaching and learning of Electricity and D.C circuits. Thus educational philosophies, approaches, curriculum materials, experiments, and equipment from the former colonial powers are often used (Gudyanga & Kurup, 2017). Subsequently, the examples enlisted on internet and in local text books are skewed towards western experiences and culture divorced from local learners and educators. Accordingly, learners struggle to construct contextualised meanings from the available materials. It is therefore imperative that the Zimbabwean education system adopts a learner-centred curriculum through the designing of localised appropriate analogies.

Whilst our paper emphases the adoption of analogies for the teaching and learning of Electricity and D.C Circuits, however, these must be right and proper to construct apposite knowledge in the target audience. It is therefore important that educators, authors and researchers develop relatable analogies that can be used in the teaching and learning of Electricity and D.C Circuits (Yener, 2012). Prior researches unearthed that a number of teachers struggle to generate culturally based analogies instigating confusion and misconception (Ijioma & Onwukwe, 2011). As a result, they should select appropriate culturally based analogies and develop lesson plans based on the Teaching with Analogical Concepts model (Ijioma & Onwukwe, 2011).

Above and beyond all, analogies make Electricity and D.C Circuits knowledge more intelligible and plausible when relatable concepts are introduced as a foundation for more abstract concepts (Cruz-Hastenreiter, 2014) which will facilitate the understanding and visualisation of such abstract concepts. As a result, we reiterate that academic analogies are powerful and effective in constructing the learner knowledge but they can be interpreted as the actual concepts themselves. We stand to advise educators that whilst the major aim is to construct the new knowledge, learners could just retain the most obvious and appealing details of the analogy or they may not recognise the analogy and may fail to derive its explicit usefulness.

Abstract And Challenging Nature of Physics

It is well documented in literature that many students find Physics concepts to be abstract and difficult. A study conducted by Ornek, Robinson, & Haugan, (2008) reported that students cited the abstract nature of Physics as a reason for the difficulty of the subject, although faculty staff and teaching assistants did not concur. Arguably, students may find these Physics concepts difficult because of their conceptual nature and complexity which could affect their motivation and academic performance (Ekici, 2016). A study carried out by Mustu & Sen, (2019) conveyed that electric and magnetic fields were viewed as two of the abstract topics in the teaching and learning of Physics. Various studies recounted that Quantum Mechanics is a challenging topic (Mustu & Sen, 2019; Bouchée, de Putter - Smits, Thurlings, & Pepin, 2021). Another study carried out by Chapman (2014), informed that in primary schools, electricity lessons usually involve making simple electric circuits, but learning remains at a theoretical level without understanding how the circuits work. Additionally, many students find electricity to be a difficult topic to understand because of the abstract concepts involved, such as charge and electrons, which are not directly visible to the naked eye (Open University, 2023). Other studies concur that students struggle to grasp the concepts in electricity and magnetism (Ding, Chabay, Sherwood, & Beichner, 2006; Mbonyiryivuze, Yadav, & Amadalo, 2019).

Research Approach and Design

The research employed a mixed method approach in which both quantitative and qualitative research designs were used to collect the primary data. The two designs were chosen to check on the findings from one particular method with an aim of addressing the main research question and validating the findings. Admissibly, a concurrent design helped researchers to gain a more holistic and nuanced understanding of the challenges faced by Physics teachers when teaching complex concepts (Terrell, 2012) and provided triangulated data (Kroll & Neri, 2009). A non-random purposive sample of eight Physics teachers with more than 10 years of experience in teaching Ordinary and

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Advanced level Physics in Zimbabwe was selected. Initially, questionnaires with both closed and open ended questions were distributed simultaneously by email and WhatsApp to three Physics teachers to identify abstract topics that teachers found challenging to teach which are also difficult to learn and collect contextually appropriate analogies already being implemented in the classroom setting. A short message service was sent after one week to remind respondents to complete and submit the questionnaire before the lapse of the week. Unstructured interviews aimed at triangulating and validating the quantitative findings were employed sequentially to gather qualitative data on existing analogies used to explain difficult topics and to explore effective strategies as well as potential drawbacks associated with the use of analogies in Physics education. Reasonably, unstructured interviews are open-ended, flexible and allow in-depth exploration of teachers' experiences and insights. Informed consent was sought for participation and to record notes and audio recordings to be used exclusively for the purpose of the research.

Ethical Considerations

Invitations were extended to selected participants in advance for a pre-interview meeting and a short introduction about the aim of the research in accordance with ethical standards was given. Confidentiality and anonymity was assured and overview of the research questions was done. The questionnaire and interview guides were designed with clear questions and instruction guided by the review of the existing literature, consultations and results of the pilot study. A pilot study was carried out to participants outside the main sample to ensure that the instruments would capture the research objectives and content areas of interest such as challenging physics topics, the effectiveness of analogies and contextual relevance.

RESULTS AND DISCUSSION

Difficult and Abstract Syllabus Topics

It has been raised that the study was aimed at identifying the most challenging topics/concepts in Physics that need to be taught in the Zimbabwean context. Interview participants and questionnaire respondents were asked to rate the difficulty in teaching and learning, and abstractness of particular Physics topics. The results were analysed using statistical Pearson correlation coefficient and a Pearson correlation coefficient of 0.95 was calculated. Interpretation of the findings indicated that abstract physics topics are as well difficult to teach and learn. Fig 1 presents a comparative analysis of the rankings of the 'difficulty' and 'abstractness' of all the syllabus Physics topics.

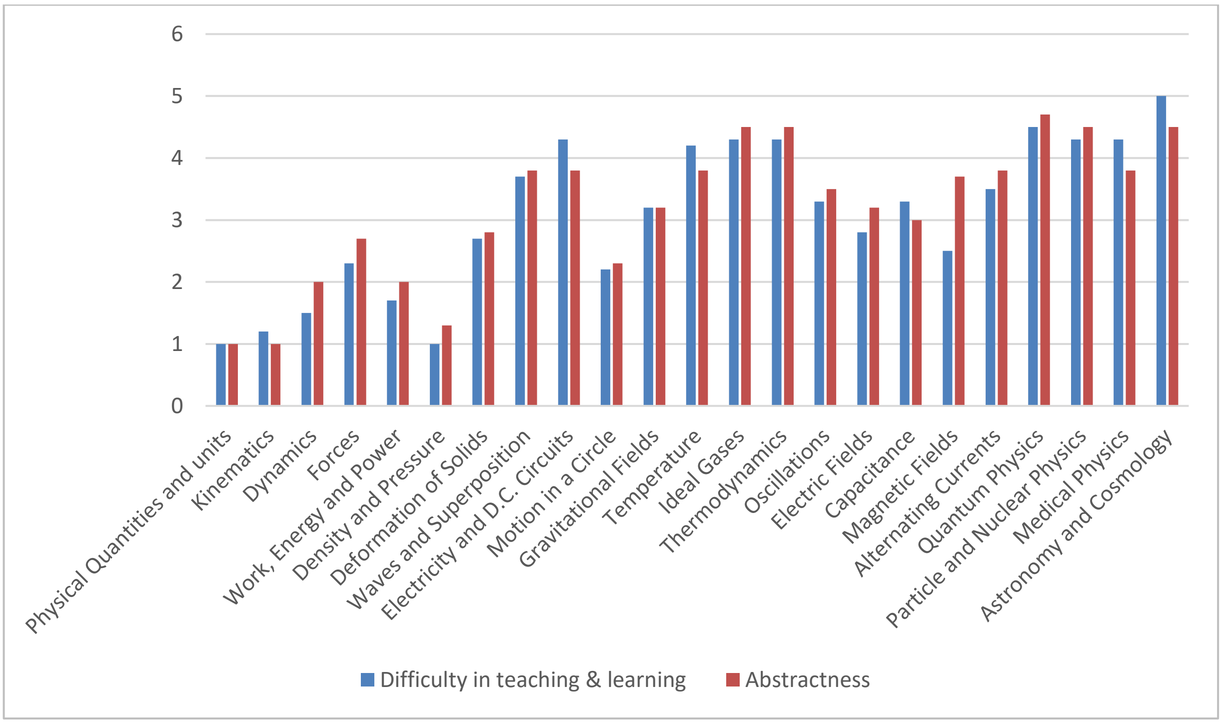

Figure 1: Rankings comparison of the 'difficulty' and 'abstractness' of Physics topics

The illustrative Fig 1 indicates that the most abstract topics are Quantum Physics, Thermodynamics, Ideal Gases, Particle and Nuclear Physics, and Astronomy and Cosmology in their respective order while Work, Energy and Power, Dynamics, Density and Pressure, Kinematics, and Physical Quantities and Units are least abstract. Fig. 1 also shows that Astronomy and Cosmology, Quantum Physics, Electricity and D.C circuits, Thermodynamics, Ideal gases and Temperature are the most difficult topics to teach and learn. In unison, Fig 1 also portrays that Work, Energy and Power, Dynamics, Kinematics, Density and Pressure, and Physical Quantities and Units are easier to teach and learn.

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Findings from the Pearson Correlation Coefficient have already indicated that abstract topics are most difficult to teach and learn. Reasonably, topics that were rated as more abstract by educators were intuitively perceived as more difficult to teach and learn. Educators who participated in this research were asked to account for the difficulty of the topics in the teaching and learning process. The teachers ascribed the difficulty to the unavailability of models or hands-on demonstrations which would assist students who have a slower learning pace to visualize and comprehend these concepts fully. Consequently, abstract topics frequently require students to think beyond their daily experiences and develop a new conceptual framework. The mathematical aspect of these topics adds to the difficulties for students who struggle with advanced mathematical concepts.

And, the pattern also indicates that least abstract topics were viewed as easy to teach and learn. Justifiably, the syllabus topics are taught from simple to complex, our findings also show that initial topics are easier to comprehend compared to the last topics. Guided by our findings, educators should create appropriate instructional strategies and resources to help students better understand and engage with abstract physics concepts especially when it comes to using analogies to teach abstract Physics concepts. The consensus was that the easy to teach topics involve practical measurements using instruments, which can be easily translated into the underlying concepts. The ability to provide hands-on experiences and real-life examples enhances students' understanding and engagement with these topics.

However, our findings indicate that Magnetic fields are abstract but easier to teach and learn. This observation is besides the normal trend but educators who participated in this research enlightened that magnetic fields are easy to teach because they correspond to students' everyday experiences and that there are readily available tangible teaching and learning resources. This allows for hands-on demonstrations, interactive experiments, and the use of real-life examples, all of which improve students' engagement and comprehension.

Analogies for Electricity and D. C. Circuits

The Analogy of The Potential Difference in An Ohmic Conductor

It has been established that the topic Electricity and D.C circuits was among the abstract and difficult concepts to teach and learn in High School Physics in Zimbabwe. As a result analogies were then to be developed to mitigate this learning dilemma. Our findings submit that the potential difference, a concept under electricity and D.C circuits, is analogous to the gradient on a slope that allows water to flow down a river (Fig. 2). The Potential difference determines how electric charges flow in a circuit in the same way that the steepness of the terrain determines how water moves. In this case, the terrain represents the electrical potential difference between two points in a circuit. Electric charges flow from higher to lower potential regions in the same way that water naturally flows from higher to lower elevations.

Figure 2: Chinamata waterfall in Vumba (Hungwe, 2023)

A higher potential difference in a circuit causes electric charges to flow faster i.e. the current increases, just as a steeper gradient on the terrain causes water to flow faster increasing the water flow rate. A gentle gradient or lower potential difference results in a slower flow of charges or lower current.

In addition, Ohms law can be introduced and developed. The potential difference is directly proportional to current, provided that temperature and other physical conditions are kept constant. Experiments can then be carried out using water flowing down a trough or a conduit pipe cut in half along its length. The potential difference, like the gradient of the terrain, acts as the driving force that drives electric charges through a circuit. Emphasis is then made to explain the need for a water pump or a mechanism that uses energy to return the water to its original position. Similarly, a circuit needs an emf source that provides the energy necessary to return the electric charges to a higher potential. Equation 1 presents that the electromotive force ε, is equivalent to the energy, **E**, per unit charge **Q**, provided that the emf source is equivalent to the potential difference across the circuit.

$$\varepsilon = \frac{\mathbf{E}}{\boldsymbol{Q}} \qquad \ldots\ldots \textit{Eqn 1}$$

To avoid any form of misconception, it is imperative that an experiment using apparatus be then conducted and be linked to the water flow analogy. Experience from the syllabus has taught us that there is absolute need to emphasise that positive charges are traversing from high potential positive terminal to a lower potential negative terminal. And why is this important? For the reason that in the conventional current

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set up, negatively charged particles, electrons in particular, traverse from the negative terminal to the positive terminal. As a result, it is good physics in all D.C circuits that, a switch is always attached to the positive terminal, the ammeter affixed in series with all components and the voltmeter connected in parallel with the load resistor.

Analogy on Kirchhoff's Current Law

Preliminary findings have already submitted that Electricity and D.C Circuits was viewed as an abstract and difficult topic which motivated the researchers to develop analogies to explain concepts within D.C circuits. Our findings recommend that it is easier to explain to learners that the traffic approaching a certain intersection is equivalent to the traffic leaving that particular intersection. This is analogous to Kirchhoff's Current law in which the total sum of the current entering a junction is equal to the total sum of the current leaving that particular junction given by the equation.

$$\sum I_{in} = \sum I_{out} \qquad \ldots\ldots \textit{Eqn 2}$$

Learners can be exposed to a real-life experience at a busy crossroad intersection shown in Figure 3.

Figure 3: Traffic jam in Bulawayo (Sunday Mail Zimbabwe, 2022)

The explanatory Fig 3 reveals that when all conditions are met at a junction, the vehicles that enter an intersection should be equal to the vehicles that exit the intersection, and for a traffic jam to clear up the vehicles that entered the intersection should all leave the intersection. As presented at an intersection in Fig 3, vehicles or people in multiple roads are budging into an intersection, just like charges moving in multiple wires connecting to a junction in an electric circuit towards a wire junction, where the current can split and flow through different paths from that junction. The total number of vehicles or people passing through the crossroad represents the total current flowing into the junction.

Again, to eliminate misconceptions, it is imperative to remember that at a junction, the vehicles or people can choose to continue straight, turn left, or turn right, depending on the options of paths available. It corresponds that in an electric circuit, the current at the junction can split and flow through the different wires available. But, the amount of current flowing through each branch is not arbitrary but depends on the resistance of that branch. And why is this distinction essential to pinpoint? Since a wider road is less constricted to allow more cars or people to pass through, a thicker wire has a lower resistance that allows more current to flow through a particular branch. Given that people can decide their path after the junction based on choice, the electric charges do not reason out to find their path but are pushed to follow a given path of a known resistance in the circuit.

Analogy on Resistance

Spray races used for cows to walk through to get rid of ticks and parasites are analogous to the concept of resistance in an electric circuit, particularly when the wide collection pen and narrow entrance race are considered. In this analogy, the cows represent the flow of electric charges in a circuit. Before the cattle enter the narrow dip tunnel, they can move side by side, representing a wider cross-sectional area. In this scenario, more cows can pass through the pen simultaneously, just like how a larger cross-sectional area allows for a higher flow of electric charges (constituting current) in a circuit with lower resistance. However, as the cows enter the narrow dip tunnel, only one cow can fit at a time due to the restricted cross-sectional area. This represents an increase in resistance. The narrow tunnel impedes the movement of the cows, making it more difficult for them to pass through quickly as shown in Fig 4.

Figure 4: Spray Race (Cattle Spray Races, 2022).

Using the descriptive Fig 4, students can visualize how a spray race for cows can represent resistance in a circuit. They can understand that just as a narrow dip tunnel limits the number of cows passing through, resistance in a circuit limits the flow of electric current. Similarly, in an electric circuit, when there is a change in cross-sectional area or the presence of a component with higher resistance, it restricts the flow of electric current. This increased resistance hinders the movement of electrons, causing a decrease in the overall current flow as represented in the equation 3 which presents that the resistance R of a conductor is directly proportional to its length L and inversely proportional to its cross sectional area A provided that the resistivity ρ is constant in the conductor, hence

$$R = \frac{\rho L}{A} \qquad \ldots\ldots\ Eqn\ 3$$

CONCLUSION AND RECOMMENDATIONS

The study's findings shed light on the abstractness of various physics topics and the challenges faced in teaching them. The research confirmed that Electricity and D.C circuits among other topics such as Quantum Physics, Particle and Nuclear Physics, Ideal Gases, Thermodynamics, and Astronomy and Cosmology are highly abstract, requiring learners to apply advanced theoretical concepts beyond everyday experiences. On the other hand, topics like Physical Quantities and Units and Kinematics are considered less abstract, involving direct measurements and observations that require little manipulation. The study emphasizes the significance of incorporating local context into the analogies used to teach physics concepts, as it enhances students' understanding and engagement. By linking local contextual practices to scientific knowledge, physics education can become more meaningful and relatable for students. The developed advisory text provides practical guidance on how to effectively utilize the identified analogies in teaching physics concepts.

In conclusion, the study provides valuable insights for Zimbabwe educators to develop and use contextually appropriate physics analogies, ultimately improving the teaching and learning of physics in Zimbabwe. This study contributes to the advancement of contextually appropriate physics education in Zimbabwe. Teachers can enhance students' understanding and interest in physics by recognizing the importance of local context integration and developing relevant analogies. Further research and collaboration are encouraged to expand the repertoire of local context sensitive teaching materials and promote inclusive science education in Zimbabwe and beyond.

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