Mediating sense making by science teachers of electrical current using an analogy of water flow in a narrow and wide pipe in under resources schools

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Abstract
Analogies are used in Science practices as mediating tools for teaching and learning. This study's main goal was to explore teachers' perceptions on the use of an analogy of water flow in a narrow and wide tube for sense making of electrical resistance. The study then strove to have an insight on what teachers consider as the strengths and weaknesses of the use of the water flow in a narrow and wide tube analogy for sense making of electrical current flow to mitigate a situation where mediating tools are lacking. In an effort to ensure that the goals of education are realized in schools which are under-resourced in the Zambezi Region, the study explored the effects of incorporating an analogy of water flow in a narrow and wide pipe to teach electrical current flow and factors affecting it to Grade 10 learners.

Sometimes schools in rural settings grapple to come up with teaching and learning apparatus as their science teachers fail to promote the use of different mediating tools as they strive to ensure that education is universal. Absence of varying mediating tools compromises the goals of education systems. To address this through use of analogy, participating science teachers ended up engaging cognitive activities to make sense of factors that could affect electrical resistance. Cognitive constructivism was embraced as the theoretical framework. Through use of interviews to the teachers and observation of teachers when they used water flow in a pipe as analogy for electrical current flow some of the key findings were; analogies can be used to ensure that almost all the goals of science education in the Zambezi Region are addressed in rural schools which are under-resourced if mathematical skills are employed to map the variable concepts in water flow in a pipe to electrical current flow. Also, scientific literacy can be improved in schools which initially could not have engaged in hands-on practical activities which well-resourced schools engage in. Finally, analogy usage can lead to meaningful learning and learners' development based on their prior knowledge which serves as a key role in independent thinking.

Keywords: *analogy, mediating tool, scientific literacy, universal, goal*

Background

African countries have introduced various goals to ensure universal primary and secondary education is achieved (McGee, 2000). In the Southern African Development Community (SADC) region, for example some countries' goals are capacitating learners with equity, quality, democracy and access to education. This is evident since Namibia, a SADC country has these goals as stated in the (Namibia Ministry of Education and Culture, 1993) curriculum document. Proper explanation and understanding of these goals and their implication to the population has accelerated enrolment in schools. Shapwanale (2017) provide evidence as she reports that pupil enrolment shows improvement while survival rate of the learners is poor. Failure of the system to ensure that survival rate is high comes as challenges schools now face as they ensure that a large number of learners are in schools and have the necessary mediating tools needed to facilitate sense making of science concepts. Observations and analysis reveal that enrolment skyrocketed as these countries aim to make education universal. In the process, the supply of infrastructure, consumables and other daily needs required for sense making during learning science concepts in particular is constrained. Instead of the supply of educational consumables to be homogenous in all areas, the supply has become heterogeneous and is most noticeable in under-resourced schools. With the hope of lessening the situation, where learners' survival rate at schools is poor, analogies were embraced to level the terrain. This then justifies why we need this type of study which might assist teachers to come up with analogies as mediating artefacts in the teaching of electrical current flow to understand factors determining electrical current flow in conductors.

Also, another justification for this approach is literature on how analogies can be used, focuses only on schools that are well resourced. However, authors are aware of this scenario but no author has investigated the effects of using analogies for sense making in under-resourced schools to address equity, equality, quality and democracy. Analogies in use are only suitable to be done in schools which are well equipped as they use materials there as analogies to support the teaching of electrical current flow and understand factors determining electrical current flow in conductors.

For instance, Simayi (2014) recognizes that learners come with knowledge which can be incorporated in electrical current teaching as analogies. However, the analogies employed; the bicycle and rope are cultural artefacts found in schools which constantly receive teaching materials from the government but not seen in a disadvantaged school. Even though Hutchison and Padgett (2007) give an analogous relationship between the flow of a river down a hill and the flow of the electric current in circuits, they do not mention how this analogy can be employed in schools which suffer from heterogeneous supply of teaching materials so that factors determining electrical current flow can be understood. Also, they do not bring the mathematical relationship between variables in the base domain, the known knowledge or knowledge already in the schema of a learner as supported in cognitive constructivism (Piaget, & Inhelder, 1973) and those in the target domain, the knowledge to be assimilated.

Heterogeneous supply of mediating tools in schools sometimes perpetuates existence of inequity, inferior, unequal and undemocratic science teaching practices (Oakes, 2003). Thompson (2013) acknowledges that schools in SADC countries struggle to level the educational landscape for the goals to thrive since they are constrained materially. The heterogeneous supply phenomenon common in SADC regions creates challenges in particular in science subjects teaching which always requires hands-on practical activities for sense making. Ford (2012) understands sense making in science as to make meaning of science concepts in nature and this promotes scientific literacy to flourish. Failure to ensure that mediating tools, materials that affect or determine how science teachers interact with learners such as language, analogies, case studies and models, Engeström (1987) proposes should be used to promote deep learning. Once such type of mediating tools is embraced, this approach does not compromise the scientific literacy development of the citizens in those under-resourced schools. The study strove to address scientific literacy and educational goals mentioned in any SADC school lacking mediating tools. So, to respond to the research question; what do teachers consider as the strengths and weaknesses of the use of the water flow in a narrow and wide pipe analogy for sense making of electrical current to mitigate a situation where mediating tools are lacking. This study also sought to find out the elements teachers consider affect sense making in determining electrical current flow. This led to the use of an analogy of water flow in a narrow and wide pipe as base domain in under-resourced schools in the Zambezi Region to understand factors affecting electrical current flow which is the target domain.

Problem statement

To mitigate the problem where science teachers encounter challenges with sourcing teaching and learning materials, science teachers sometimes resort to analogy use. The belief is that analogies serve as mediating artifacts and as analogical reasoning tools that trigger creativity and critical thinking (as Jonāne, (2015) supports. This has led this study to explore what teachers consider the strengths and weaknesses of the use of the water flow in a narrow and wide pipe tube acting as the base domain analogy for sense making. For instance, water flowing in a river due to pressure is an analogy to explain why charged particles flow in an electrical conductor which is the target domain and is determined by factors such as resistance which depend on length of conductor and its cross sectional area. Substantial amount of literature stating the usefulness of analogies exist. However, none of the authors have ever mentioned the usefulness of analogies in under-resourced schools as mediating tools to offset lack of materials useful for sense making. This led to see the significance of this study and made us come up with research questions given in the section which follows.

Significance of the study
The significance of this study lies in the use of cultural artefacts and mathematical skills in the environment of the learner to mediate learning. This also allows learners who are in under-resourced schools to also discover on their own the factors which affect electrical resistance. The study focused at investigating how resistance and factors affecting electrical resistance can be understood using the perspective of an analogy.

Research goals and question
The goal of this study is to explore how an analogy of water flow in a narrow and wide pipe can be used by teachers to mediate sense making of electrical resistance and factors affecting electrical resistance. To achieve this, the following questions were asked.

Research questions
1. What do science teachers consider as the strengths and weaknesses of the use of the water flow in a narrow and wide pipe analogy for sense making of electrical flow and resistance?
2. What elements do teachers consider affect sense making of factors determining electrical current flow?

To answer the given research questions above, we found that knowledge of what literature say about an analogy is necessary. The literature about an analogy is discussed in the section.

Literature review
Analogy in Science teaching
Analogies may be taken as a comparison of a concept, an idea, an object, phenomenon or process to another that is quite at a higher level than it. Lakoff (1993) refers to knowledge used for comparison as the base domain whereas the intended conceptual knowledge is referred to as target domain. A familiar concept or situation acts as the base domain. This can be formulated by prior knowledge anchored on one's experiences and everyday knowledge. Use of everyday knowledge sometimes reflects indigenous knowledge (IK), learners possess as prior knowledge necessary for new knowledge to germinate in it (Sfard, 1998). Also, subject content knowledge received in other encounters with knowledgeable peers scaffolding can act as a familiar situation. Wood and Middleton (1975) view scaffolding as support for cognitive activity used in cognitive constructivism when a member in a community of practice uses a familiar situation with a novice (Lave, 1996)..A familiar situation is one Aikenhead (1997) refers to as science related situation. Sometimes, a familiar situation can be an analogy. A community member in practice such as a teacher uses similes, comparisons and metaphors to scaffold a learner's understanding of a concept.

Lakoff (1993) uses the lens of a metaphor while Gentner (1983) uses the lens of an analogy to map concepts in base domain to those in target domain. Mapping of water flow in a pipe of narrow and wide diameter to electrical current flow in a conductor of narrow and wide diameter to understand factors affecting electrical resistance is represented in Table 1. Electrical resistance is not isolated from electrical current flows in a conductor. This explains why Table 1, representing the analogy of water flow and electrical current flow is used to gain insight on variables which will affect resistance. Electrical resistance exists in the presence of electrical current. This allows viewing electrical resistance by first gaining insight on water flow.

Table 1: Structure mapping for water flow in a wide and narrow pipe and electrical current flow in an electric circuit to understand factors affecting resistance

Base domain [B]	Target domain [T]
Source of force $\lfloor SF_{H_2O} \rfloor$ (Water at a certain pressure or with certain amount of potential energy in a dam.)	Source of force $\left[SF_{E.current}\right]$ (An electrical cell with a certain amount of potential difference.)
Energy $\lfloor E_{H_2O} \rfloor$ (Potential energy used to facilitate the movement of water particles.)	Energy $\left[E_{E.current}\right]$ (Electrical energy used to facilitate movement of charged particles.)
Medium of transportation $\lfloor MT_{H_2O} \rfloor$ (pipe of	Medium of transportation $\left[MT_{E.current}\right]$

different length and constant area.)	(electrical conductors e.g. copper of certain length and constant area)
Volume of water $\lfloor V_{H_2O} \rfloor$ flow (water flow in a given cross section area through lengths which are constant.)	Volume of charge $[V_{E.current}]$ flow (current flow per given cross section area through lengths which are constant).

Adapted from Gentner and Jeziorski (1993, p. 466)

It is of interest to have the comparison in Table 1. It shows the variables in the base domain, the water flow in a wide and narrow pipe and the target domain, the electrical current flow. The variables in the base domain are mapped into the target domain and then allow discussion of electrical resistance. These variables in the two domains are discussed and explained below.

In the target domain, voltage supplied from an electrical cell or battery can be compared to the constant pressure maintained through keeping same amount of water. The voltage provides electrical energy that pushes charges along a conductor. Whereas pressure in the water tank pushes water particles through the pipe and as they move they resist the flow. On the other hand, the electrical resistance of a conductor is an indicator of how challenging it is to drive the charges along. Using the water flow analogy, electrical resistance is similar to friction. For water flowing through a pipe, a long narrow pipe provides more resistance to the flow than does a short fat pipe.

Resistance in a pipe occurs at the water-pipe interface only, whereas the resistance in the wire occurs across the diameter. The (open) water level in a pipe varies for different amounts of water whereas the diameter of the wire is constant for different amounts of potential difference.

Hydraulic resistance to water flow may be understood as restriction in the water pipe. For example, if there is a throttle. Opening the throttle wide reduces resistance and partially closing it increases resistance. This explains why water flow in a narrow pipe encounters more resistance. In addition, most of the area inside the narrow pipe can be occupied by adhesion forces. Adhesion forces in water are found in the inside surface of the pipe and it consists of water molecules which are strongly attached to the pipe surface. It is not easy for such water to move. This contributes to a higher resistance to the water flow. The flow of water might be due to the water with weaker adhesion forces but stronger cohesion forces. Cohesion forces, between particles of the same type, make it possible for water to flow. So, the wider pipes might have more of the cohesion forces as compared to adhesion forces which imply that they might have less resistance to water flow. This also applies to the flowing charged particles which constitute electrical current: long thin wires provide more resistance than do short thick wires. This allows mapping variables in base domain to those in the target domain as (Gentner, 1983).

Gentner (1983) using the lens of an analogy uses a mathematical approach to relate parts in the base domain to parts in the target domain. If the acronyms in Table 1 are made use of to show the mapping, then the following relationship is noted.

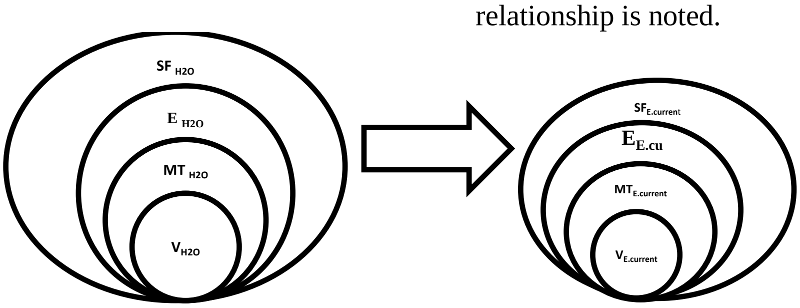

Figure 1: **Structure mapping for current flow in an electric circuit and water flow in a wide and/or narrow pipe** (Adapted from Gentner, 2012, p. 132)

From this, our view is that an analogy is a function in which each concept in the base domain is related to only one concept in the target domain. The mapping or function of such a type is a one to one relationship. It follows then that if an analogy is to be a representative of the two domains it must be of the one to one type.

Jonāne (2016) posits that the analogies' role is to provide scientific explanation. Analogies have been in use since the time science subjects emerged. In Physics in particular, Boyle compared gas particles with mobile coiled springs (Gingras, & Guay, 2011). Huygens on the other hand came with the perspective of water waves behaving as light waves, historically Carnot compared heat engines with waterfalls and Coulomb's law is analogous with Newton's law of gravitation as well as many others (Jonāne, 2016)

The spectrum of analogies given can be grouped based on increase on the level of abstraction, that is, from simple to abstract or concrete to abstract. Boyle's and Carnot's analogy are of the concrete-concrete type, Huygens' and Podolefsky's solar system and atom and water system electrical circuit are concrete-abstract analogy and Coulomb's is an abstract-abstract analogy. Jonāne (2015) and Podolefsky (2016) propose grouping based on presentation. This type yields verbal to verbal, an example is an analogy in Table 1 and Coulomb's analogy. Pictorial-verbal and pictorial-pictorial analogies also exist. Therefore, the level of increase in abstraction ensures that there is evidence of cognitive development in learners' thinking. In the process, learning gradually becomes clouded with higher mental constructions which are offered in various presentations that signify sense making of concepts.

Presentational type of analogy can be taken to a hands-on practical activity level. This is manifested in Ramasike's (2017) study. After comparing Ohm's law with blowing air into a drinking straw which was inserted in water and engaging with some of the above types of analogy, she showed how Ohm's law can be taught. Jonāne (2015) suggests that such an approach allows deep learning of science concepts. The focus of this study was to take an analogy representation to the level where it might support cognitive constructivism. In this study electrical resistance and factors affecting electrical resistance were conceptualized by using a verbal-verbal analogy, i.e. relating water flow to electrical current flow as in Table 1. This was used to develop and compare activities using cultural artefacts as mediating tools at the disposal of a learner (Mukwambo, 2017). The mathematical skills automatically evolve and gave a special type of variation and contribution into the study. Shaw (1999) argues that mapping of elements in the base domain which is cultural artefacts to those in the target domain can be expressed using a mathematical function.

Research methodology

To respond to the questions posed, this study was supported by the theoretical perspectives of an analogy which support cognitive constructivist teaching and learning philosophy. The study drew on conceptual framework of an analogy. As a qualitative and interpretive research, it acknowledges and embraces the "contextual nature of inquiry" (Glesne & Peshkin, 1992, p. 7). In this interpretive study ten Grade 10 Physical science teachers from ten different schools in the Zambezi Region of Namibia were observed in their natural environment teaching concepts of electrical current flow and factors affecting the flow of moving charged particles. Kirk and Miller (1986) refer to natural environment as "watching people in their own territory ... interacting with them in their own language, on their own terms" (p. 9). Ethical issues, such as concealing identity of participants and seeking permission from participants were considered throughout the research process.

The permission to conduct the research was requested from the following: subject advisor so as to know the research which was taking place in his region and the headmasters for the ten schools so as to understand the support that was to be offered for using the research site as well as the benefits to science teachers if any that the study would contribute. The ten Physical science teachers were requested in writing and verbally to grant permission to participate in the study. Furthermore, the use of a video-recorder to capture most of the data during observations and interviews was discussed before the research process started.

Interviews were aimed at finding out the perceptions of the teachers, the enablers and the constraints of using the water flow analogy in order to gain insight into factors teachers considered affected sense making of electrical resistance. To respond to research question 2, where we needed to know constraints and enablers of using an analogy, excerpts from the interviews were used. This was also related to analogical mapping illustrated in the literature review.

Mapping of variables in Table 1 was done with participants to generate data. The ten teachers only generated data using base domain elements at first. Variables in the base domain were used to infer how water flowed in three pipes of varying diameters but constant length and different length with constant diameter. This allowed the teachers to relate how the flow varied with cross section area and length.

Four components exist in each domain (base domain and target domain) shown in Table 1 and in Figure 1.They are presented as a one to one function basing on Gentner's (1983) conception of an analogy. The last two in the base domain (Medium of transportation $\lfloor MT_{H_2O} \rfloor$ and Volume of water $\lfloor V_{H_2O} \rfloor$ flow) were selected for investigation in order to understand their behaviour. These were compared with components in the target domain and in the last two rows (Medium of transportation [$MT_{E.current}$] and Volume of current [$V_{E.current}$]), those were mapped within column 2.

To understand how the flow of water depends on length, three pipes of different lengths L_1; L_2 and L_3 were used to estimate volume flow rate V_1, V_2 and V_3, each pipe transported when time and area were kept constant. The pipes had the characteristics L_1=10 cm< L_2= 20 cm< L_3= 30 cm. Similarly, to understand how flow of water depended on cross section area, pipes of different areas were considered; A_1= 0,8 cm^2< A_2 = 3,1 cm^2< A_3 = 4.5 cm^2 to estimate volume V_x, V_y and V_z. The aim of the activities was to understand opposition to flow rate and see how it depended on length and cross section area in the base domain set.

Two types of tables were obtained when work done by the teachers was finally rewritten by the researchers and the participating science teachers. The tables represented how volume water flow rate transported in relation to length of pipe and to cross section area. The same tables were used to detect the pattern of opposition to flow rate then map the pattern with corresponding components in the target domain, in particular the resistance. That is they were asked to do some inferences based on the tenets of analogy.

Data presentation and analysis

The data generated when water volume flow rate was compared with cross section area are indicated in Table 2. This data was generated when the two groups each with five members from the teacher component each came together and worked with the researchers to come up with the pattern which they thought was suitable to accommodate their observations which they presented using mathematical reasoning. The data on the observation schedule which each group yielded was then transcribed using medium of instruction, English to fit literature in analogy (Gentner & Jeziorski, 1993; Gentner, 1983). The volume flow rate of water was found to be high when the diameter was highest, r_1 = 0,5 cm; r_2 = 1 cm and r_3 = 1,2 cm, . A pipe, whose diameter was A_1 and smallest had the highest volume flow rate opposition compared to A_3.

Table 2: Volume flow rate and area values used to compare

Volume flow rate V (cm^3)	**Cross section area A (cm^2)**	**cm^3min^{-1}(VFRO) -**
V_x	A_1	50
V_y	A_2	100
V_z	A_3	150
Where V_x= 50< V_y = 100 < V_z= 150	Where A_1 < A_2 < A_3	VFRO $\propto$ 1/A

Also, the data generated when volume flow rate was compared with length is indicated in Table 3. Similarly, this data was generated when the two groups each worked with the researchers to emerge the patterns that agree with their observations they presented using mathematical reasoning. Volume flow rate opposition increased as the length of the pipe was made longer, as shown in the table shows.

Table 3: Volume flow rate and length values used to compare

Volume flow rate V(cm^3min^{-1})	Cross section area A (cm^2)
V_1= 50	L_1
V_2= 100	L_2
V_3= 150	L_3
V_1> V_2> V_3	$L_1 < L_1 < L_1$

Data presented in Table 2 and 3 were generated aimed at understanding the variables in the last two rows of Table 1 showing the elements of base domain. To understand behaviour of elements in the last columns of the target domain, mapping was done. Tables 2 and 3 were mapped to the elements in the last two rows of the target domain to come up with data suitable for electrical current flow to respond to the stated research questions. Tables 2 and 3 data acted as baseline data for data which was obtained through mapping for target domain variables which could not be done using conventional tools on account of lack of materials in the mentioned schools. Table 4 presents the data which the participants emerged.

Table 4: Variable mapping for water flow in a wide and narrow pipe and current flow in an electric circuit

Base domain	Target domain
Medium of transportation $\lfloor MT_{H_2O} \rfloor$ (pipes which are of different lengths and constant cross section area.)	Medium of transportation [$MT_{E.current}$] (electrical conductors e.g. copper of certain length and constant cross section area.)
VFRO $MTH_2O \propto L$	VFRO $MT_{E.current} \propto L$
Volume of water [V_{H2O}] flow (water flow per given cross section area in lengths of constant length.)	Volume of current [$V_{E.current}$] flow (current flow per given cross section area in lengths of constant length.)
VFRO $MT_{H_2O} \propto 1/A$	VFRO $MT_{E.current} \propto 1/A$

Adapted from Gentner and Jeziorski (2012, p. 466)

The mapping in Table 4 is based on Lakoff's (1993) view of a metaphor. In the base domain, VFRO MT_{H_2O} was found to be inversely proportional to the area and directly proportional to length. Most compelling evidence is that, VFRO MT $_{E.current}$ is also inversely proportional to area and directly proportional to length. If Gentner's (2012) lens is used, the mapping of variables in base domain to those in target domain can be illustrated as in Figure 2. According to Gentner (2012) the compared variables can be represent using mathematical symbolism. This is done in Figure 2.

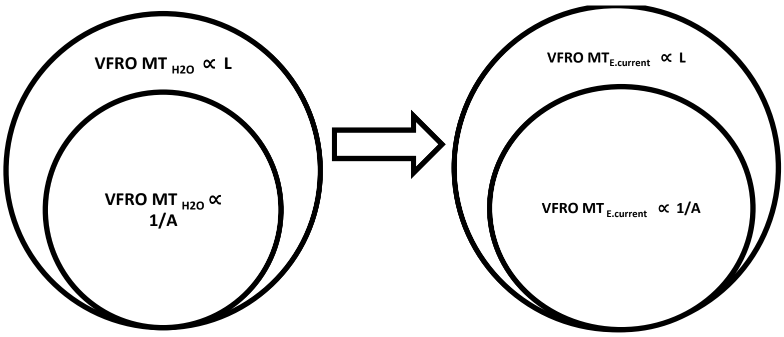

Figure 2: Structure mapping water opposition flow to current opposition flow

To further include logical reasoning more familiar to mathematics used to explain physical phenomenon like the one under study, the participants together with the researchers related the variables under study through use of a constant ρ. ρ was explained as the resistivity which depended on the characteristics of the material used for the study, water and charge flow respectively. This emerged two mathematical relations obtained through mapping with each illustrating how opposition depended on the length and cross section area. This is shown in Figure 3. The idea to show them as converging arrows was to convey the idea that a water system and a charge flow system are not in conflict but share some similarities.

Data from interviews

The theme that surfaced from the interviews on the extent which the use of an analogy was helpful or limiting sense making on investigating teachers' perceptions on the use of an analogy of water flow in a narrow and wide tube for sense making of electrical resistance when an analogy is used to understand factors that determine electrical resistance is revealed in the following except.

> Work on understanding factors affecting electrical resistance in textbooks and that teachers reflect in their practices in most cases is based on rigorous mathematical approach which learners cannot understand on account of their weak mathematical background. Also, sometimes it is based on hands-on practical activities which cannot be done on account of lack of resources. However, the practical use of an analogy allows learners to gain insight on elements that affect electrical resistance easily.

$$R_{H_2O} = \rho L/A \quad \Longleftrightarrow \quad R_{Elect} = \rho L/A$$

Figure 3: Factors determining resistance in a water system and electric system

Findings

One of the research questions aimed at finding what teachers consider the strengths and weaknesses of the use of the water flow in a narrow and wide tube analogy for sense making of electrical resistance? This research question was responded when teachers used analogies embracing materials which are around the learners' environment and their mathematical skills. Their observations generated Table 2 and 3. Teachers considered the mathematical strengths which come with water flow analogy. Transcribing the data yielded during observation required that participants possess the idea of mathematical functions that Gentner (1983) supports. Weaknesses might arise if participants fail to understanding the mapping presented in Table 1 which was adapted from (Gentner & Jeziorski, 1993) and used to familiarize participants with mapping skills. Understanding how components in the base domain operate and then relate how such a physical phenomenon operates if not understood can come as a challenge hampering the use of an analogy to make sense of factors affecting resistance. The skill to relate and compare water flow in pipes with electrical charge flow in a conductor removed weaknesses. Small pipes picked from around the community were used and teachers were tasked to observe the phenomenon under study using physical features.

Research question 2 aimed at finding the elements teachers consider affect sense making of factors determining electrical resistance. This was responded through mapping. It was found that factors affecting resistance are area and length. Through mapping with parameters which are known from learners' environment with electrical current flow, these were found to be directly proportional to length and inversely proportional to cross section area. Also, teachers pointed out during discussion that lack of mathematical skills might lead one not to find the factors which affect electrical resistance.

Basing from the findings from the excerpt, the use of an analogy does not bring constraints. Instead, it is an enabler. This is evidenced from the excerpt where theme revealed is rigorous mathematical treatment of elements affecting electrical resistance can be substituted with the use of an analogy which embraces the idea of a function, Gentner

(1983) proposes. The except from the interviews affirms the goal of the study which was to investigate teachers' perceptions on the use of an analogy of water flow in a narrow and wide tube for sense making of electrical resistance.

Conclusion

Science textbooks sometimes use analogy of physical science phenomenon and others in learners' environment. However, sometimes they offer a surface treatment of the physical phenomenon as they do not bring the mathematical relations existing in elements in base domain and those in target domain. As a result it hampers sense making of science concepts. From the view of the teachers science textbooks do not use analogies that engage the mathematical skills required to surface relation existing between variables to make the concepts that are difficult to be comprehensible, as this is one of the roles of an analogy. It is necessary to penetrate further. This can be done through mathematical analysis of how variables determining the phenomenon are related. In doing so, the use of an analogy level the terrain made rough by lack of resources so that equity, democracy, quality, access and sense making of science concepts are addressed to all learners and in all area of a country which has made its education system universal.

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