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Evaluation of the periodic table as a teaching tool and content for conceptual change in chemical processes

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Abstract: This study focused on two crucial chemistry concepts, chemical bonding and related reactions. It explored how learners may conceptually use the periodic table in their scientific understanding. Specifically, the study's goal was to ascertain the effect of the use of this tool on learners' conceptual knowledge and/or reasoning abilities during learning or knowledge construction. The study utilized qualitative methodology and was based on a case (the school). For the purposes of the experiment, the participating learners—learners in grade 11 chemistry—were split into two groups (control group and experimental group). The study's findings indicate relationships between learners' knowledge (re)construction of chemical processes and their applicability to the periodic table. Future research is suggested by the researchers on the links between learning conceptual change and teaching approaches using the periodic table.

Keywords: Periodic table; conceptual change; chemical bonding; chemical reactions.

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INTRODUCTION

The periodic table has been utilized in teaching chemistry in a variety of ways with varying learning outcomes (Mokiwa, 2017). The purpose of this study was to determine how learners utilized the periodic table for their understanding of chemistry. In other words, the understanding of perspectives on the periodic table, other affective learner qualities, and their conceptual development were the subjects of the investigation. Despite having comparable prior information, learners approach their learning with varying degrees of learning objectives, motives, sentiments of self-concept, interest, control beliefs, and values (Steinmayr et al., 2019).

Teachers can improve learner understanding of chemical ideas; the periodic table alone does not guarantee this (Mhlongo & Sedumedi, 2023). Because conceptual change cannot occur spontaneously, this is the situation (Ugwuanyi et al., 2023). According to Paunesku and Farrington (2020), teachers must inspire learners and foster a supportive learning environment. As a result, learners flourish in these settings because they receive the right assistance and feel valued (Paunesku & Farrington, 2020). Thus, Ausubel's theory that the learner's prior knowledge is the main element determining learning (Ausubel, Novak, & Hanesian, 1978) holds true. In other words, the student’s capacity for learning or conceptual growth is mainly determined by his or her prior knowledge (Hattan et al., 2023). Hence, how a teacher employs chemical tools and assesses learners has an impact on learner motivation and progress (Clores & España, 2023). When learner's curiosity is piqued, their work will be of a higher calibre and their comprehension will increase (Wong et al., 2020).

The key problem impeding learners' performance and future accomplishment, according to research studies in science and Chemistry in particular, is a lack of conceptual understanding with regard to the periodic table application (Mhlongo & Sedumedi, 2023; Tóthová et al., 2021; Mokiwa, 2017). Studies on learning and the periodic table, uncovered additional and varied barriers to conceptual knowledge (Bierenstiel and Snow, 2019). According to Bierenstiel and Snow (2019), for instance, some of these issues include teachers neglect of the periodic table system's finer points and accompanying misunderstandings in their instruction. It seems to reason that student's attitudes about mastering a certain subject or topic might have an impact on their progress (Wong et al., 2020).

Clearly, there are many challenges involved in studying science in general and Chemistry in particular. It actually has several facets because it has more than just to do with the learners' or the subject's nature (Siddique et al., 2023). The teaching and learning settings are also included (Siddique et al., 2023). Thus, there are a variety of circumstances in which the periodic table's usefulness might improve students' understanding of chemistry (Stanley Lourdes Benedict, 2023). The suggestion is that as teachers, we should emphasize and incorporate the crucial element of how learners learn to our learning facilitation. In other words, we need to connect students' knowledge creation and representation processes to their abilities with the periodicity of elements in their study of chemistry topics (Mhlongo & Sedumedi, 2023). Teachers will also benefit from this connection capacity as it may help ensure the monitoring and diagnosis of the periodic table learning content (Mhlongo & Sedumedi, 2023). Therefore, if teachers are to improve conceptual comprehension in Chemistry learning, they must be able to pinpoint efficient ways to correctly incorporate the knowledge of the periodic table into situations relevant to learners from their everyday lives.

The researchers sought to determine whether utilizing the periodic table may have had an effect on learners' conceptual understanding or knowledge and/or reasoning abilities during learning or knowledge construction by posing the following study question "What conceptual effect does the use of the periodic table have on learners' learning of selected chemistry concepts and/or phenomena?".

METHOD

Research Design

The study adopted a multiple case study approach on the basic assumption that knowledge representation varies between different groups or individual learners and in different social settings. The notion of 'multiple case study' derives from the fact that learners as individuals learn differently (Leung, & Cheng, 2023). That is, they construct knowledge idiosyncratically hence they are cases within the classroom or in the same school. They are cases within the case (school) in this study. Different learning environments may instigate different knowledge representation, even if the content taught is the same (Siddique et al., 2023). Therefore, qualitative content analysis (QCA) and the quantitative determination are deployed. The two analytical approaches stem from the quasi-experimental design adopted for the empirical process. This was due to the fact that the researchers aimed at understanding the differences in knowledge representation of learners in different contexts and/or environments and highlight the associated effect through a descriptive quantitation.

Respondents

The respondents for the investigation were drawn from the school's Grade 11 Physical Sciences learners. In addition, one of the researchers and the participant teachers were from the same school. That is, two Physical Science teachers with a combined thirty (30) years of experience teaching grades 8-12 participated in the study. During the data collection process, the teachers taught chemistry (a part of the Physical Science subject) to the Grade 11 learners. Participants' differentiated teaching experiences would add to the study's value. This study comprised forty-six (46) Grade 11 Physical Sciences learners (23 learners in experimental group and 23 learners in control group). The participant learners had already been exposed to teachers utilizing the periodic table to teach and for their learners to learn.

Data Gathering Procedure and Instruments

The data gathering procedures included a series of prior knowledge assessments using tests. That is, all participants' prior knowledge was first established by a diagnostic test. Following that, learners were randomly divided into experimental groups (2 groups). Both groups of learners were then assessed (post-test) to determine their understanding of specific aspects of the periodic table. Following the teachers participating under the supervision of one of the researchers, the teachers facilitated intervention teaching of the periodic table, in which learners were assessed for the third time (Knowledge Instantiation Test). The two test results were compared (i.e. diagnostic-test and post-test). For comparison, the same concepts were assessed in both the diagnostic-test and post-test. The comparisons of the two groups were undertaken to see what kind of qualitative changes there had been.

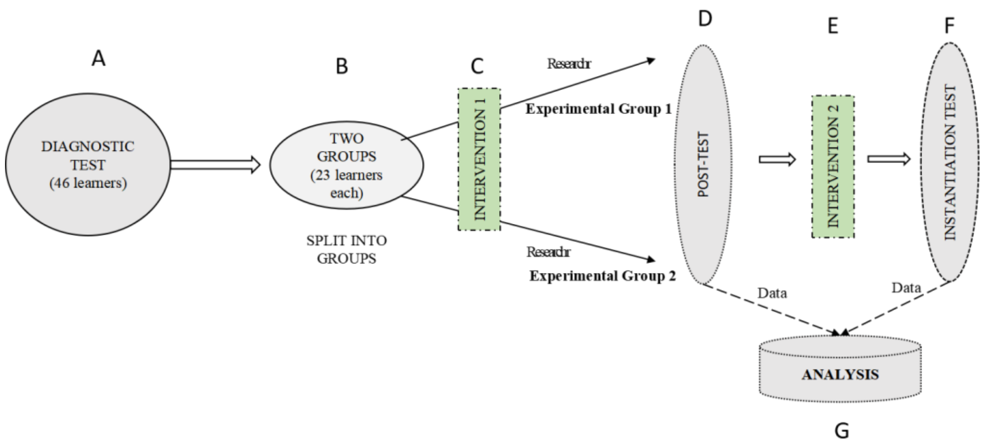


Figure 1. The Experimentation Process

Data analyses

A qualitative content analysis (QCA) was carried out on text data drawn from learners' responses in the diagnostic-test, post-test and Knowledge Instantiation Test. This was to ascertain what, if anything, could have induced the difference in the learners' understanding following the intervention.

Qualitative content analysis is a systematic methodological procedure for analysing data that allows researchers to analyse manifest and descriptive content (Lindgren, Lundman, & Graneheim, 2020). This methodological approach to data analysis also allows for the establishment of categories, hidden and interpretive content, and themes (Graneheim, Lindgren, Lundman, 2017). To answer the study question, this method was used. That is, forming concepts necessitated the classification of mental structure components as outlined by Thompsons (1992) and complemented by Hewson and Hewson's (1988) teaching analytical framework. Learner and teacher reactions from the researcher' observations of teacher activities were used to create content. In addition, content and activity interpretations gave useful information for answering the research question.

RESULTS AND DISCUSSION

Since teaching involves both teachers and learners, it was crucial in the context of the studies of this kind to determine the condition and level of comprehension of the learners because their understanding—or lack thereof—might be related in some way to how their teachers used the periodic table as *content* or a teaching and learning *tool*. But this does not imply that teaching always has an impact on learning and/or leads to a certain learning outcome (Tothova, Rusek & Chytry, 2021).

As a result, the answer to the research question reveals how the learners represented the knowledge they had acquired and/or understood through the teaching process. There is a difference between knowledge that is learned and knowledge that is comprehended, argues Gardner (1997). Given that it "cannot be activated when needed," the learned information may not necessarily have been understood (p.73). The discussions of the results are the syntheses of the findings in Table 1-3.

Table 1. Learners' achievement in the experimental group (Taught by teacher 1)

Learners	**Diagnostic Test %**	**Post-Test %**	**Knowledge Instantiation Test**		
			Claim %	**Reason %**	**Evidence %**
KT	56	50	45	32	29
ME	48	82	56	53	41
KM	48	76	52	51	39
L3	48	62	43	34	32
N	64	62	40	42	39
NE	60	56	48	37	30
RP	68	88	53	30	32
PK	58	82	56	38	35
MM	48	86	54	35	33
MK	58	74	45	33	30
L2	62	68	83	97	75

MJ	60	54	39	35	33
NR	58	68	35	32	32
MS	44	48	44	36	36
OF	44	82	54	40	36
SK	56	68	39	29	24
TM	50	52	52	41	37
GP	56	66	54	33	28
L1	68	74	92	75	96
EM	56	72	60	42	33
KM	52	70	51	41	29
TB	56	48	52	32	37
ZK	58	48	43	42	21
Average	**55**	**67**	**52**	**42**	**42**

Table 2. Learners' achievement in the comparison group (Taught by teacher 2)

Learners	**Diagnostic Test %**	**Post-Test %**	**Knowledge Instantiation Test**		
			Claim %	**Reason %**	**Evidence %**
OS	66	66	48	23	29
PM	54	52	44	27	30
MM	58	64	52	38	32
KM	32	78	45	43	30
L6	40	46	52	45	29
LG	56	64	48	41	30
MM	54	48	47	43	28
KM	50	66	45	36	32
KS	20	54	48	36	30
SH	62	66	50	40	32
CN	18	46	48	36	29
LM	56	62	42	37	32
TN	68	66	50	47	33
LB	60	66	43	48	34
LM	18	58	45	42	26
JT	64	70	52	43	30
HH	66	34	51	41	30
L4	62	76	85	77	90
TM	42	54	66	54	40
TM	58	62	57	57	36
LR	40	66	52	43	32
L5	48	62	33	15	23
SM	66	66	52	43	32
Average	**50**	**61**	**50**	**42**	**33**

The tables present the achievement of learners in an experimental group (taught by teacher 1) and a comparison group (taught by teacher 2) in a chemistry class. The results are based on learners' diagnostic test scores, post-test percentages, and knowledge instantiation test scores in three categories: claim, reason, and evidence. The experimental group achieved an average of 55% in the diagnostic test, 67% in the post-test, and 52% in the knowledge instantiation test. In contrast, the comparison group achieved an average of 50% in the diagnostic test, 61% in the post-test, and 50% in the knowledge instantiation test. These findings suggest that learners taught by teacher 1 in the experimental group had higher achievements compared to learners taught by teacher 2 in the comparison group. Overall, both teachers had varying levels of success in teaching chemistry concepts and phenomena, which can impact learners' understanding and achievement in the subject. The two tables were used by the researcher to sample six learners, three in both groups to determine what conceptual effect does the use of the periodic table have on learners' learning of selected chemistry concepts and/or phenomena.

Table 3. Synthesis of individual learners' representation of knowledge representations of the periodic table as content and system.

Learner Achievement According to Levels	Learner Knowledge Representations for Diagnostic, Post-Test & Knowledge Instantiation Test
L1 (Higher)-Taught by T1	PERIODIC TABLE TEST **LEARNER 1** Diagnostic Test score: 68% Post-Test score: 74% **Learner responses** 4. How are elements grouped on the periodic table? **Diagnostic Test Response***: From the smallest atomic number to the highest atomic number* **Post-Test Response:** *The s-p and d-block elements of the periodic table are arranged into 18 numbered columns or groups* 5. What are the common features of each row in the periodic table? **Diagnostic Test Response***: All the amount in a periodic the elements in each.* **Post-Test Response:** *Each column is called a group. The elements in each groups have same number of electrons in the outer orbital.* 6. What are the common features of each column in the periodic table? **Diagnostic Test Response***: number of electrons.* **Post-Test Response:** *Each column is called a group the element in each or group have the same number of electrons in the outer orbitals, those electrons are also called valence electrons.* **FINDINGS** In this finding, the learner's representation of knowledge as a learning response based on the understanding of the periodic table as content and tool were the focus of analysis. The answers to questions (Q.4, Q.5, and Q.6) show that the learner (L1) classifies the elements in the periodic table into groups. According to the learner, the arrangement in

this instance is made up of the "eighteen groups" that make up the top half of the periodic table. The learner includes the transitional elements in these "eighteen groups" (Q.5). The primary group representative elements for the learner's groups are the -s- (metals), -p- (non-metals), and -d- (transitional metals), with the transitional elements being included in the groups. The f- is not included as a designation of "group" in the learner's groups or is not indicated. This might be that Grade 11 curriculum does not include or does not cover the f- as a group.

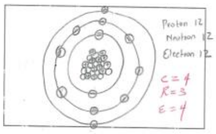
Additionally, the learner is focused on the first 18 elements in the periodic table. In fact, the learner makes it evident which groupings might be present in the periodic table's organization. The three periodic table questions focus primarily on content and, to some extent, characterization. The learner's knowledge has improved based on the shifts in the status of his knowledge. These are listed in the periodic table's element arrangement. This learner was enrolled in T1's (Teacher 1) class.

Knowledge instantiation: Chemical bonding and chemical reactions

Test score
C= 92%; E=96%; R=75%

Learner responses

2. In the box below draw a magnesium atom. Indicate and label the nucleus.



(b) Complete the following table:

Atoms	No. Of neutrons	No. of protons	No. of electrons
Oxygen	8	8	8
Sodium	12	11	11
Boron	6	5	5

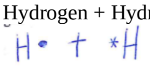
6. Write formulas for the following ionic compounds (salts)

a) magnesium fluoride MgF_2
b) iron (II) sulfate $FeSO_4$
c) calcium nitride $Ca(NO_3)_2$
d) barium nitrate $Ba(NO_3)_2$

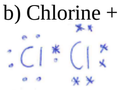
7. Write formulas for the following basic oxides (metal oxides)

a) lithium oxide Li_2O
b) iron (III) oxide Fe_2O_3
c) magnesium oxide MgO
d) silver oxide Ag_2O

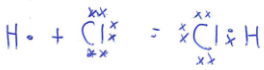
10.
Hydrogen + Hydrogen



b) Chlorine + Chlorine



c) Hydrogen + Chlorine



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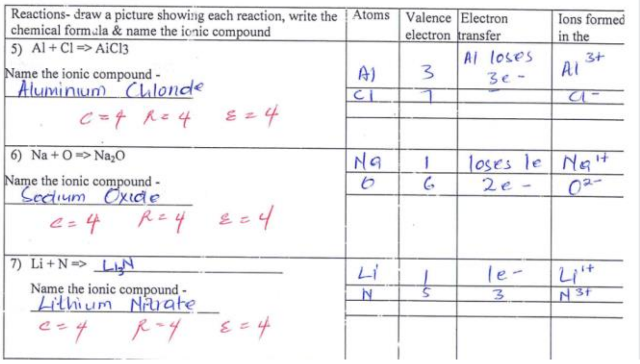


Reactions- draw a picture showing each reaction, write the chemical formula & name the ionic compound	Atoms	Valence electron	Electron transfer	Ions formed in the
5) Al + Cl => AlCl3 Name the ionic compound - Aluminium Chloride c = 4 R = 4 E = 4	Al Cl	3 7	Al loses 3e -	Al^{3+} Cl^{-}
6) Na + O => Na_2O Name the ionic compound - Sodium Oxide c = 4 R = 4 E = 4	Na O	1 6	loses 1e 2e -	Na^{1+} O^{2-}
7) Li + N => Li_3N Name the ionic compound - Lithium Nitrate c = 4 R = 4 E = 4	Li N	1 5	1e - 3	Li^{1+} N^{3+}

FINDINGS

In this part of the investigation report, the learner's exhibited knowledge representation was looked at. In other words, this evaluation of knowledge use is based on an understanding of how the magnesium atom is represented in relation to its position on the periodic table as both content and a tool. The first orbital can accommodate up to two electrons, according to the learner's depiction of the magnesium (Mg) atom, which is legitimate (a). The second energy level, which must contain a total of eight (8) electrons, is likewise correct. As a result, the learner was able to recognize the three (3) different orbitals and how their electrons were distributed.

Further, the learner accurately identified the protons and neutrons that make up the nucleus as well as their numbers. Additionally, in Question 2, the learner positioned electrons in orbitals according to their energy levels (b). The interpretation of chemical bonding and chemical reactions is built on these knowledge representations of atomic structure, which are stressed in Grade 10. The learner's answers to the questions on the molecular formula (Q.6 and Q.7), the Lewis-dot diagram (Q.10), and the chemical equation (Q.12) show that he can recognize the valence electrons in an atom and how they are shared, lost, or gained during chemical processes. The learner's understanding of the periodicity of elements led to accurate scientific representations of chemical bonding and chemical reactions, even though not all learner interpretations of chemical reactions were valid.

The learner found it difficult to explain and/or support (R) the information/statements made based on the concept (claim and evidence). The overall learner knowledge representation had strength only lay in making accurate scientific statements (C) and providing evidence (E) to substantiate his statements. There exists the consistent association between achievement (74%) and distribution (C= 92%; E=96%; R=75%).

L2 (Middle)-Taught by T1

PERIODIC TABLE TEST

LEARNER 2

Diagnostic Test: 62%

Post-Test: 68%

Learner responses

4. How are elements grouped on the periodic table?

Diagnostic Test Response: *The elements of the periodic table are arranged into 18 numbered columns or groups.*
Post-Test Response: *Elements with a small number of electronegativity are on the left, then the number of electronegativity increases as you go to the right side of the periodic table.*

5. What are the common features of each row in the periodic table?

Diagnostic Test Response: *Every element in the top row has one orbital for its electrons.*

Post-Test Response: *All the elements in a period have the same number of atomic orbitals.*

6. What are the common features of each column in the periodic table?

Diagnostic Test Response: *They all have +1 valency electron at the outermost energy.*
Post-Test Response: *The element in each group has the same number of electrons in the outer orbital.*

FINDINGS

In response to question 4 on the post-test, the learner categorizes the groups of elements based on their electronegativity, one of the features of the periodic table, after receiving the intervention training. The learner was able to use her knowledge of the periodic table as both a tool and a representation of her knowledge based on the periodicity of the elements. For instance, she answered post-test questions 5 and 6 with accurate knowledge of the periodic table and appropriately applied the content to assess the periodic table system. This is valid because the idea of the number of valence electrons and orbitals may be applied accurately in relation to the element and its location in the periodic table.

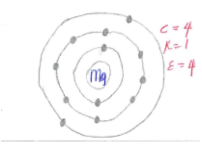
Placement of elements in the periodic table, understanding of how elements are grouped, and recognizing different kinds of bonds in various compounds are among the changes in knowledge representation from the diagnostic test to the post-test after being taught by teacher 1 (T1).

Knowledge Instantiation Test: Chemical bonding and chemical reactions

Test score
C= 83%; E=75%; R=97%

Learner responses

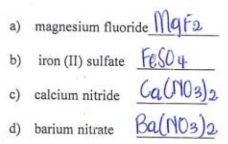
2. (a) In the box below draw a magnesium atom. Label the nucleus.



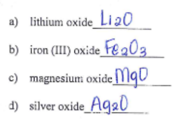
(b) Complete the following table:

Atoms	No. Of neutrons	No. Of protons	No. Of electrons
Oxygen		8	8
Sodium		11	11
Boron	6	5	5

6. Write formulas for the following ionic compounds (salts)



7. Write formulas for the following basic oxides (metal oxides)



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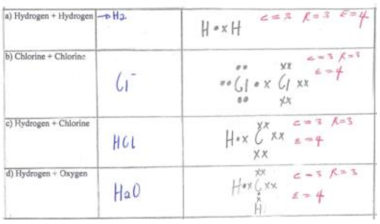

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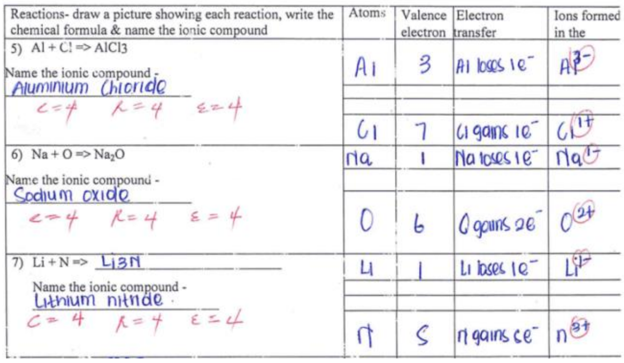


Reactions- draw a picture showing each reaction, write the chemical formula & name the ionic compound	Atoms	Valence electron	Electron transfer	Ions formed in the
5) Al + Cl => AlCl3 Name the ionic compound - Aluminium Chloride c=4 R=4 E=4	Al	3	Al loses 1e⁻	Al^{3-}
	Cl	7	Cl gains 1e⁻	Cl^{1+}
6) Na + O => Na_2O Name the ionic compound - Sodium oxide c=4 R=4 E=4	Na	1	Na loses 1e⁻	Na^{1-}
	O	6	O gains 2e⁻	O^{2+}
7) Li + N => Li3N Name the ionic compound - Lithium nitride c=4 R=4 E=4	Li	1	Li loses 1e⁻	Li^{1-}
	N	5	N gains 5e⁻	N^{3+}

FINDINGS

The learner specifies that the atom of magnesium only has particles in its orbitals in response to the knowledge representation of the atomic structure, but he or she does not mention the precise names or sorts of atoms that are present in the atom. In other words, the learner was unable to name protons and electrons or to identify the charges attached to the particles in Q.2 (a). The learner struggled to complete the table in Q.2(b) and the chemical equation representation in Q.12 because of these constrained representations. In Q.2(b), the learner had trouble counting the number of protons and electrons, and in Q.12, they had trouble distinguishing the ion generated and the electrons that are transferred during a chemical reaction. The learner may not have been able to apply the knowledge of content and the system of content (relations of contents) effectively to interpret chemical processes since the basic periodic table information was absent.

According to the assertion made above, the learner was able to apply the periodic system effectively because of her level of understanding of some aspects of the periodic table's subject matter. For instance, the interpretation and depiction of Lewis-dot diagrams, as well as the accurate description of molecules and compounds in writing, were both evident (Appendix A, Table 6, L2 Profile, Knowledge Instantiation Test).

The learner was able to offer most of the scientific representation accurately (C) and develop arguments (R) of scientific representation accurately with provided evidence (E) thanks to his understanding of the periodic table's content and his ability to apply it effectively. The distribution of knowledge utilization (C= 83%; E= 75 %; R= 97 %) and the learner's achievement level (68 percent) are not significantly correlated.

L3 (Lower)-Taught by T1

PERIODIC TABLE TEST

LEARNER 3

Diagnostic Test: 48%

Post-Test: 68%

Learner responses

4. How are elements grouped on the periodic table?

Diagnostic Test Response: *Vertical columns are called groups; the seven horizontals are called periods.*

Post-Test Response: *According to the electronegativity.*

5. What are the common features of each row in the periodic table?

Diagnostic Test Response: *Every element in the top raw has its atomic.*

Post-Test Response: *H of the element in a period have the same number of atomic orbitals.*

6. What are the common features of each column in the periodic table?

Diagnostic Test Response: *Each box represents an element and contains its number symbol.*

Post-Test Response: *The element in each group have the same number of electrons in the outer orbital.*

FINDINGS

The learner's prior understanding of the periodic table was full of errors. In the post-test question Q.4, he demonstrated his understanding of the periodic table by describing the groupings of elements based on electronegativity without explaining how electronegativity is utilized to categorize these elements. Despite having the correct periodic table information in some parts of his response to Question 6, he was unable to explain the meaning of the table as a whole or as a tool. As a result, the learner had difficulty classifying the elements in the periodic table for the task or exercise. Additionally, the learner had issues with the interpretation of general periodic table-related concepts.

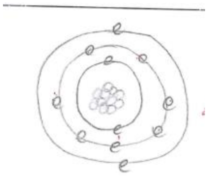
Changes in learner knowledge representation were observed in the following areas after teacher 1 (T1) had taught them: placement of elements in the periodic table; awareness of how elements are grouped; identification of the types of bonds in various molecules; classification of elements; understanding of how atoms react; and how to use the periodic table to correctly predict properties of an element.

Knowledge Instantiation Test: Chemical bonding and chemical reactions

Test score
C= 43%; E=32%; R=34%

Learner responses

2. (a) In the box below draw a magnesium atom. Label the nucleus.



(b) Complete the following table:

Atoms	No. Of neutrons	No. Of protons	No. Of electrons
Oxygen	8	8	8
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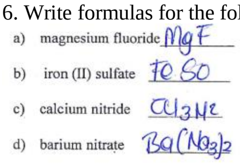
Boron	6	5	5

6. Write formulas for the following ionic compounds (salts)



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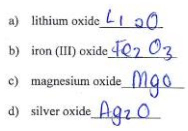

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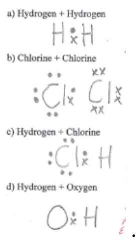

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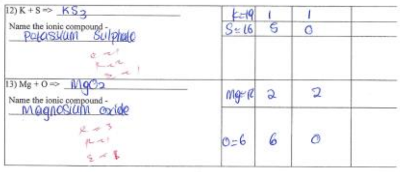

FINDINGS

The learner was able to represent an atomic model with orbitals, nucleus, and electrons (Q.2a). These were precisely positioned in their respective atomic locations. However, in terms of the number of electrons, the representation was not an accurate picture of a magnesium atom. That is, the second energy level has fewer electrons (7 not 8) than it should. The learner did not understand that the second energy level has two sorts of orbitals, namely s- and p-orbitals. Before the remaining electrons can occupy the next higher energy level, the second energy level must have a maximum of eight (8) electrons.

The mistake in the learner's description of magnesium's atomic structure implies that the learner was unable to identify the s-orbital in the second energy level. In response to Q.2, the learner was able to determine the proper number of electrons, protons, and neutrons (b). The learner's depiction of magnesium fluoride (MagF_2) as "MgF" shows errors and/or incoherence in using the periodic table system. The valid response to Q.10, the representation of the Lewis dot diagram, confirms the learner's incoherence application.

The learner's overall performance on the general test backs up the preceding findings. The learner performed better on sections or parts of knowledge that consisted of the claim (C), which is mostly declarative knowledge, and worse on sections or parts of knowledge where the learner had to provide reasons (R) or steps of his solution, as well as struggled to provide evidence that supported both his claim and reasoning. Declarative knowledge can be obtained through rote learning, however, reasoning and the ability to provide evidence-based based on scientific statements necessitate continual conceptual development.

The given findings analyze the knowledge representation of three learners (L1, L2, and L3) before and after being taught chemistry concepts by Teacher 1 (T1). The first part of the report discusses the learners' understanding of the Periodic Table as a content and tool used to classify elements and its features. Learner L1 demonstrated a higher level of accuracy in the post-test, showing improvement in content representation of the periodic table, whereas, L3 had significant errors on both diagnostic and post-tests in the conceptualization of the periodic table. The second part of the report analyzes the learners' knowledge representation of chemical bonding and reactions, which include atomic structure, ion formation, and other related topics. L2 had the most significant improvement in knowledge representation from the diagnostic test to the post-test, while L3 struggled to demonstrate a valid understanding of the concepts tested. The learners' performance in knowledge instantiation was strongly correlated to their representation of knowledge. Overall, the findings highlight the importance of an effective teacher in developing learners' understanding of chemistry concepts, such as the periodic table, and their ability to apply this knowledge in relevant contexts like chemical bonding and reactions.

Learner 1

The learner's achievement/performance shows an improvement between the pre-and post-intervention tests. The better performance (i.e., 68 percent to 74 percent) maybe associated with the quality and/or ability to apply knowledge (Li, et al., 2023) as represented in the distribution (C:92 percent; E:96 percent; R:75 percent), but this cannot be reliably ascribed to the learner's performance of understanding. For example, this learner's legitimate responses were weighted toward content understanding and less toward the PT as a system.

Learner 2

The learner presumably used the periodic table as both material and a system (tool) in answering questions about chemical characteristics, and interpreting and applying system knowledge. This skill may be linked to achievement (62 percent; 62 percent) and performance (C:83 percent; E:75 percent; R:97 percent). Achievement and performance may be indicative of conceptual shift (Li & Wang, 2023; McLure et al., 2020). This, however, cannot be determined with certainty because there are other intervening factors on learning indication, such as assessment content (McLure et al., 2020).

Learner 3

The findings for this learner demonstrate reliance in responding to questions on the learner's responses on declarative knowledge reproduction (Krebs et al., 2023). This assumption is supported by a significant increase in learner achievement (from 48 percent to 68 percent), which is related to a reduced distribution of characteristics indicating knowledge usage or application (C: 43 percent E: 32 percent R: 34 percent). As previously stated, the figures utilized in this analysis serve as a reference in terms of conceptual change and application of knowledge.

Finally, while there are elements of association in the teacher's understanding with learners' performance and/or achievement, based on the findings of both the learners and the teacher, it is difficult to draw any conclusive direct inferences about the teacher's and learners' associations of periodic table comprehension as content or tool (i.e., Teacher 1). This is due to the incoherence of the teacher's approach prior to the intervention. That is, the teacher’s knowledge is not organised to be comprehensible to the learner.

Learner 4

The learner appears to use the periodic table as both content and a tool (the periodic table system) for learning. This assertion is supported by the learner's responses to the following questions: What are the characteristics shared by each row of the periodic table? The learner's response in the diagnostic test, atomic mass, differs from the same response in the post-test. All elements in the periodic table have the same number of orbitals. However, this may not reflect the learner's deliberate use of the periodic table as both information and/or system (tool), but rather what was learned through memorization (Demirdöğen et al., 2023; Zamhari et al., 2023). According to Zamhari et al. (2023) even if a learner does not grasp the topic, rote learning can produce valid answers (62 percent to 76 percent). In this context, the learner appears to make sense of the content and/or use of the periodic table in responding to questions (C: 85 percent; E: 90-

percent; R: 77-percent). Finally, the learner has progressed because there were few errors in the representation of molecular formulas such as $FeSO_4$ as iron sulphate and he was unable to discern between the chemical representations of nitrate and nitride.

Learner 5

The learner replies in the post-test show a tremendous improvement, as seen by the exhibited achievement (48 percent to 62 percent). However, this does not necessarily imply that the learner understood the content or used the periodic table correctly because many elements, such as teacher efficacy and environment can influence a learner's performance and/or achievement (Paunesku & Farrington, 2020). In addition, scenario, the learner's performance, as revealed by the distribution (C: 33%; E: 23%; R: 15%), cannot reflect on learner understanding and application of the periodic table as content and tool. The learner's knowledge representation structure does not provide a basic build-up of concepts, but instead concentrates on recalling periodic table information without understanding the meaning and importance of the knowledge. As a result, the learner's conceptual built representation for periodic table material was inconsistent and structurally unorganized (Qian et al., 2023). This could have affected the periodic table's use as a system, as well as its ability to describe molecular formulas and chemical equations correctly.

Learner 6

The difference in achievement (40 percent to 46 percent) between the two measures is small. This could point to several intervening factors in addition to the teaching strategy based on the teacher's conception of the periodic table as material and a tool (system) for teaching chemistry. Clearly, the findings of the analysis on the structure of this learner's knowledge (C:52 percent; E:29 percent; R:45 percent) indicate a disorganized knowledge of the periodic table (Qian et al., 2023). This is said to have resulted in the learner exhibiting inconsistent scientific presentation of how elements are grouped in the periodic table after the teacher's teaching approach. The lack of improvement in learner knowledge representation suggests that the learner has difficulty to constructing representations of molecules/compounds, chemical equations, and Lewis-dot diagrams that correspond to a valid understanding of the periodic table.

Generally, the findings indicate varied levels of understanding and subsequent interpretation of the periodic table as content and/or system. Clearly, most of the participating learners conceived the periodic table mostly at the level of content to be learned. This indicates a surface level of learning and was apparent in their responses. That is, most of the responses were drawn from a reproduction of their declarative knowledge with an apparent lack of meaningful conceptual construction and/or providing or demonstrating any rationale for their responses. Such responses are generally and presumably a product of *what* and *how* learners are taught and/or the methods they are exposed to from their teachers.

As a result, certain of the learners' levels of achievement may not necessarily show what Gardiner (1997) refers to as performance of understanding in his comprehensive account of what understanding implies. That is, rote learning can improve success but not comprehension, especially when questions are oriented toward a specific sort of assessment question. Indeed, certain questions and/or responses emphasized this assumption, as learners answered questions without necessarily comprehending what their representations meant in terms of the periodic table system. As a result, if the learner comprehends periodic table content at an average level, he or she is most likely to comprehend chemistry concepts at an average level, specifically chemical bonding, and chemical reactions.

If learners can have a better knowledge of the periodic table as both content and system (a tool), they may be able to interact meaningfully with all parts of learning about chemical bonds and chemical reactions in their chemistry classes. The researcher also discovered that learners associated periodic table meanings (concepts) with their interpretation of chemical bonding and chemical reaction concepts. As a result, if a learner has misconceptions about the periodic table concept or struggles with some interpretation of periodic table properties, he or she will likely struggle to understand the chemistry of chemical bonding and chemical reactions, resulting in an invalid representation of molecules and atom reactions.

The level of achievement demonstrated by some of the learners may not necessarily be indicative of what Gardner (1997) refers to as performance of understanding in his description of what understanding means, holistically. That is, rote learning can result in enhanced achievement but not understanding especially in assessment questions skewed towards certain knowledge types (e.g., towards declarative knowledge) In fact, some questions and/or their responses highlighted this assertion where learners answered questions without necessarily understanding how their representations meant in terms of the system of the periodic table. Hence, if the learner understands the periodic table content at an average level, he/she is most likely to comprehend the concepts of chemistry at an average level, specifically chemical bonding, and chemical reactions.

We can explain and defend these shifts using constructivism (Schmitz, 2010). That is, different techniques to teaching the periodic table may have resulted in different cognitive learning outcomes for chemical bonding and related chemical reactions. That is, these had diverse effects on learners' comprehensions, resulting in different constructions of meaning and knowledge of the concepts in these themes. According to the constructivist perspective of learning, concepts are "building blocks for knowledge organisation," and how they are arranged determines the quality of learning results (Schmitz, 2010).

Furthermore, conceptual change takes knowledge as a process into account because each moment of change represents a different sort of information in a new organised knowledge form. As a result, if the fundamental building blocks of knowledge are at an average level of competency, the learner's conceptual development is more likely to suffer, or the learner is more likely to comprehend the associative notions at the building knowledge level.

While the intervention training did not result in generally substantial changes, the activity itself was eye-opening in terms of its focus. That is, from the perspective of the periodic table as content and a system in the classroom, there must be a focus on its usage. Learners and teachers must make this a point of understanding in chemistry teaching and learning. The fact that there was an apparent association between learner's knowledge representation in chemistry and researchers approach of teaching using the periodic table highlights the need for additional in-depth research on the investigated subject.

CONCLUSION

The goal of this study was to investigate how learners used the periodic table to learn about chemical bonding and related reactions. Learners clearly have different perspectives on what is taught and/or learned in the classroom. This is understandable given the level of knowledge they bring to the learning environment. The focus of this study was primarily on the periodic table and its usage in the teaching and learning of chemistry for learner's conceptual change. Clearly, there were variations in the learner's conceptual change, particularly in their knowledge representation and usage of the periodic table as a content and/or tool (system). The findings provided significant insights into how various learners learn and interpreted the periodic table as content and tool. In general, learners comprehended the concept of the periodic table as a tool (system) with limited content knowledge of the periodic table. That is, the periodic table was used unconsciously and/or inconsistently as a system.

The key finding of the research question provides the learners' representation of knowledge as they learned and/or understood it from the two stages of the researchers' teaching in this experimental study. Therefore, in this experimental process, there was potential for differences in knowledge representation. According to Gardner (1997), there should be differences between learned and understood knowledge. The learned knowledge may not necessarily be understood as it "cannot be activated when needed" (p.73). Therefore, the finding from the research question may indicate both types of knowledge representation that learners were supposedly in possession of at various points during their teaching of chemical bonding and related chemical reaction phenomena.

In general, the results suggest varying levels and types of comprehension and subsequent interpretation of the periodic table as content and/or system (i.e., tool). Clearly, many of the participants conceived of the periodic table primarily at the level of content to be learned. This reflects a surface degree of learning, as evidenced from their responses. That is, most of the responses were based on a reproduction of their declarative knowledge, with an obvious absence of significant conceptual formulation and/or offering or demonstrating any rationale for their responses. Such responses are most likely a result of what and how learners are taught, as well as the tactics they are exposed to from their teachers.

The major limitation in the way learners conceived and used the periodic table may be the main reason why they find chemistry difficult to understand, particularly when its system is to be used to justify the formation of chemical bonds and/or chemical reactions between and/or among atoms of different elements. That is, by teaching the periodic table as both content and a tool, teachers can simplify how they teach chemistry ideas and learners can understand chemical bonds and reactions using the periodic table. This assumption, however, is not an attempt to divorce content from the periodic system. Rather, the goal is to emphasize the significance of viewing the content as a component of a system that defines the qualities that impact and allow chemical bonds to form and chemical reactions to occur. The incoherent use of the periodic table as material and/or tool poses gaps in learner's conceptual change, especially in teaching and learning of chemistry and it requires focus for future research.

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