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ORIGINAL ARTICLE

Chemistry Teacher Trainees' use of Molecular Models in Learning Spiro and Bicyclic Compounds

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ABSTRACT

The study diagnosed chemistry teacher trainees' difficulties in naming and writing structures of spiro and bicyclic compounds. The case study design was conducted in a constructivist environment to enhance chemistry teacher trainees' ability to construct, represent, and interpret the structural formulae of spiro and bicyclic compounds. Purposive sampling technique was employed to select 126 1st-year chemistry teacher trainees from University of Education, Winneba for the study. The results revealed that chemistry teacher trainees had difficulties in naming and writing structural formulae of spiro and bicyclic compounds. However, through the effective use of molecular model kits in teaching naming and writing structures of spiro and bicyclic compounds, these chemistry teacher trainees became conscious of IUPAC rules for naming and writing spiro and other cyclic compounds. A t-test conducted indicated that a statistical significance difference existed between students' performance before the implementation of the intervention and after the intervention. It is recommended that chemistry teachers should adopt the use of molecular model kits in teaching concepts of organic nomenclature.

KEY WORDS: Bicyclic compounds; spiro compounds; chemistry teacher trainees; molecular models

INTRODUCTION

Naming and writing structures of hydrocarbons serve as the foundation for moving to similar tasks for organic compounds containing other functional groups. Naming and writing structures of hydrocarbons, like all other chemical concepts are associated with some degree of difficulty in respect to learning their equations, structures, and chemical reactions (Sarkodie and Adu-Gyamfi, 2015; Das, 2021).

According to Adu-Gyamfi et al. (2017), science students in senior high schools in Ghana have difficulty in writing and drawing structural formulae of organic compounds using the International Union of Pure and Applied Chemistry (IUPAC) nomenclature system. Among the difficulties exhibited by the science students in giving correct IUPAC names of organic compounds include their inability to identify the correct number of carbon atoms forming the parent chain as well as substituent or functional group positions. Invariably, when concepts become difficult for students, they tend to shy away from assessments based on these concepts, especially, during examination. This problem is prevalent in most organic chemistry classes (Halford, 2016).

Structures and formulae of compounds are important ingredients in chemistry. However, science students' inability to form mental models of compounds makes naming and writing of structures difficult. Students' difficulties in organic chemistry can be improved in the classroom if appropriate teaching materials are employed. Molecular model kits have been proven to be effective in improving students' concepts on nomenclature of inorganic and organic compounds. Molecular model kits are physical devices used to enhance students' visualization and perception of three-dimensional shapes of organic molecules. According to Al-Balushi and Al-Hajri (2014), concrete models enhance students learning of organic structures by providing diverse visual representations in chemistry. Again, molecular model kits provide visual prompts and provide learners with a way of imaging the model of a concept (Al-Balushi and Al-Hajri, 2014: Adu-Gyamfi et al., 2017). The value of a model or diagram is to make a link with an abstract concept which depends on being in line with a learner's need. Modeling has been found to connect between a target and an analog as well as develop mental and visual prompt, although it is sometimes disregarded by students when employed by teachers (Talanquer, 2011; Chittleborough and Treagust, 2007).

Teachers play an important role in education as their input is directly linked to students' performance. Teachers have to be equipped with the requisite content, pedagogical knowledge, and best practices to facilitate student learning. Teachers' level of understanding of models has been described as limited even after their diploma degree because they have a simplified understanding of models and modeling in science (Danusso et al., 2010). El-Deghaidy and Mansour (2015) have also shown that many science teachers do not have the pedagogical knowledge as well as effective modeling skills needed for teaching science concepts. The inadequate pedagogical skills of teachers in delivering lesson pose a challenge for professional teacher training institutions that

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have to redesign their science education courses to introduce new concepts to address these issues (Yoon and Klopfer, 2006). This study fills the gap by equipping the skills of 1st-year chemistry teacher trainee students of the University of Education, Winneba (UEW) on the use of molecular model kits in teaching organic chemistry.

Objectives of the Study

The objectives of the study were to:

i. Examine the difficulties chemistry teacher trainees have in writing and naming spiro and bicyclic compounds
ii. Determine the impact of molecular models on chemistry teacher trainees in learning spiro and bicyclic compounds.

Hypothesis

Ho: The use of molecular model kit has no significant impact on students' performance in learning spiro and bicyclic compounds.

Theoretical Framework

The theoretical framework for this study was based on constructivism theory. In the constructivist perspective "learners are seen as active in constructing their own knowledge but not as responding to external stimuli only" (Sjoberg, 2007, p. 486). Constructivism transforms students from passive recipients to active participants in a learning process. In the classroom, students are guided by the teacher to construct knowledge but not just to mechanically ingest knowledge from teachers (Sibomana et al., 2020).

In chemistry, the use of teaching materials makes lessons more productive, dynamic, and enhance active participation among students (Knudtson, 2015; Stringfield and Kramer, 2014). Studies have revealed that this method has many advantages such as increasing students' interest in class, focusing their attention, affecting motivation positively, increasing their personal self-confidence, and improving their social-cognitive skills (Kavak, 2012; Samide and Wilson, 2014). In teaching chemical concepts, teaching materials like molecular model kits are used as educational tools to reinforce learning and identify concepts (Knudtson, 2015). Inadequate resources for teaching and learning usually result in teachers having less positive impact on students' academic development (Lingam and Lingam, 2013).

METHODOLOGY

Research Design

The study adopted a case study design which used the action research approach. In the study, molecular model kits were used to enhance first year chemistry teacher trainees' performance in naming and writing structures of two groups of cycloalkanes – spiro compounds and bicyclic compounds in the University of Education, Winneba (UEW). Action research equips practitioners with new knowledge to improve educational practices or resolve problems related to classrooms and schools (Mills, 2011; Stringer, 2008). In this study, the chemistry teacher trainees' (herein referred to as students) difficulties were identified through a pre-intervention test which was later addressed using intervention strategies. The chemistry teacher trainees' performance after the implementation of the intervention strategies was evaluated through a post-test.

Population and Sampling

The study's target population was all 1st-year chemistry teacher trainees in the Faculty of Science Education, University of Education, Winneba. The accessible population for the study was 1st-year science students reading chemistry as their major subject with their ages above 18 years. Purposive sampling technique was used to select 126 undergraduate chemistry teacher trainees for the study. Only chemistry teacher trainees reading chemistry as their major course were involved in the study because they were more knowledgeable in elective chemistry among the target population (Cohen et al., 2007) and they often assist the teacher trainees who read chemistry as their minor subject.

Research Instruments

The main instrument for data collection was test (pre-test and post-test). Each test (pre-test and post-test) consisted of 10 items which were scored 20 marks. Those who scored less than half of the scores were considered to perform poorly or below average and vice versa.

Data Collection Procedure

The researchers administered a pre-test to the students to determine their prior conceptual understanding in drawing and naming structural formulae of spiro and bicyclic compounds and so their score sheets were analyzed. It was found out that the students' performance in the pre-test was low and so an intervention was designed to improve their knowledge and performance in drawing and naming structural formulae of spiro and bicyclic compounds using organic molecular model kits. A post-test was administered at the end of the study to find out the effectiveness of the intervention procedure.

Validity of test items

An expert in the Chemistry Education Department went through the tests items to ensure that the various items were in line with the objectives of the study.

Ethical consideration

Permission to conduct the study was obtained from the Head of Department of Chemistry. The researchers also sought permission from the lecturer taking the organic chemistry course. Students were made aware that any information given would be confidential for the purpose of this study. Furthermore, it was ensured that students signed the consent form to demonstrate their willingness to partake in the study.

COVID-19 compliance

In this study, COVID-19 protocols were observed. During the intervention, both face-to-face and virtual teaching modes were employed. During the face-to-face interactions, students applied alcohol-based hand sanitizer and wore nose mask. They practiced social distancing as well.

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Data Analysis

The results obtained from the instruments were grouped for analysis. In the analysis, descriptive statistics such as mean and standard deviation were calculated and analyzed. Inferential statistics like t-test (confidence level of 95%) were determined to establish the relationship between chemistry teacher trainees' performance at the pre-intervention and post-intervention stages. In addition, students score sheets were thematically analyzed for their difficulties and used for discussion.

RESULTS AND DISCUSSIONS

In this study, a pre-intervention test was conducted to identify difficulties that students have in drawing structural formulae of spiro and bicyclic compounds of alkanes and alkenes as well as naming them. The mean score obtained by the students in the pre-intervention test was 7.8 with a small standard deviation of 3.15 to indicate that majority of the chemistry teacher trainees scored close to this mean value. This implies that most students in this study performed poorly as they could not obtain half or more of the test scores that had a maximum of 20 marks. Analysis of students score sheets revealed that they were unable to properly write and name the structural formulae of organic compounds and hence, their difficulties in writing and naming structural formulae of spiro and bicyclic compounds of alkanes and alkenes. Furthermore, most students misapplied the rules required for naming bicyclic compounds for spiro compounds. The order of numbering of the carbons as well as naming of spiro compounds was done wrongly. In addition, some of the chemistry teacher trainees were not able to introduce the prefix bicyclo or spiro in naming bicyclic or spiro compounds. In some cases where students were asked to write structures for named compounds of spiro and bicyclo, almost all the participating students were not able to write the structures for the compounds. These observed difficulties are in line with the findings reported by Wu et al. (2001). Similarly, Adu-Gyamfi et al. (2012) as well as other researchers have indicated that students have difficulties in writing structural formulae of hydrocarbons (e.g., Girija and Deepa, 2004; Gilbert, 2005; Uttal and Doherty, 2008; Ayalew, 2015).

In one of the questions given to these students in the present study, they were to give the IUPAC name of the bicyclo compound as shown in Figure 1.

They were to locate the bridge head carbons and move through the bigger arm that had more carbons to the side with a smaller number of carbons. Unfortunately, the students rather counted the smaller arm with less carbon chains before the bigger arm. This suggests that students did not know that counting on the bigger arm with more carbons implies giving priority over the carbon-carbon double-bond functional group. These students repeated this error in their naming of the spiro compounds as well. The study agrees with that reported by Ayalew (2015). He identified difficulties 1st-year chemistry teacher trainees had in naming organic compounds from given structures and writing out organic structures from given names. Ayalew's study concluded that none of the candidates scored up to 50% in the content assessment test he administered. The research findings from Ayalew's study indicated that there is a general problem of a lack of understanding of the organic nomenclature. Some of the students in Ayalew's (2015) study attributed their challenges to inadequate time spent on the teaching of organic chemistry by teachers. Furthermore, Cooper et al. (2010) reported in a study conducted in Clemson University in South Carolina in the United States of America that many students were confused about how to construct valid bonding structures of organic molecules. Cooper et al. also noted in their study that as the number of carbon atoms in the structure increased, the percentage of students constructing correct representations of the organic structures fell significantly. In a similar fashion, students in the present study demonstrated some difficulties with increasing number of carbon atoms in the naming of spiro compounds as shown in Figure 2.

In response to demonstrating understanding with Figure 2, students in the present study did not recognize the structures above (A, B, C) as spiro compounds. They were confused with the cyclic substituent attached to another mono cyclic compounds (as shown in A) and two monocyclic compounds that are fused to form spiro compounds (as shown in A and B above). However, the rules for naming formulae A and B are the same. For instance, in determining the total number of carbons forming the parent chain, carbon atoms in the two rings are counted. The next is to count the carbon starting from the smaller ring followed by the larger ring and counting should be done in the directions where substituents bear the least count. The carbon which joins the two rings is never the starting point for naming spiro compounds, but most students started their counting from that carbon and is an indication that the chemistry teacher trainees had difficulties in applying the rules in naming spiro compounds. In compound C, the ring with the least number of carbon atoms is a substituent. It is an isolated ring with no common atom and hence the rules for naming

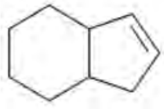

Figure 1: Bicyclo [4, 3, 0]-1-ene

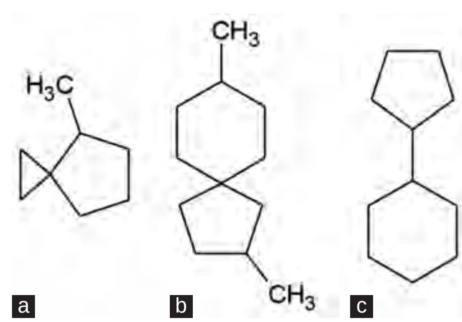

Figure 2: (a-c) Examples of spiro compounds

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spiro structures do not apply. Instead, the ring with the least number of carbon atoms is the substituent, counting should start from the carbon bearing the substituent to the larger ring.

Again, the students had difficulty in identifying the position of the functional groups in the compound. Skonieczy (2006) as cited by Sarkodie and Adu-Gyamfi (2015) identified the first most important step in naming organic compounds as the identification of the presence of functional group molecule of that compound. In instances where more than one functional group occurs, the principal group must be given preference. According to Gillette (2004), any written IUPAC name of an organic compound has three aspects. These are the number of carbon atoms in the longest continuous carbon chain, which usually forms the parent name; the ending which indicates the family or the root; and the number, position, and identity of any atoms or group of atoms in place of the hydrogen atom in a hydrocarbon that indicates the prefix.

To determine the impact of naming and writing skills, students have developed through the use of molecular model kits in learning spiro and bicyclic compounds, a post-test was conducted. In the post-test, the mean score obtained by students was 18.20 (SD = 1.61) while that of their pre-intervention test was 7.8 (SD = 3.15). The highest score obtained by students in the pre-test was 16 compared to 20 marks obtained in the post-intervention test. The mean score in the pretest suggests that most of the students were not able to obtain more than half of the marks. Meanwhile, the mean score in the post-intervention test had a smaller standard deviation (SD = 1.61) than that of the pre-test (SD = 3.15) and it, therefore, suggests that the majority of the students obtained a score consistent with the mean value and hence performed better in the post-intervention test. The improvement in students' performance in the post-test could be attributed to the effectiveness of the intervention strategy which was the use of model kits.

In this study, students became conscious of the IUPAC rules for naming spiro and other cyclic compounds. Furthermore, through modeling of molecular models and identification of least counts positions of substituents in substituted cyclic, spiro and bicyclo compounds were enhanced. They were assisted through modeling and counting of carbon chains at both forward and the reverse directions and choosing the direction where substituents bear least counting positions. Again, the difficulties that students have in drawing named compounds reduced since they developed the habit of modeling organic structures before drawing. The findings made in this study supports that of Yip et al. (2011), who indicated that students who sketch during simulation activities develop more accurate mental models of chemical phenomena and produce more accurate sketches of scientific models. Models of molecules enabled students to do mental transformations and visualizations from a two dimensional to a three-dimensional structure (Cody et al., 2012). Cody et al. use of model kits enhanced students' spatial ability of molecular identification, a phenomenon that has been shown to be specifically related to

Table 1: Paired sample t-test analysis of pre-intervention test and post-intervention test

Test	N	Mean	SD	t-value	p-value
Pre-intervention	126	7.80	3.15	−17.29	0.000
Post-intervention	126	18.20	1.61		

(Source: Field data, 2021)

enhance performance in organic chemistry even though that is not always the case (Bodner and Domin, 2000; Wu et al., 2001).

The mean score results obtained from the pre-test and the post-test were made through sample paired t-test analysis see Table 1. This was done to determine whether there was any statistical difference in academic performance of chemistry teacher trainees in the pre-intervention test and the post-intervention test. The mean scores obtained for pre-intervention test and post-intervention test were 7.80 (SD = 3.15) and 18.20 (SD = 1.61), respectively. The results in the t-test indicate a statistical significance difference between students' performance before the implementation of the intervention and after the intervention since $t = -17.29$; $\rho = 0.000 < 0.05$. This can be attributed to the effectiveness of the intervention strategy employed.

CONCLUSION

The aim of this study was to assess the impact of molecular models in teaching and learning the structural formulae of two groups of cycloalkanes – spiro compounds and bicyclic compounds. The difficulty observed was that students were unable to write and name the structural formulae of organic compounds correctly. Majority of these students misapplied the rules required for naming bicyclic compounds for spiro compounds. Furthermore, chemistry teacher trainees did not know that counting on the bigger arm with more carbons implied giving priority over the carbon-carbon double bond functional group. Again, students had difficulty in identifying the position of the functional groups in the compound.

The improvement of these students' performance in the post-test indicates that they acquired the necessary skills in the use of molecular models to facilitate their representation of spiro and bicyclic compounds. A paired t-test analysis indicated that there was a statistically significant difference between students' performance after the use of molecular model kits in lesson delivery.

Recommendations and Implications

Based on the findings of the study, it is recommended that students should use molecular models in learning organic chemistry so that it will enhance their ability in naming and drawing of structural formulae of spiro and bicyclic compounds as well as other organic compounds. Science/chemistry departments of teacher training institutions like the Chemistry Department of University of Education, Winneba need to purchase more molecular model kits to ensure their availability and usage in teaching and learning. This will help the students to do more modeling on their own to write and name structural formulae meaningfully. Molecular modeling will also help the students to actively construct and organize knowledge to solve problems in other real-life situations.

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Ethical Statement

Students who agreed to participate in the study were informed of their right to decline from the study. They were not improperly influenced to participate in the study. Students were also made aware of the findings and their relevance to the research under consideration.

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