e-ISSN: 2710-2122, p-ISSN: 2710-2114
2024: Vol 6, pp 1-23. https://doi.org/10.38140/ijer-2024.vol6.03
Interdisciplinary Journal of Education Research

Assessing the Efficacy of Locally Constructed Model Kits in Teaching and Learning of Writing and Naming Binary Compounds

Eric Appiah-Twumasi[1*]
Issah Iddrisu[2]
Kenneth Darko Ateko [2]

AFFILIATIONS
[1]Department of Educational Studies, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Kumasi, Ghana.
[2]Department of Integrated Science, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Kumasi, Ghana.

CORRESPONDENCE
Email: eatwumasi@aamusted.edu.gh*

EDITORIAL DATES
Received: 10 December 2023
Revised: 25 January 2024
Accepted: 09 February 2024
Published: 15 February 2024

DOI: 10.38140/ijer-2024.vol6.03

Abstract: The study constructed Valency Arm and Y-shaped Model Kits using local materials from the school community, serving as interventions for Sekyere Central District junior high students in Ghana. Effectiveness was tested using a quasi-experimental pre-test post-test control group design in teaching binary compounds writing and naming. The researchers randomly selected four intact classes, two as the experimental group (n = 69) and the other two as the control group (n = 67). After constructing and using the model kits in the teaching and learning process of writing and naming binary compounds, it was found that the experimental group, who received instruction with the model kits, had better retention of the concepts and principles learned compared to the control group. These improved learning gains were evident in the three successive tests (Pillai's Trace = 0.440, F (2, 133) = 52.319, p = 0.000, partial eta squared = 0.440). Additionally, a semi-structured interview was conducted with 11 randomly selected respondents from the experimental group. This interview identified four critical features that the junior high school students perceived as benefits of using the model kits in teaching writing and naming binary compounds. These benefits were a better understanding of the principles, improved attitude towards writing and naming binary compounds, better retention of concepts, and active participation and interest in class lessons. The results imply that junior high school science teachers who want to promote effective teaching and learning of writing and naming binary compounds should consider using these model kits if the original models are unavailable.

Keywords: Model kits, binary compounds, junior high schools, retention, feedback.

1. Introduction

Hartshorn and Yerin (2019) argue that one of the reasons why element nomenclature studies were introduced in science was to facilitate communication about chemical compounds, their structures, properties, and uses. Due to the numerous benefits of element nomenclature studies, it is included in the chemistry curriculum at all levels of education. For instance, in Ghana's education context, one of the main concepts studied in junior high school science is the nomenclature of binary compounds (Ministry of Education, 2020). Despite the importance given to chemical nomenclature studies, some studies, such as Adesoji and Babatunde (2016) and Keshavarz (2018), have reported that students generally perceive the nomenclature of inorganic compounds as difficult and uninteresting. Students claim that the concepts of chemical nomenclature are not directly observable.

In Ghana, evidence suggests that high school students struggle to understand and retain the concepts and principles of the nomenclature of binary compounds. For example, the West African Examination Council (WAEC) has reported that most junior high school students have difficulty

How to cite this article:
Appiah-Twumasi, E., Iddrisu, I., Ateko, K. D. (2024). Assessing the efficacy of locally constructed model kits in teaching and learning of writing and naming binary vompounds. *Interdisciplinary Journal of Education Research*, *6*, 1-23. https://doi.org/10.38140/ijer-2024.vol6.03

answering test questions on the IUPAC nomenclature of binary chemical compounds in the Basic Education Certificate Examination (BECE). Specifically, the WAEC Chief Examiners' reports indicated that most candidates struggle with the International Union of Pure and Applied Chemistry (IUPAC) naming of inorganic binary compounds, as well as writing correct formulas for the compounds (WAEC 2017, 2018, 2019, 2020).

Some students say that since little or no instructional materials are used during the study of writing and naming binary compounds, they view it as too abstract (Adu-Gyamfi et al., 2017; Essiam et al., 2023). This highlights the need for effective teaching methods integrated with appropriate instructional materials, such as model kits (Erlina et al., 2021), to make the teaching of writing and naming binary compounds more effective and reduce the abstract nature of the content. However, in developing countries like Ghana, model kits are expensive and not easily accessible. Therefore, in such situations, it is recommended to build models or prototype molecular kits from locally available materials within the environment (Quayson et al., 2022). As a result, the Ministry of Education in Ghana recommends that when the original instructional materials for science teaching are not available, the use of improvised instructional materials can be considered (Ministry of Education, 2020). However, in the context of this study, there has not been an extensive examination of how the application of locally constructed or improvised model kits can influence the learning outcomes of junior high school students in the naming and writing of binary compounds.

Therefore, the current study is important in filling the existing evidence gap on the influence of locally constructed model kits on chemistry learning, with a specific focus on binary compounds in the teaching and learning of chemistry in junior high school classrooms. Moreover, the locally constructed molecular kits presented in this study could contribute to science teaching in developing countries where model kits are expensive and difficult to access. They could also revive the interest of science teachers in such situations to adapt or adopt the developed Valency Arm and Y-shaped Model Kits for their lessons. Specifically, the study was guided by the following research questions:

- Does the use of locally constructed model kits in teaching the writing and naming of binary compounds help junior high schools retain the concepts learned?
- What is the nature of feedback from junior high school students on the use of locally constructed model kits in teaching the writing and naming of binary compounds?

2. Theoretical Review of the Study

This study is based on Kolb's Experiential Learning Theory (ELT). According to the pioneering work on ELT, knowledge is obtained through both grasping and transforming experience (Kolb et al., 1999). Drawing on ELT, some students learn by experiencing the tangible and sensory aspects of the world, relying on their senses and immersing themselves in real-life situations. On the other hand, other students may prefer to analyse, plan, and think in detail rather than relying solely on their feelings to acquire, comprehend, or retain new information. Proponents of ELT, such as Akella (2010) and McCarthy (2016), conceptualise learning as consisting of four phases: concrete experience, reflective observation, abstract conceptualisation, and active experimentation.

***Concrete experience* (CE):** This stage provides the foundation for the learning process. Individuals acquire lessons through adaptation and openness rather than by systematically approaching a scenario or problem. It is during this stage that learners actively engage in an activity. According to the theory, every experience must begin with something new to us or a repetition of something that has already happened to us (Akella, 2010). Kolb believed that participation was the key to learning. Similarly, McCarthy (2016), a proponent of concrete experience, asserts that students must be actively involved in the teaching and learning process in order to gain new knowledge.

Reflective observation **(RO):** This phase of learning involves reflecting on the experience and taking note of any new encounters. It also involves explaining how and why these new experiences occurred. During the RO phase, learners consciously reflect on their experiences (Akella, 2010) and have the opportunity to discuss them with others. They can also ask questions at this point in the learning cycle (McCarthy, 2016). Therefore, effective communication is crucial during the RO phase, as it allows learners to identify any discrepancies between their understanding and their experiences.

Abstract conceptualisation **(AC):** At this stage of learning, students rely on ideas, logical methods, and theories to understand situations and problems rather than interpersonal problems or feelings. They are consciously guided to use a systematic plan of ideas and theories to solve practical problems (Main, 2022). Therefore, in this stage of learning, theories and subjective concepts are connected to observations and reflections made in the RO. As a result, in the AC, new concepts are created by guiding students to understand events and challenges using logic and concepts.

Active experimentation **(AE):** In the final phase, students apply newly learned concepts to different scenarios. They engage in a task once again, but this time, the objective is to apply their knowledge to unfamiliar situations. Students were encouraged to predict outcomes, evaluate tasks, and plan how to utilise their newly acquired knowledge. In line with this, Akella (2010) suggested that teachers could ensure long-term knowledge retention by allowing students to practice their learning and demonstrate its relevance to their everyday lives.

The theory is relevant because it aligns with the research focus on improving chemistry education, specifically in teaching binary compounds. ELT's emphasis on active engagement, reflection, conceptualisation, and practical application resonates with the objectives of the study. By applying ELT, the research aims to tackle challenges in chemical nomenclature education, providing a comprehensive approach that promotes experiential and reflective learning. This theoretical foundation guides the design of the study, ensuring a holistic exploration of the impact of locally constructed model kits on learning outcomes in junior high school chemistry classrooms. Ultimately, this research contributes to pedagogical improvements in developing countries.

2.1 Improvisation in science teaching and learning

It will be extremely difficult for teachers to adequately explain topics to basic school students if science lessons are taught and learned without tangible instructional aids (Mboto et al., 2011; Yeboah et al., 2019). However, the problem of insufficient teaching resources for students in African educational institutions has persisted over time (Akuma & Callaghan, 2016; Mayeem et al., 2018). Thus, it is essential to pay sufficient attention to the improvisation of instructional materials. The ultimate goal, according to Ndihokubwayo et al. (2018), is to empower kids to learn by doing and actively investigating their surroundings.

Improvisation can be defined as the process of creating instructional materials using locally accessible resources within a specific community when standard materials are scarce or unavailable (Okori & Jerry, 2017). Akuma and Callaghan (2016) used the terms "low-cost equipment" and "self-created models" to characterise improvised teaching materials. Typically, these materials, according to Akuma and Callaghan (2016), as well as Botes (2021), are made from easily accessible local resources or materials like plastic, cardboard, straws, wood, tin cans, etc.

To determine the benefits of these materials in science teaching and learning, Udu (2018) asserts that when particular teaching tools are unavailable or insufficient, instruction can be carried out using makeshift resources. Resources could improve students' performance and participation in class (Mboto et al., 2011; Rivera & Sanchez, 2020). It can also improve the creative skills of students (Mayeem et al., 2018), as well as sustain the interests of learners (Osei-himah et al., 2018). Given this, experimental studies have been conducted by researchers to determine the effectiveness of improvised instructional materials in science teaching and learning. For instance, Mayeem et al.

(2018) developed improvised conceptual models to teach senior high school (SHS) students chemical formulae and nomenclature. Mayeem et al. (2018) found that the use of improvised conceptual models enhanced SHS students' understanding of chemical formulae and nomenclature. Rivera and Sanchez (2020) also used improvised instructional materials to teach gas laws to seventh-grade students and found that students' understanding of gas laws improved compared to the conventional teaching method. Furthermore, Obodo et al. (2020) observed that the use of improvised teaching materials improved second-year Junior Secondary School students' achievement in science compared to the use of the conventional teaching method.

2.2 The concept of binary compounds

According to Wirtz et al. (2006), binary compounds are one of the four groups of inorganic compounds. Binary compounds are made up of only two elements; however, they can have complex properties. These compounds have strong chemical bonds, such as ionic, metallic, and covalent. Ionic compounds are made of metal and non-metal. A binary compound can contain more than two atoms, even though it contains only two elements. Examples of binary compounds include carbon dioxide (CO_2), silicon oxide (SiO_2), sodium chloride (NaCl), and magnesium oxide (MgO). The three types of binary compounds. These are binary acids, binary ionic compounds, and binary covalent compounds. (Anne, 2021; Wirtz et al., 2006). A binary acid is formed between hydrogen (cation) and non-metal (anion). Binary acids are also called hydracids. Examples are hydrogen fluoride acid (HF), hydrogen bromide (HBr), and hydrogen sulphide (H_2S).

A binary ionic compound is a compound with a metal (cation) and a non-metal (anion). Examples include sodium fluoride (NaF), magnesium oxide (MgO), iron (III) and Beryllium chloride ($BeCl_2$). Binary covalent compounds or binary molecular compounds are formed between two non-metals, usually with a variety of ratios. Two non-metals frequently combine in a variety of ratios. Nitrogen and oxygen, for example, produce Nitrogen (IV) oxide NO_2 and Carbon (II) oxide (CO) (Hartshorn et al., 2015; Petrucci et al., 2011).

The naming of binary compound requirements is fundamental to the study of chemical nomenclature (Taskin & Bernholt, 2014); hence, it was introduced early in the study of chemistry. Before the introduction of the system for naming compounds in chemistry, names such as quicklime (CaO), Epsom salt ($MgO_4.7H_2O$), milk of magnesia $Mg(OH)_2$, dry ice (CO_2), limestone ($CaCO_3$), and laughing gas (N_2O) were coined by early chemists (Anne, 2021). Such names are called common names. Currently, an estimated 100,000 to 1 million names of inorganic chemical compounds exist (Djoumbou et al., 2016). Developing common names for these compounds would be impossible; however, having a basic understanding of compounds and chemicals is crucial for our safety. Many of the chemicals we encounter daily are highly reactive and should be handled with caution (Taskin & Bernholt, 2014). Therefore, according to Egorova and Ananikov (2017), chemical nomenclature makes it easier to understand and identify which chemical compounds are safe and which have the potential to cause harm. The solution, of course, is to adopt a system for naming compounds that indicates something about their composition. After learning the chemical nomenclature of the IUPAC, a chemist should be able to name a compound when given its formula or construct the formula when given its name without any ambiguity.

2.3 Model Kits and their benefits in chemistry lessons

Adu-Gyamfi et al. (2017) argue that the acquisition of chemistry concepts at the microscopic and symbolic levels presents significant challenges. This is because understanding chemistry concepts goes beyond sensory perception, as chemistry encompasses both invisible and abstract microscopic and symbolic levels. To address the abstract nature of chemistry concepts, including binary compounds, teachers can utilise model kits (Ibe et al., 2021). In this study, model kits have been identified as the most effective and suitable hands-on activity for teaching students the naming of binary compounds. They facilitate a deeper understanding and retention of concepts (Keshavarz, 2018; Owo, 2022).

Model kits involve assembling atoms and connectors to create three-dimensional models of molecules or atoms. These kits typically contain plastic or wooden pieces of various shapes and colours that can be assembled to represent atoms, bonding isomerism, and other molecular structures (Dori & Barak, 2001). Visualising the structures of molecules helps students better understand their properties and interactions (Ramesh et al., 2020). The use of physical models to teach chemistry concepts has been proven effective and accepted for several decades. For example, J. J. Thompson and Rutherford developed the concrete representation of atomic structure in 1904 and 1911, respectively (Gyasi et al., 2022). Model kits aid in the comprehension of chemical bonding by allowing students to physically see how compounds are formed. To understand chemical structures, bonding and other concepts, it is important to grasp the concept of particles within matter, interpret symbols, and visualise atoms in compounds (Turner, 2019). Additionally, model kits provide a hands-on chemistry experience, promoting clear understanding and fun through active participation in the lesson. This approach ensures that teaching and learning begin with concrete examples before moving to abstract concepts, thus enhancing retention (Quayson et al., 2022). Model kits are designed to cater to a range of learners, from beginners to advanced students, and serve as a pedagogical device, aiding in better learning and memorisation. Adu-Gyamfi (2017) also emphasises that the use of model kits in chemistry teaching and learning allows for the representation of microscopic-level concepts at the macroscopic level. Importantly, it helps students visualise abstract concepts in a concrete form (Comba et al., 2009).

Consequently, according to literature (Kaumal & Wijayawardana, 2017; Quayson et al., 2022), it has been suggested that using model kits is more appropriate for teaching the writing and naming of binary compounds. The use of model kits during instructional sessions allows for hands-on learning, engaging students' senses by actively observing, touching, and manipulating tangible objects to complete various tasks. This provides a lifelike and accurate representation of letters, numbers, shapes, symbols, colours, and objects. Incorporating fun activities can enhance enthusiasm and participation, increasing students' attention span and helping them understand the underlying purpose of their tasks. By learning to manage, communicate, concentrate, and dedicate themselves to completing activities and developing problem-solving skills, students also acquire knowledge, improve their ability to create mental images, and understand and interpret symbols and chemical formulas (Turner, 2019; Sulyman et al., 2022). In the classroom, when students are given the opportunity to manipulate, gather data, process information, and arrive at their own conclusions about a problem, they learn more effectively compared to relying solely on textbooks.

Model kits allow learners to acquire knowledge through hands-on experience and participation, both in using the kits and acquiring new skills (Sulyman et al., 2022). They foster student independence, nurture creativity and innovation in problem-solving for both teachers and students, and enhance various abilities such as reading, arithmetic computation, and communication. Additionally, model kits promote learning, conceptual understanding, and overall development, serving as a foundation for studying nomenclature at a higher level (Ekwueme et al., 2015; Sulyman et al., 2022). These kits involve activities that engage both the hands and the mind (Ateş & Eryilmaz, 2011). When students are fully engaged with model kits, the content being taught and learned is more meaningful to them (Alkan, 2016; Pirttimaa et al., 2017). Importantly, this approach aligns with the demands of 21st-century classroom instruction, emphasising "hands-on" science lessons and problem-solving techniques (Gakuba et al., 2021).

Students taught with model kits are more likely to retain what they have learned, experience a sense of accomplishment, and have the ability to apply their knowledge in different learning environments (Ekwueme et al., 2015). According to Abban-Acquah and Edusei (2023), model kits are especially beneficial for students who face challenges in the classroom, such as behaviour disruption or hearing difficulties, as they help these students stay engaged during instruction. Additionally, using model kits not only allows students to learn scientific concepts but also fosters creativity and critical thinking through hands-on experiences with science. Rather than simply memorising correct answers, students are encouraged to analyse observed phenomena, prompting them to think critically. Therefore, it is crucial to recognise that learners have diverse needs when entering the classroom, and effective methods must be employed in lesson planning and delivery to meet these needs. Penny et al. (2017) assert that the use of model kits can address all three domains of learning. Consequently, when model kits are utilised in science education, students can gain knowledge about the unique aspects of science and technology, enabling them to develop explanations for natural phenomena (science) and solve problems related to human adaptability in the environment.

The use of model kits also contributes to the psychomotor (skills) component of learning, as students develop coordination abilities in gross, fine, and eye-hand dimensions. Through the use of model kits, students engage their senses by seeing, touching, and manipulating actual objects to complete tasks. This results in a realistic representation of letters, numbers, shapes, colours, and other objects. Furthermore, learners become enthusiastic and actively participate in this hands-on approach, which improves their attention span. Similarly, Sulyman et al. (2022) argue that the use of molecular kits helps learners manage their own learning, communicate effectively, concentrate, and remain dedicated to completing activities. They also suggest that incorporating molecular kits into chemistry instruction enhances problem-solving skills, facilitates knowledge acquisition, improves long-term memory, and supports the development of fine motor skills.

3. Methodology

This study, which took place from 2nd May to 2nd August 2023, falls under the pragmatism paradigm. According to proponents of pragmatism, there is no single 'correct' way of understanding the world (Kankam, 2019). Kankam argues that there are multiple perspectives that can be used to find solutions to a problem. As a result, pragmatists acknowledge that different beliefs or theories may be valid or useful in different contexts (Turyahikayo, 2021). In a pragmatist study, what is required is a worldview that offers research methods or a combination of methods that can shed light on the actual behaviour of participants (Kivunja & Kuyini, 2017). Following these principles, a mixed-method approach was utilised to investigate the effectiveness of using locally constructed model kits for teaching the writing and naming of binary compounds.

In accordance with this adopted paradigm, a research design, specifically the explanatory sequential design, was employed. This design involves collecting quantitative data first and then using qualitative data to provide further insights into the quantitative results (Creswell, 2012). Quantitative data was used to address research question 1, while qualitative data was used to address research question 2. With this in mind, four junior high schools from the Sekyere Central district in the Ashanti Region of Ghana were randomly selected. These selected schools were then assigned randomly to either the experimental group (n=69) or the control group (n=67). In total, the study included 136 third-year junior high students, with an average age of 12.6 years and a standard deviation of 1.2. The experimental group received instruction on the writing and naming of binary compounds using the Valency Arm and Y-shaped locally constructed model kits, while the control group received the same instruction without the model kits. To gather students' perspectives on the benefits of using the locally constructed model kits for teaching and learning writing and naming binary compounds, 11 students from the experimental group were selected for face-to-face interviews using simple random sampling.

3.1 Data collection instruments

Two main research instruments—tests and a semi-structured interview guide—were used to collect data for the study. The tests were in the form of pre-test, post-test, delayed post-test 1 and delayed post-test 2, which were used to measure junior high school students' retention of writing and naming binary compounds. The pre-test and post-test consisted of essay-type items on writing and naming of binary compounds. However, the delayed post-test 1 and delayed post-test 2 comprised of parallel and reshuffled items from the pre-test and post-test, respectively. The semi-structured interview guide consisted of five open-ended items designed to gather students' feedback on the benefits of using locally constructed model kits in teaching and learning to write and name binary compounds. The interview was conducted after delayed post-test 2.

The instruments were validated by three experienced chemistry educators as well as two researchers in the field of science education. Panelists were asked to evaluate the items in the pre-test, post-test, delayed post-test 1, and delayed post-test 2, which were designed to assess students' ability to retain the learned concepts of writing and naming binary compounds. After considering their suggestions and making changes where applicable, the instruments were pilot tested. Since essay-type items were used in the study, the responses of the pilot test were given to two raters for scoring. The scores of the raters were then subjected to reliability analyses using inter-rater reliability, specifically Cohen's kappa. The kappa values obtained for the pre-test, post-test, delayed post-test 1, and delayed post-test 2 were 0.732, 0.719, 0.779, and 0.765, respectively. According to Mchugh (2012), these values indicate moderate agreement between the raters for each set. Therefore, the scores from the pilot test were deemed reliable for the instrument to be used in the main study.

3.2 Teaching intervention

The Valency Arm model kit was constructed using plywood, nails, printed chemical symbols, a pencil, a screw, aluminium metal rods, a hammer, and a hacksaw blade. On the other hand, the Y-shaped model kit was constructed using plywood, printed numerals, printed chemical symbols, shower sandals, a pencil, a saw, glue, and a paintbrush. You can refer to Tables 1 to 4 for images of the model kits.

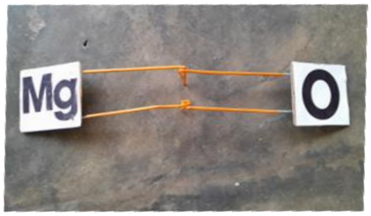
3.3 Application of the locally constructed model kits for the teaching of binary compounds

This section provides four examples of how to apply the locally constructed model kits to teach the naming of binary compounds. Specifically, the section demonstrates how to use our Valency Arm model kit to form magnesium oxide and silicon dioxide. Similarly, it presents how to use the Y-shaped model kit to form aluminium oxide and calcium fluoride.

Exemplar 1: How to form the chemical formula of magnesium oxide (MgO) using the Valency Arm Model Kit is shown in Table 1. The step-by-step process of forming magnesium oxide (MgO) using the Valency Arm model kit is outlined.

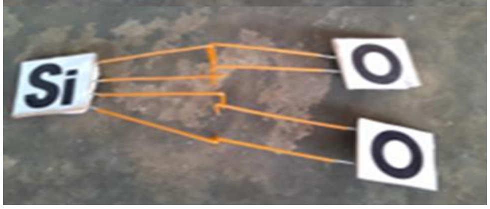
Table 1: *Procedure to write the chemical formula of magnesium oxide using the Valency Arm Model Kit*

Step	Description	Diagram
1.	Guide pupils to select the valency arm model of Magnesium (**Mg**) with two valencies.	

2.	Assist pupils in joining the valency arm model of Oxygen (**O**), which has two valencies with the valency arm model of Mg.	
3.	Brainstorm pupils to come up with the name of the binary chemical formula obtained after Step 2	**MgO**

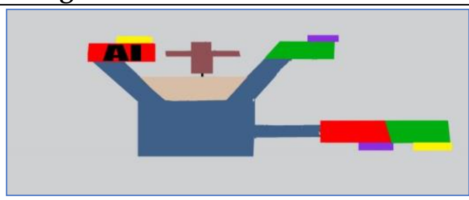
Exemplar 2: How to form the chemical formula of silicon dioxide (SiO_2) using the Valency Arm Model Kit is explained in Table 2. The table provides a step-by-step process for forming silicon dioxide (SiO_2) using the Valency Arm Model Kit.

Table 2: *Step-by-step procedure to form the chemical formula (SiO_2) using the Valency Arm Model kit.*

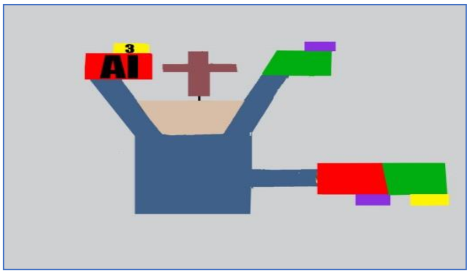
Step	Description	Diagram
1.	Guide pupils to select the valency arm model of silicon (**Si**) with 4 valencies	
2.	Guide pupils in joining one valency arm of oxygen (**O**) with two valencies to the valency arm model of Si.	
3.	Assist pupils in joining the remaining two valencies of silicon with the other valency arm of oxygen.	
4.	Brainstorm pupils to come out with the name of the binary chemical formula obtained after Step 3.	**SiO_2**

Exemplar 3: How to form the chemical formula of aluminium oxide (Al2O3) using a Y-shaped model kit is shown in Table 3. It provides a step-by-step process for using the Y-shaped model kit to form the oxide (Al_2O_3).

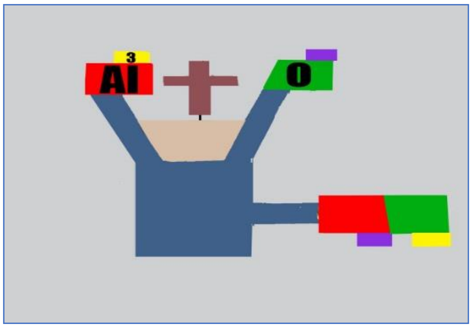
Table 3*: Using a Y-shaped Model Kit to form Al_2O_3*

Steps	Description	Diagram
1.	Guide pupils to fix the chemical symbol **Al** on the orange colour on the left arm of the model.	

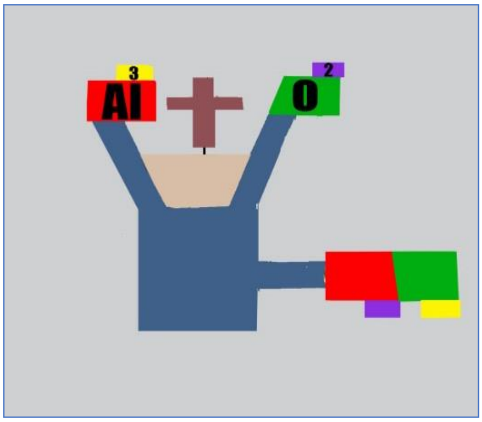
2. Help pupils fix the corresponding valency 3 on the yellow colour above **Al** on the left arm of the model.



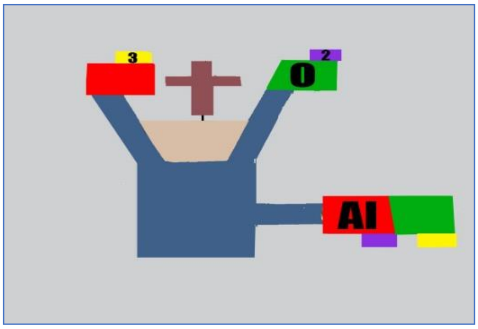
3. Guide pupils to fix the chemical symbol **O** on the part painted green on the right arm of the model.



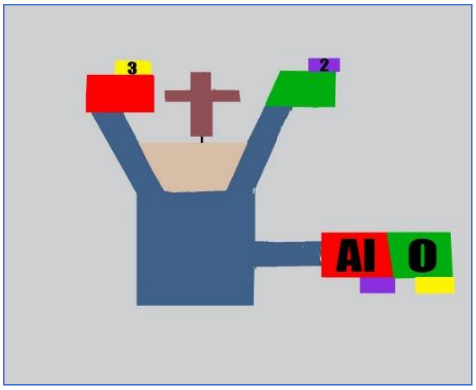
4. Guide pupils to fix the corresponding valency 2 on the violet colour above **O** on the right arm of the model.



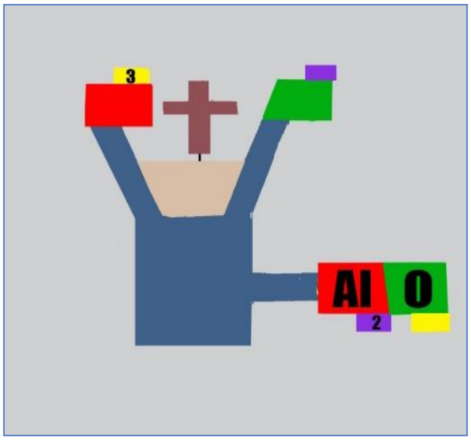
5. Guide pupils to remove the chemical symbol **Al** on the left arm and fix it on the part painted orange on the lower arm of the model.



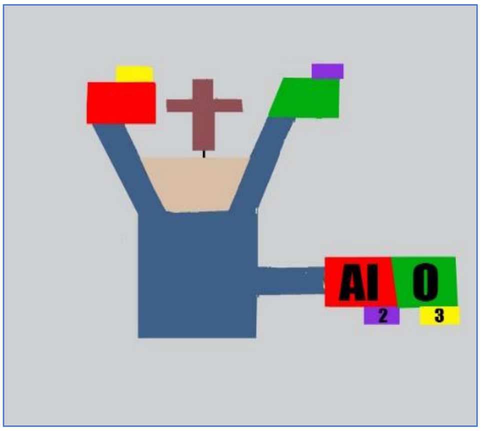
6. Help students remove the chemical symbol **O** on the right arm and fix it on the green part painted on the lower arm of the model.



7. Assist pupils in removing the valency 2 on the left arm and fix it on the part painted violet below **Al** on the lower arm of the model.



8. Guide the pupils to remove the valency 3 on the right arm and fix it on the yellow part below **O** on the lower arm of the model.

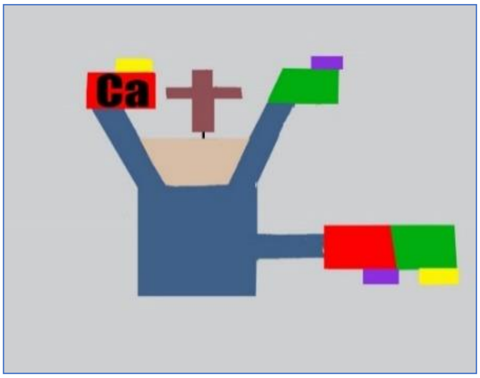
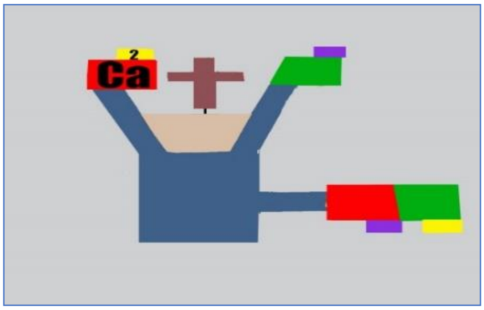
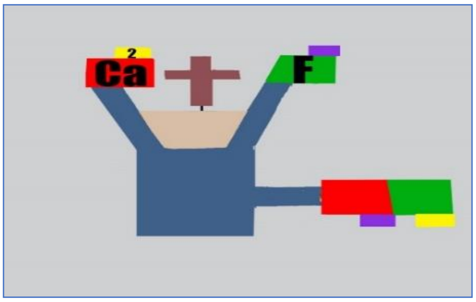
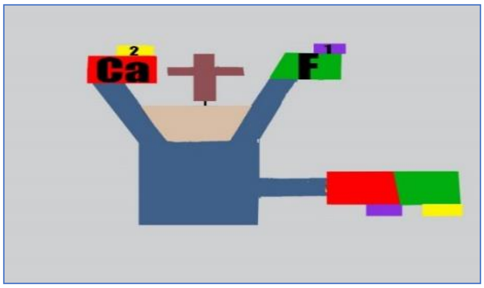


9. Brainstorm pupils to come out with the name of the binary chemical formula obtained after Step 8.

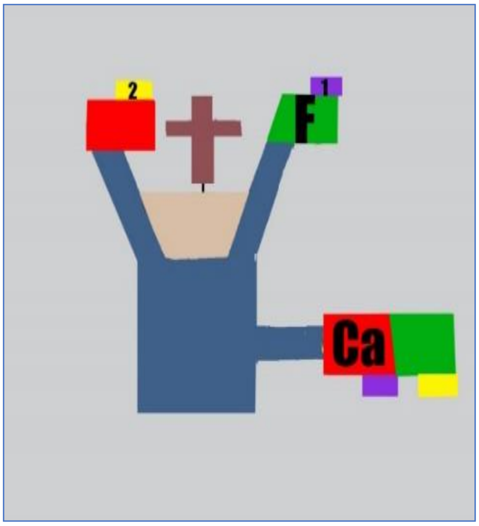
Al_2O_3

Exemplar 4: How to form the chemical formula of calcium fluoride (CaF_2) using a Y-shaped model kit. Table 4 illustrates the step-by-step process of using the Y-shaped Model Kit to form calcium fluoride (CaF_2).

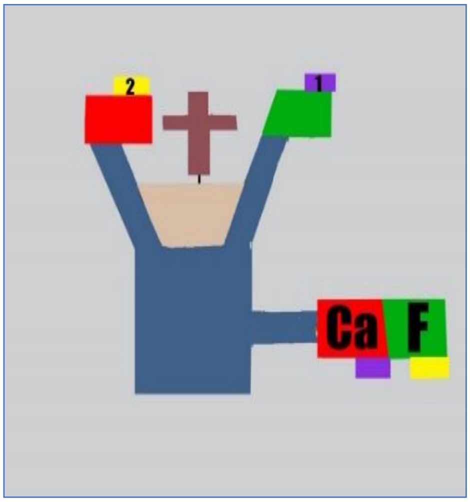
Table 4: *Description of How to use the Y-shaped Model Kit to form Calcium fluoride (CaF_2)*

Step	Description	Diagram
	Help pupils fix the chemical symbol **Ca** on the part painted orange on the left arm of the model.	
2	Guide pupils to fix the corresponding valency 2 on the part painted yellow on the left arm of the model.	
3	Assist pupils in fixing the chemical symbol **F** on the part painted green on the left arm of the model.	
4	Guide pupils to fix the corresponding valency 1 on the part painted violet up on the right arm of the model.	

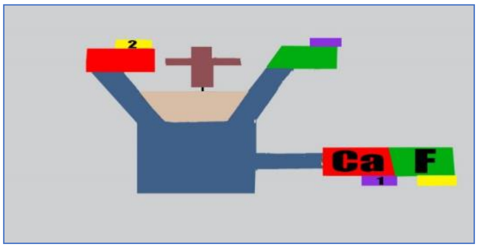
5 Help pupils remove the chemical symbol **Ca** on the left arm and fix it on the part painted orange on the lower arm of the model.



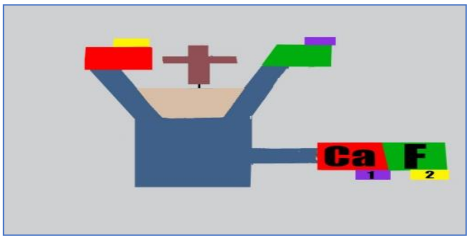
6 Assist pupils in removing the chemical symbol **O** on the right arm and fix it on the part painted green on the lower arm of the model.



7 Help pupils remove the valency 1 on the left arm and fix it on the part painted violet below **Ca** on the lower arm of the model.



8. Guide pupils to remove the valency 2 on the right arm and fix it on the part painted yellow below F on the lower arm of the model



9.	Brainstorm pupils to come out with the name of the binary chemical formula obtained after Step 8.	**Ca_1F_2** **CaF_2**

3.4 Ethical considerations

Prior to the study, permission was obtained from various head teachers of the participating schools, science teachers, and the students themselves. The purpose of the study was discussed with them during the initial interaction, and they were assured of confidentiality. To ensure confidentiality, the names of the students and participating schools were made anonymous.

4. Presentation of Results

This section presents the results of the study, including the analysis and interpretation of the data. The results include the entry characteristics, which were analysed using an independent sample t-test. The quantitative part of the study (research question 1) was analysed using descriptive statistics such as mean, standard deviation, mean difference, and mean gain. Any significant differences in means were tested using Mixed Between Within-Subject Analysis of Variance, also known as Split Plot Analysis of Variance (SPANOVA). The qualitative part of the study (research question 2), however, was analysed using thematic analysis.

4.1 Entry characteristics

In this study, both quantitative and qualitative analyses were conducted. The first section presents the quantitative results, which involve analysing the pre-test scores of both groups using an independent sample t-test. This analysis aims to determine the entry characteristics of participants from both the experimental and control groups and to establish whether there is a significant difference between the two groups before the intervention. The results are presented in Table 5.

Table 5: *Independent Sample T-test on Pre-test Scores of Experimental and Control Groups*

Group	**N**	**Mean**	**SD**	**t**	**df**	**p**
Experimental	69	8.87	2.711	.262	134	.794
Control	67	8.76	2.075			

As revealed in Table 5, there was no significant difference in the pre-test scores between the experimental group (M=8.87, SD=2.711) and the control group (M=8.76, SD=2.075; t(134)=0.262, p=0.794). This indicates that the junior high school students assigned to the experimental and control groups did not differ significantly in their understanding of the principles of writing and naming binary compounds before the intervention. Therefore, any difference in understanding of the writing and naming of binary compounds resulting in their retention rate after the intervention could be attributed to the use of the model kits.

4.2 Effect of locally constructed model kits on retention

In the literature, Coleman (2022) and Clearwater (2022) claim that learners forget an average of 50% to 70% of the concepts they learn within 1 to 24 hours and 90% within a week. However, there is a lack of consensus in the literature regarding the specific time interval for measuring the retention of concepts by learners. For instance, Kovács et al. (2019) measured the retention of learners after two months, while Valderama and Oligo (2021) measured it every week for seven consecutive weeks. Faught et al. (2016) also used a three-month interval for 12 months to measure students' retention. In our study, we measured the effect of locally constructed model kits on the ability of junior high school students to retain concepts in writing and naming binary compounds. We measured this retention at three-week intervals, specifically during the post-test, delayed post-test 1, and delayed post-test 2.

The results were quantitatively analysed using the mean, standard deviation, and mean difference of the scores after the tests. Please refer to Table 6 for the detailed results.

Table 6: *Post-test Delayed Post-test 1 and Delayed Post-test 2 scores*

Group	Post-test		Delayed Post-test 1		Delayed Post-test 2	
	Mean	SD	Mean	SD	Mean	SD
Experimental	20.06	4.011	18.36	2.491	16.99	2.592
Control	15.66	2.056	12.07	2.382	6.73	3.112
	4.40		6.29		9.93	

DP; Delayed Post-test
SD; Standard Deviation

The results presented in Table 6 show that, after the intervention, the trend in retention in the writing and naming of binary compounds for the experimental group observed in the post-test, delayed post-test 1, and delayed post-test 2 was 20.06 (SD=4.011), 18.36 (SD=2.491), and 16.99 (SD=2.592) respectively. Also, the control group obtained a trend in retention scores of 15.66 (SD=2.056), 12.07 (SD=2.382), and 6.73 (SD=3.112) for the post-test, delayed post-test 1, and delayed post-test 2 respectively. This increased mean differences of 4.40, 6.29, and 9.93 for the post-test, delayed post-test 1, and delayed post-test 2, respectively. The trend in retention in writing and naming of binary compounds between the experimental and control groups can be inspected graphically using the estimated marginal means of post-test, delayed post-test 1, and delayed post-test 2 scores for both groups, as shown in Figure 1.

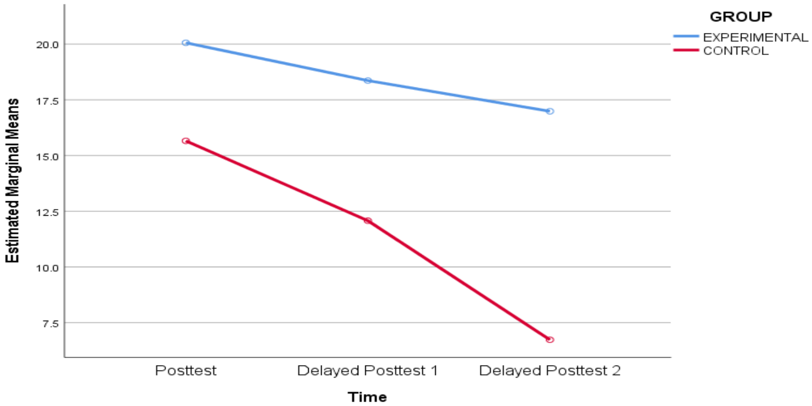


Figure 1: *Graphical Representation of Retention Analysis*

As shown in Figure 1, the experimental group consistently had higher estimated marginal mean scores than the control group across the three testing times: post-test, delayed post-test 1, and delayed post-test 2. However, the control group experienced a sharp decrease in estimated marginal means from post-test to delayed post-test 1, and subsequently to delayed post-test 2. In comparison, the experimental group only saw a small decrease in estimated marginal mean scores from post-test to delayed post-test 1 and then to delayed post-test 2. This decline in scores can be attributed to a decay in the writing and naming of binary compounds for both groups over time (Ansquer et al., 2019). Nevertheless, Figure 1 clearly shows that the control group experienced a significantly greater decay than the experimental group did.

The difference in retention scores was analysed using a mixed within-subjects analysis of variance, known as Split Plot Analysis of Variance (SPANOVA), on JHS students' scores across three time periods after the intervention: post-test, delayed post-test 1 and delayed post-test 2. However, the assumptions of homogeneity of variance-covariance matrices (also known as homogeneity of intercorrelations) and homogeneity of variances were violated. Given the violations of assumptions, including intercorrelations and variances for post-test scores, and considering that this study only involved two groups, Pillai's Trace was employed as the statistic for analysis instead of the commonly reported Wilk's Lambda (Pallant, 2011) during the conduct of the mixed between-within subjects analysis of variance. The results are presented in Table 7.

Table 7: *Results of Mixed Between-Within Subjects ANOVA*

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Time of test	Pillai's Trace	.734	183.721	2.000	133.000	.000	.734
Time * Group	Pillai's Trace	.440	52.319	2.000	133.000	.000	.440

Therefore, as shown in Table 7, there was a significant interaction between the teaching method and the test time (Pillai's Trace =0.440, $F_{(2, 133)}$ = 52.319, p=0.000, partial eta squared=0.440). Furthermore, there was a significant main effect for the test time of test (Pillai's Trace=0.734, $F_{(2, 133)}$ = 183.721, p=0.000, partial eta squared=0.734) with both groups showing a reduction in test scores between the three testing periods as shown in Table 6 and Figure 1, suggesting a significant difference in the retention trend in the writing and naming of binary compounds between the experimental and control groups. Therefore, the null hypothesis is rejected.

Since there was a significant interaction effect between the teaching method and the time of the test, a simple effect analysis was performed to determine significant differences in scores at each test time for the experimental and control groups. The results of this analysis are presented in Table 8. In conducting the simple effect analysis, a Bonferroni adjustment was made since three comparisons were made simultaneously in order to reduce the risk of committing a Type I error – that is, rejecting the null hypothesis when it is true (Pallant, 2011). The Bonferroni correction was done by dividing the original α-value, which is 0.05, by the number of comparisons made, which in this case is three. This then provided a new α-value of 0.0167. Therefore, the mean differences in Table 8 are significant if their p-values are less than 0.0167.

Table 8: *Simple Effect Analysis on Post-test, Delayed Post-test 1 and Delayed Post-test 2*

Time	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig. ^{b}	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Post-test	Experimental	Control	4.401*	.549	.000	3.315	5.487
Delayed Post-test 1	Experimental	Control	6.288*	.418	.000	5.461	7.115
Delayed Post-test 2	Experimental	Control	10.254*	.491	.000	9.284	11.224

Based on estimated marginal means

*. The mean difference is significant at the .0167 level.

b. Adjustment for multiple comparisons: Bonferroni.

As revealed in Table 8, there were significant differences between the experimental and control groups in all three test times, thus post-test (mean difference=4.401, p=0.000), delayed post-test 1 (mean difference=6.288, p=0.000), and delayed post-test 2 (mean difference=10.254, p=0.000). These differences favoured the experimental group, as shown in Table 6 and Figure 1.

4.3 Feedback from students

The semi-structured interview was conducted with 11 respondents after applying the Valency Arm and the Y-shaped model kits to teach junior high school students how to write and name binary compounds. The feedback received from the students was generally positive. The 11 students were selected from the experimental group through simple random sampling. The application of locally constructed model kits resulted in four main themes of feedback: better understanding of the principles, improved attitude towards writing and naming binary compounds, better retention of concepts, and active participation and interest in class lessons. Below are some representative statements from students for each theme.

Theme 1: Better understanding of principles

In the semi-structured interview, JHS students revealed that they did not easily understand the application of the principles in naming and writing binary compounds. As a result, they could only memorise the formulas and names of some common compounds without applying the principles. However, using locally constructed model kits in teaching and learning the naming and writing of binary compounds helped them understand the principles better. For example, student A stated in a transcribed voice:

> "*…I now see and understand all the laws and principles which apply to the writing and naming of binary compounds. For example, I now know that a positively charged ion can only form a compound with a negatively charged ion, and the positively charged ion must be a metal ion while the negatively charged ion must be a non-metal ion so that the compound formed will be electrically neutral*".

Student **B** also stated:

> "Sir, *I have now understood how the writing and naming of binary compounds work better. Now, I know that the charge and valency of the atoms determine the nature of the compound to be formed. For example, I know that Aluminium (Al), which is positively charged and has three valence electrons, can only form a compound with a negatively charged atom with any valence electron, let us say chlorine (Cl). And when they combine, the ions* Al^{3+} *and* Cl^{-} *will exchange their charges and be written as subscripts*".

Student **C** also expressed:

> 'I *now know that the valency is determined by the number of electrons in the last shell of the atom, and the charge is determined by how many electrons are lost or gained in the last shell to become stable. Also, I know that an ion with a positive charge cannot form a compound with another ion with a positive charge, but only with a negative charge. For example, sodium ions cannot form compounds with calcium ions because they are all ions with positive charges.*"

Theme 2: Improved Attitudes toward the learning of naming of binary compounds

The JHS students also noticed how the use of locally constructed model kits positively affected their attitudes toward writing and naming binary compounds. For example, a transcribed perception from student **D** stated:

> "*I enjoyed how you used the model kits to teach writing and naming binary compounds. At first, the topic was boring because everything from the principles to the application had to be memorised. Now I know how the principles work by using the model*".

In congruent with student **D**'s feedback, student **E** also expressed:

> "Sir, *what I can say about using this model to teach writing and naming of binary compounds is that now I like the topic. Therefore, I try to find questions and solve them on my own. And because I did not pay much attention at first, this time I want to understand everything under that topic so that I can perform well in my exams*".

Theme 3: Better retention of concepts

JHS students further expressed the importance of using locally constructed model kits to help them retain the application of principles in writing and naming binary compounds. For instance, student F stated:

> "Sir, *since you taught us this topic, I still remember that it is the ions of the atoms that are involved in forming the compounds, not the elements. Therefore, if I want to form a compound involving potassium and chlorine, I need to determine the ions of those elements first before I can write the compounds. And I know that the ions are formed using the electrons on the last shell, which is whether they gain or lose electrons for them to be stable*".

Student **G** also stated:

> "...I *remember what we did in the classroom during the writing and naming of binary compounds. Sir, for example, I still remember the principle of positively charged ion to negatively charged ion, and also the principle of outer shell electrons. Now I do not need to chew and pour*".

Concerning retention of principles and concepts, student **H** uttered:

> "*Sir, using the model kits was very practical and helped me to understand and remember all the principles and their applications involved in writing and naming binary compounds. Especially, in the naming, I remember that binary compound formulas start with the metal ions, which are mostly the positively charged ion, followed by the non-metal ion, which is mostly the negatively charged ion. Also, I remember that, when the compound is formed, the ions exchange their charges, and they are written as subscripts, but the subscripts should be written in their simplest ratios*".

Theme 4: Active Participation and interest in lessons

During the semi-structured interview, the JHS students highlighted how happy they were with their participation in the lessons using the locally constructed model kits. Students acknowledged that being actively involved in the lessons, during the use of the chemical symbols and valencies, was a major factor that made them better understand the principles and concepts, as well as develop an interest in the lessons.

Student **I** stated:

> "*... what made me like the use of these models was that I saw that almost everyone was involved in the activities we were doing in class. That even made me ask my classmates questions when I did not understand some aspects. And I was also happy that my classmates helped me when I went to them to ask them questions*".

In the same manner, student **J** stated that:

> "*Sir, the use of the model kits in teaching writing and naming of binary compounds was very interesting. I did not miss any class because how you were teaching us using the model made me gain more interest in the topic. I felt like we were more involved, and each student could ask or discuss with each other. That was good for me*".

In addition, student **K** stated that:

> *"Sir, I remember that I did not miss any science class when you taught us the writing and naming of binary compounds. The use of the model made classes enjoyable to me because we always took part in how the model was used. That made me get more interested in the lessons".*

5. Discussion of Findings

Models can greatly improve students' recall and application of the rules for writing and labelling binary compounds through their tactile involvement and spatial imagery (Mushimiyimana et al., 2022; Udu et al., 2022). Accordingly, in agreement with the literature (Mushimiyimana et al., 2022; Udu et al., 2022), this study revealed that the use of locally constructed model kits to teach writing and naming binary compounds in the Ghanaian junior high school science teaching context improved students' learning outcomes with the corresponding increased student retention of the principles. This finding is in agreement with Lombardi et al. (2014), Mayeem et al. (2018), Gyasi et al. (2018), Erlina et al. (2021), and Quayson et al. (2022), who also found that the use of improvised models in teaching promotes hands-on activities in the classroom, which subsequently helps students retain concepts better.

The Valency Arm and Y-shaped model kits were effective tools for enhancing students' retention in writing and naming binary compounds due to their hands-on and visually stimulating nature. According to Stull et al. (2016), with model kits, students can physically alter and examine the interactions between atoms, giving them a concrete picture of the principles involved in writing and naming compounds. Students were able to attach elements with varying valencies in the Valency Arm, for example, which helped them grasp the idea of valency and how elements combine to produce a binary compound. Also, these kits help students build their grasp of the concepts and processes involved in writing and naming binary compounds by actively involving them in the construction and manipulation of models, as equally found by Nsabayezu et al. (2023).The use of models in teaching fits well into the experiential learning theory proposed by Kolb, which encourages students to think critically and solve problems as they work through practical exercises (Andres, 2017), leading to a more thorough and long-lasting understanding of the principles underlying the production of binary compounds. This is in line with educational theories that highlight the value of student participation and active learning as a means of fostering long-term retention and application of knowledge (McCarthy, 2016). It must be emphasised that when it comes to learning, students differ in their preferred style of learning, and these kits provide a multimodal approach that meets those needs (Suprayogi et al., 2017). While some students may learn concepts more quickly through practical exercises, others might gain from using visual aids. Therefore, according to Mushimiyimana et al. (2022), combining tactile engagement with the models with the visual depiction of atomic and ionic structures allows for a more flexible approach to learning, which guarantees that a wide range of learners may successfully assimilate the concepts of writing and naming a binary compound.

In addition, the findings of the semi-structured interview indicated that junior high school students generally gave positive feedback on the use of locally constructed model kits in teaching the writing and naming of binary compounds. Consistent with the study by Adu-Gyamfi (2015), our research subjects similarly reported that they had developed positive perceptions and attitudes towards the writing and naming of compounds. This positive feedback could be explained partly in line with the assertion of Holstermann et al. (2010). Holstermann et al. (2010) asserted that when students become active in the classroom through concrete experiences, the relevance of what they learn becomes clear and meaningful in real life, which consequently leads to the development of an interest in what they learn. The findings of this study confirm the importance of using improvisation in the teaching and learning of science concepts and for that matter the writing and naming of binary compounds. As the results indicate, the application of locally constructed model kits, which is in the context of improvisation, helped students understand the principles of writing and naming of binary compounds, leading to good retention rates of these concepts. Our study's findings support the findings of Mayeem et al. (2018). Mayeem et al. (2018) found that using improvised conceptual models improved students' understanding of chemical formulas and nomenclature. In the same way, the findings of our study revealed that the use of locally constructed model kits in teaching and learning promoted students' understanding and retention of the writing and naming of binary compounds.

6. Conclusions and Recommendations

Based on the findings of this study, it can be concluded that the use of locally constructed model kits is effective in helping junior high school students in the Sekyere Central district retain the concepts and principles involved in the writing and naming of binary compounds. This is because the use of locally constructed model kits provided students with the opportunity to understand, through hands-on activities, the various principles involved in writing and naming binary compounds. This made learning concrete, which increased the interest of students in actively participating in lessons, as expressed in the feedback section.

It is recommended that educational authorities prioritise in-service training and workshops for junior high school science teachers in the Sekyere Central District on how to improvise teaching and learning materials for science lessons when standard teaching resources are not available. Based on the results obtained, it is also recommended that junior high school science teachers within the Sekyere Central District resort to improvising the Y-shaped Model Kit and the Valency Arm Model Kit for teaching and learning the writing and naming of binary compounds when standard materials are not available or are excessive.

7. Limitations of our model kits

The limitation of the constructed Valency Arm Model Kit is that it can only be used to illustrate binary chemical formulas between elements with 1, 2, and 4 valencies. Similarly, the Y-shaped Model Kit can also be easily used to illustrate binary chemical formulas between elements with 2 and 3 valencies. The authors recommend that in a situation where the Valency Arm Model Kit is limited, the Y-shaped Model Kit will be useful, as is the case for the Y-Shaped Model Kit limitation. The authors also recommend that more studies should be done to explore more of our model kits to improve their quality and aid in the teaching and learning of binary compounds.

Declarations

Author Contributions: Conceptualisation (E.A., I.I. & K.D.A.); Literature review (E.A); methodology (E.A); software (N/A); validation (E.A.); formal analysis (I.I. & K.D.A); investigation (E.A., I.I. & K.D.A); data curation (E.A., I.I. & K.D.A.); drafting and preparation (E.A. & K.D.A.); review and editing (E.A. & K.D.A.); supervision (E.A.); project administration (I.I. & K.D.A.); funding acquisition (N/A). All authors have read and approved the published version of the article.

Funding: The study received no funding.

Acknowledgements: We express our gratitude to the junior high school science teachers at Sekyere Central District for their valuable support in ensuring the success of this study.

Data availability: Data for the study is available from the corresponding author on request.

References

Abban-Acquah, F., & Edusei, J. A. (2023). The impact of 3-dimentional molecular model on the elucidation of structure of aliphatic hydrocarbon. *International Journal of Research and Innovation in Social Science, 7*(3), 764 -776. https://doi.org/10.47772/ijriss.2454-6186

Adesoji, F. A., & Babatunde, A. G. (2016). Investigating gender difficulties and misconceptions in Inorganic Chemistry at the Senior Secondary Level. *International Journal of African & African American Studies*, *7*(1), 1–6.

Adu-Gyamfi, K., Ampiah, J. G., & Appiah, J. Y. (2017). Students' difficulties in IUPAC naming of organic compounds. *Journal of Science and Mathematics Education*, *6*(2), 77–106.

Alkan, F. (2016). Experiential learning: Its effects on achievement and scientific process skills. *Turkish Journal of Science Education*, *14*(2)15-26. https://doi.org/12973/tused.10164a

Anne, H. (2021). *Science notes: Learn science, do science.* https://sciencenotes.org/what-is-a-binary-compound-definition-and-examples/

Akella, D. (2010). Learning together: Kolb's experiential theory and its application. *Journal of Management & Organization*, *16*(1), 100–112. https://doi.org/10.1017/s18333672000 02297

Akuma, F. V., & Callaghan, R. (2016). Framework for reducing teaching challenges relating to improvisation of science education equipment and materials in schools. *Eurasia Journal of Mathematics, Science & Technology Education*, *12*(10), 2697–2717. https://doi.org/10.12973/eurasia.2016.1305a

Andres, H. P. (2017). Active teaching to manage course difficulty and learning motivation. *Journal of Further and Higher Education*, *43*(2), 220–235. https://doi.org/10.1080/0309 877X. 2017.1357073

Ansquer, R., Mesnier, T., Farampour, F., Oriot, D., & Ghazali, D. A. (2019). Long-term retention assessment after simulation-based-training of pediatric procedural skills among adult emergency physicians: A multicenter observational study. *BMC Medical Education*, *19*(1), 1–10. https://doi.org/10.1186/s12909-019-1793-6

Ateş, Ö., & Eryilmaz, A. (2011). Effectiveness of hands-on and minds-on activities on students' achievement and attitudes towards physics. *Asia-Pacific Forum on Science Learning and Teaching*, *12*(1), 1–22.

Botes, W. (2021). *The Development and use of improvised science-teaching models : A case of natural science pre-service teachers*. *20*(5), 18–37. https://doi.org/10.26803/ijlter.20.5.2

Clearwater, L. (2022). *Understanding the science behind learning retention*. https://resources.indegene.com/indegene/pdf/articles/understanding-the-science-behind-learning-retention. pdf.

Coleman, H. (2022). *Learning retention – how to make information stick*. https://www.ispringsolutions.com/blog/learning-retention. Accessed on 6th November, 2023.

Comba, P., Hambley, T. W., & Martin, B. (2009). *Molecular modeling of inorganic compounds*. John Wiley & Sons.

Creswell, J. W. (2012). Educational research: Planning, conducting, and evaluating quantitative and qualitative research. In *Pearson Education, Inc.* (4th ed.). Pearson Education, Inc.

Djoumbou F, Y., Eisner, R., Knox, C., Chepelev, L., Hastings, J., Owen, G., & Wishart, D. S. (2016). ClassyFire: Automated chemical classification with a comprehensive, computable taxonomy. *Journal of cheminformatics*, *8*, 1-20. https://doi.org/10.1186/s13321-016-0174-y

Dori, Y. J., & Barak, M. (2001). Virtual and Physical Molecular Modeling: Fostering Model Perception and Spatial Understanding. *Journal of Educational Technology & Society*, *4*(1), 61-74.

Egorova, K. S., & Ananikov, V. P. (2017). Toxicity of metal compounds: knowledge and myths. *Organometallics*, *36*(21), 4071-4090. https://doi.org/10.1021/acs.organomet.7b00605

Ekwueme, O. C., Ekon, E. E., & Ezenwa-Nebife, C. D. (2015). The impact of hands-on-approach on student academic performance in basic science and mathematics. *Higher Education Studies*, *5*(6), 47. https://doi.org/10.5539/hes.v5n6p47

Erlina, E., Eny, E., & Rahmat, R. (2021). Using simple molecular model to enhance students' understanding on molecular geometry based on VSEPR Theory. *Jurnal Pendidikan Dan Pembelajaran Kimia*, *10*(1), 24–33. https://doi.org/10.23960/jppk.v10.i1.April2021.04

Essiam, C., Osei-Antwi, D., & Quayson, C. (2023). Are Chemistry topics difficult to learn? the stance of Ghanaian senior high school students. *International Journal of New Trends in Arts, Sports & Science Education*, *12*(2), 112–121.

Faught, B. E., Law, M., & Zahradnik, M. (2016). *How much do students remember over time? longitudinal knowledge retention in traditional versus accelerated learning environments*. Higher Education Quality Council of Ontario.

Gakuba, E., Kibga, E. S. & Sentongo, J. (2021). Effectiveness of hands-on activities to development chemistry learners' curiosity in community secondary schools in Tanzania. *Journal of Turkish Science Education, 18*(4),605-621. https://doi.10.36681/tused.2021.93.

Gyasi, H., Ofoe, E. O., & Samlafo, V. B. (2018). The effect of Molecular Model Sets on students' academic performance in naming organic compounds. *Education*, *8*(3), 37–41. https://doi.org/10.5923/j.edu.20180803.01

Hartshorn, R. M., Hellwich, K. H., Yerin, A., Damhus, T., & Hutton, A. T. (2015). Brief guide to the nomenclature of inorganic chemistry. *Pure and Applied Chemistry*, *87*(9-10), 1039-1049. https://doi.org/10.1515/pac-2014-0718

Hartshorn, R. M., & Yerin, A. (2019). The past, present, and future in the nomenclature and structure representation of inorganic compounds. *Dalton Transactions*, *48*(26), 9422–9430. https://doi.org/10.1039/c9dt00352e

Holstermann, N., Grube, D., & Bögeholz, S. (2010). Hands-on activities and their influence on students' interest. *Research in Science Education*, *40*(5), 743–757. https://doi.org/10.1007/s11165-009-9142-0

Ibe, N., Obikezie, M., & Chikendu, R. (2021). Effect of improvised instructional materials on chemistry students' academic retention in secondary school. *International Journal of Research in Education and Sustainable Development, 19-3*1. https://doi.org/10.46654/ij resd.1520

Kankam, P. K. (2019). The use of paradigms in information research. *Library and Information Science Research*, *41*(2), 85–92. https://doi.org/10.1016/j.lisr.2019.04.003

Kaumal, N. M., & Wijayawardana, D.N.U. (2017). Build-it-yourself atomic modeling kit: Development of a low-cost atomic modelling kits using waste material for middle and upper level of school students. *International Journal of Environmental & Science Education*, *12*(8), 1737-1742.

Keshavarz, E. (2018). Hand -made, three-dimensional molecular model for active inorganic chemistry learning. *Creative Education*, *09*(07), 1168-1173. https://doi.org/10.4236/ce .2018 .97086 .

Kivunja, C., & Kuyini, A. B. (2017). Understanding and applying research paradigms in educational contexts. *International Journal of Higher Education*, *6*(5), 26. https://doi.org/10.5430/ijhe.v6n5p26

Kovács, E., Jenei, Z. M., Csordás, K., Fritúz, G., Hauser, B., Gyarmathy, V. A., Zima, E., & Gál, J. (2019). The timing of testing influences skill retention after basic life support training: A prospective quasi-experimental study. *BMC Medical Education*, *19*(1), 1–7. https://doi.org/10.1186/s12909-019-1881-7

Lombardi, S. A., Hicks, R. E., Thompson, K. V., & Marbach-Ad, G. (2014). Are all hands-on activities equally effective? Effect of using plastic models, organ dissections, and virtual dissections on student learning and perceptions. *American Journal of Physiology -Advances in Physiology Education*, *38*(1), 80–86. https://doi.org/10.1152/advan.001 54.2012

Main, P. (2022), Kolb's Learning Cycle: What is Kolb's Learning Cycle and how can this transform effective classroom practice? https://www.structural-learning.com/post/kolbs-learning-cycle

Mayeem, B. P., Naa, A. M., & Adjei, A. (2018). Enhancing senior high school students understanding of chemical formulae and nomenclature of inorganic compounds by the Use of Improvised Conceptual Models. *Journal of Education and Practice*, *9*(6), 22–45.

Mboto, F. A., Udo, N. N., & Stephen, U. (2011). Effects of improvised materials on students' achievement and retention of the concept of radioactivity. *International Multi-Disciplinary Journal*, *5*(18), 342–353.

McCarthy, M. (2016). Experiential learning theory: From theory to practice. *Journal of Business & Economics Research*, *14*(3), 91–100. https://doi.org/10.19030/jbe r.v14i3.9749

Mchugh, M. L. (2012). Lessons in biostatistics interrater reliability: The kappa statistic. *Biochemia Medica*, *22*(3), 276–282. https://hrcak.srce.hr/89395

Ministry of Education. (2020). *Science Common Core Programme Curriculum (BASIC 7 - 10)* . National

Council for Curriculum and Assessment.

Mushimiyimana, D., Kampire, E., & Dushimimana, E. (2022). Impacts of improvised instructional materials on grade nine learners' performance in Chemistry. *African Journal of Educational Studies in Mathematics and Sciences*, *18*(1), 127–135. https://dx.doi.org/10.4314/ajesms.v 18i1.10

Ndihokubwayo, K., Uwamahoro, J., & Ndayambaje, I. (2018). Use of improvised experiment materials to improve teacher training college students' achievements in Physics, Rwanda. *African Journal of Educational Studies in Mathematics and Sciences*, *14*(1), 71–85.

Nsabayezu, E., Uwihanganye, A., & Nsengiyumva, P. (2023). Examining teachers' and students' perceptions on the use of science kits to improve Chemistry performance in lower secondary schools. *Journal of Classroom Practices*, *2*(2), 1–17. https://doi.org/10.58197/prbl/aori1073

Obodo, A. C., Ani, M. I., & Thompson, M. (2020). Effects of improvised teaching- learning materials on the academic performance of junior secondary school students. *IOSR Journal of Research & Method in Education*, *10*(4), 23–30. https://doi.org/10.9790/7388-1004062330

Okori, O. A., & Jerry, O. (2017). Improvisation and utilisation of resources in the teaching and learning of science and mathematics in secondary schools in Cross River state. *Global Journal of Educational Research*, *16*(1), 21. https://doi.org/10.4314/gjedr.v16i1.4

Osei-himah, V., Parker, J., & Asare, I. (2018). The effects of improvised materials on the study of science in basic schools in Aowin Municipality - Ghana. *Research on Humanities and Social Sciences*, *8*(8), 20–23.

Pallant, J. (2011). *SPSS Survival Manual* (4th edition). Everbest Printing Co.

Owo, J. O., (2022). Effects of using molecular model kits, charts and board drawings in teaching chemical bonding to secondary school Chemistry. *International Journal of Discoveries and Innovations in Applied Sciences*, 2(12), 42-49. https://doi.org/10.2172/7028078

Penny, M. R., Cao, Z. J., Patel, B., Sil dos Santos, B., Asquith, C. R., Szulc, B. R., ... & Hilton, S. T. (2017). Three-dimensional printing of a scalable molecular model and orbital kit for Organic Chemistry teaching and learning. *Journal of chemical education*, *94*(9), 1265-1271. https://doi.org/10.1021/acs.jchemed.6b00953

Petrucci, R. H., Herring, G. F., Madura, J. D., & Bissonette, C. (2011). *General Chemistry: Principles and Modern Applications* (10th ed.). MacMillan Publishing Company.

Pirttimaa, M., Husu, J., & Metsärinne, M. (2017). Uncovering procedural knowledge in craft, design, and technology education: A case of hands-on activities in electronics. *International Journal of Technology and Design Education*, *27*, 215-231. https://doi.org/10.1007/s10798-015-9345-9

Quayson, C., Kwarteng, T. A., Koranteng, E., & Hanson, R. (2022). Chemistry teacher trainees' use of molecular models in learning spiro and bicyclic compounds. *Science Education International*, *33*(3), 291–295. https://doi.org/10.33828/sei.v33.i3.4

Ramesh, B. V., Selvam, A. A. A., Kulkarni, S., Dattatreya M., A., & Bettadapur, K. R. (2020). Designing and using an atomic model kit with H, C, N, and O Model Atoms having a mass ratio of 1: 12: 14: 16 to teach the concept of mole and associated stoichiometric relationships. *Journal of Chemical Education*, *97*(4), 986-991. https://doi.org/10.1021/acs.jchemed.9b00665

Rivera, G. M., & Sanchez, J. M. P. (2020). Use of contextualised instructional materials : The case of teaching gas laws in a public Uptown High School. *The Electronic Journal of Chemistry*, *12*(4), 276–281. https://dx.doi.org/10.1780 7/orbital.v12i4.1526

Sarkodie, P. A., & Adu-Gyamfi, K. (2015). Improving students' performance in naming and writing structural formulae of hydrocarbons using the ball-and-stick models. *Bulgarian Journal of Science Education*, *24*(2), 203–219. http://hdl.handle.net/123456789/8112

Stull, A. T., Gainer, M., Padalkar, S., & Hegarty, M. (2016). Promoting representational competence with molecular models in Organic Chemistry. *Journal of Chemical Education*, *93*(6), 994–1001. https://doi.org/10.1021/acs.jchemed.6b00194

Sulyman, H. T., Abubakar, A. O., & Oladoye, E. O. (2022). *Effect of hands-on activities on pupils ' academic performance in basic science in Ilorin East Local Government Area , Kwara State*. [Doctoral dissertation, Kwara State University]. Kwara State University, Malete.

Suprayogi, M. N., Valcke, M., & Godwin, R. (2017). Teachers and their implementation of differentiated instruction in the classroom. *Teaching and Teacher Education*, *67*(1), 291–301. https://doi.org/10.1016/j.tate.2017.06.020

Taskin, V., & Bernholt, S. (2014). Students' understanding of chemical formulae: A review of empirical research. *International Journal of Science Education*, *36*(1), 157-185. https://doi.org/10.1080/09500693.2012.744492

Turyahikayo, E. (2021). Philosophical Paradigms as the Bases for Knowledge Management Research and Practice. *Knowledge Management and E-Learning*, *13*(2), 209–224. https://doi.org/10.34105/j.kmel.2021.13.012

Turner, K. (2019). *Reasons to craft your own molecular models*. https://edu .rsc.org/ideas/reasons-to-craft-your-own-molecular-models/3009984

Udu, D. A. (2018). Innovative practices in science education: A panacea for improving secondary school students' academic achievement in science subjects in Nigeria. *Global Journal of Educational Research*, *17*(1), 23–30. https://doi.org/https://dx. doi.org/10.4314/gjedr.v17i1.4

Udu, D. A., Nmadu, J., Uwaleke, C. C., Anudu, A. P., Okechineke, B. C., Attamah, P. C., Chukwuemeka, C. O., Nwalo, C. N., & Ogonna, O. C. (2022). Innovative pedagogy and improvement of students' knowledge retention in science education: Learning activity package instructional approach. *Pertanika Journal of Social Sciences and Humanities*, *30*(3), 1405–1426. https://doi.org/10.47836/pjssh.30.3.25

Valderama, J., & Oligo, J. (2021). Learning retention in mathematics over consecutive weeks: Impact of motivated forgetting. *International Journal of Evaluation and Research in Education*, *10*(4), 1245–1254. https://doi.org/10.11591/IJERE.V10I4.21577

WAEC. (2017). *Chief examiners' reports for integrated science: BECE*. https :/www.ptonline .com/articles/how-to-get-better-mfi-results

WAEC. (2018). *Chief Examiners' Reports for Integrated Science: BECE*. https://waecgh.org /chief-examiners-report/#1679644696468-0aa0c1d6-0482

WAEC. (2019). *Chief examiners' reports for integrated science: BECE*. https://www.ptonline .com/articles/how-to-get-better-mfi-results

WAEC. (2020). *Chief examiners' reports for integrated science: BECE*. https://waecgh.org/ chief-examiners-report/#1679644696468-0aa0c1d6-0482

Wirtz, C. M., Kaufmann, J., & Hawley, G. (2006). Nomenclature made practical: Students discovery of the nomenclature rules. *Journal of Chemistry Education*, *83*(4) 595. https://doi.org/10.1021/edo83p595

Yeboah, R., Abonyi, U. K., & Luguterah, A. W. (2019). Making primary school science education more practical through appropriate interactive instructional resources: A case study of Ghana. *Cogent Education*, *6*(1), 1–14. https://doi.org/10.1080/2331186X.2019.1611033