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USING MOLECULAR MODELS TO NAME AND ILLUSTRATE STRUCTURES OF MONOCYCLIC COMPOUNDS

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Abstract. This study examined the ability of 103 undergraduate chemistry students to understand how to illustrate and name monocyclic organic compounds using molecular models in a case study that employed the action research approach. The theory that underpinned the study was constructivism. The model proved to be a powerful tool that allowed participants to build cognition and develop the necessary symbolisation and representational skills to interpret IUPAC rules for the nomenclature and structures of monocyclic organic compounds through engaging activities. They also demonstrated higher order thinking and reflective skills.

Keywords: constructivism; monocyclic compounds; molecular model; symbolisation; visualisation

Introduction

Chemistry, which is related to the structure of matter, is one of the important branches of science that enables learners to understand what happens around them (Chittleborough & Treagust, 2007). However, it is full of abstraction as basic components of matter are not visible. Organic chemistry, which is one of the branches of chemistry is particularly considered a challenging subject for students as most of the governing principles and reacting conditions appear to be incomprehensible (Taber, 2002). Although chemistry education seeks to simplify the understanding of the governing principles and the role of chemistry in sustainable development, students are unable to demonstrate conceptual comprehension due to inability to form mental models (Hanson, 2020). Organic chemistry also demands mastery of related concepts such as types of bonding, reactions, conformations, reaction mechanisms, isomerism, and derivatives of compounds. When concepts become difficult for students they tend to answer questions based on them poorly (Halford, 2016).

Mastery of nomenclature of organic compounds has been identified as another student difficulty by Adu-Gyamfi, Ampiah and Appiah (2017). They found that students' difficulties in illustrating structures from the International Union of Pure and Applied Chemistry (IUPAC) formula resulted from their inability to identify the correct number of carbons atoms and substituents at points of attachment. The researchers noted that such mastery could facilitate the application of principles to all compounds, especially organic compounds. This could be achieved if underlying concepts for naming substances could be translated into tangible forms, through the active use of molecular models, as they motivate, arouse curiosity and activate background knowledge, which is vital for student-learning (Stull, Hegartey, Dixon, & Stieff, 2012). Tertiary students have also been found to exhibit challenges with representations of cyclic hydrocarbons (Aryeetey, 2018); an indication that there is a problem with the characterisation or symbolisation of organic nomenclature as a whole.

Studies indicate that students cannot represent organic compounds, have low content knowledge on translation with models, poor understanding of the three-dimensional nature of molecules, visualisation, and navigation between two- and three-dimensional structures (Sam, Niebert, Hanson, & Twumasi, 2015; Stull, Hegartey, Dixon, & Stieff, 2012; Uttal & Doherty, 2008). Without this understanding, students memorize lists of rules and structures of molecules, with poor retention. Teaching through games and learning materials like molecular models provide positive motivation, self-confidence, and ease to learn concepts as a 'free' environment changes the apprehensive perspective of students towards chemistry (Bayir, 2014).

According to Kaberman and Dori (2009) and Dori and Barak (2001), a model is a representation of an object, event, process, or system (physical or computational), which interactively depicts the composition and structure of molecular phenomena so that a mental model is formed in the brain. A molecular model is an example of a concrete three-dimensional structure used in organic chemistry class to make abstract phenomena and concepts real to learners in a simple process. Visualization elements such as molecular models support students in connecting levels of mental concept representation ((Gilbert, 2005). Chemical modelling kits are frequently used as visualisation tools for understanding the 3-dimensional structure of molecules.

A mental model is an idea of the mind which is inaccessible to others unless expressed outwardly (Gilbert, 2005). Humans construct mental models to display understanding publicly, when necessary (Treagust, Chttleborough, & Mamiala, 2002). Models help in the presentation of constructs so that students with intrinsic spatial abilities can visualize molecules, possible interactions, and relation of structures to their functions (Stull, Hegartey, Dixon, & Stieff, 2012). The nature of organic chemistry, in particular, requires high-level spatial reasoning skills as an understanding of a chemical structure is influenced by one's spatial ability (Dori & Barak, 2001). Teaching resources play an important role in such respect.

Teaching resources or materials are essential and significant tools that promote teachers' efficiency, improve students' performance, make learning more active, interesting, practical, realistic, appealing, and aid explanation. They enable both teachers and students develop self-confidence, and self-actualisation (Oluwagbohunmi & Abdu-Raheem, 2014). Yitbarek (2012) defined teaching resources as materials used for practical work and demonstration to assist with lesson presentation in a logical and sequential manner. Resources could be concrete or software models. Concrete models are objects with the likeness of natural or manmade systems that highlight and describe structures, functional processes, and relationships as appear in the original. They enable understanding of phenomena and their causes. Yitbarek further added that instructional resources from local materials are cheap to produce and useful in teaching large numbers of students at a time, encourage proper attention and enhance interest. Onasanya and Omosewo (2011) summarized the role of models (like molecular models) as simplification and concretization of complex phenomena, bridging of gaps in distance and time between phenomenon, and enhancing of students' ability to communicate 'reality' in science. Resources increase students' interest, focus their attention, enhance motivation, and improve their social-cognitive skills (Samide & Wilson, 2014). Lack of these resources could lead to misconceptions that arise from misunderstanding and uncoordinated mental models of concepts (Hanson, 2020). Hanson (2020) also alluded that teaching resources support the sense organs to form and retain knowledge. Chemistry education that is devoid of teaching resources becomes teacher-centred so students assume passive roles, as they do not get opportunity to engage with the learning process to construct and own knowledge. There is therefore the need to provide models and real-life application scenes in lessons for positive effect.

Molecular models

Molecular (chemical) models are commercially available or teacher-constructed devices for visualisation and perception of three-dimensional shapes of organic molecules. They emphasise the arrangement of atoms and bonds within molecules. Models are important because the focus of chemistry is on the molecular structure of substances (Kaberman & Dori, 2009). Models make demonstrations and self-paced student practice possible for concept formation by portraying aspects of phenomena in concrete form. These representations support thinking and reasoning about spatial relationships within and between molecules (Wu & Shah, 2004). They also provide visual prompts and provide learners with avenues to visualise concepts and so develop mental models for desired impressions in 2-and 3-dimensional (2D and 3D) forms (Chittleborough & Treagust, 2007). Representing chemical compounds in 2D and 3D help students to relate among the macroscopic, microscopic, and symbolic forms (Gilbert, 2005), do mental transformations and visualizations from 2D dimensional to 3D (Cody, et al., 2012) and enhance their conceptual and spatial abilities (Barak & Bori, 2011). Models, constructively, challenge students' internal knowledge schemes for deconstruction, construction and reconstruction of knowledge during lessons. Modelling is frequently used as a visualization strategy for understanding 3D conformations of molecules, which profits students with poor intrinsic spatial ability, and addresses challenges in translating visualised 2D diagrams into 3D structures. Molecular models encourage students to use active techniques (experiments, real-world problem solving) to create higher knowledge through reflection and meaningful communication. Computer visualisations could also be used to illustrate molecular structures in 3D forms but will not be discussed here.

There have been several studies on the use of molecular models to facilitate conceptual understanding in chemistry as they provide students with the opportunity to conceptualise subject matter and learn about the nature of scientific knowledge (Stull, Hegartey, Dixon, & Stieff, 2012; Dori & Barak, 2001). These researchers found that the ability to represent structures of organic compounds in displayed form or 2D is correlated with spatial ability. Models assist the learning process as they allow difficult internal processes to be replaced or augmented by external actions on them. The importance of social constructive learning is exemplified when students discuss, predict, solve problems, evaluate, and assess the logic of their thinking with models. According to Sam et al. (2015) students learn effectively from models and other learning aids that provide active learning. The forgone suggests that the use of educational resources such as models could enhance learning among students.

Empirical studies (Hanson, 2020; Wu & Shah, 2004) revealed that understanding symbolic representations is difficult for students, because these representations are invisible and abstract, while students' thinking relies heavily on sensory information. Stieff (2007) found out that the study of organic chemistry is a challenge for students as they develop diverse alternative conceptions in class from poor mental configurations. Adu-Gyamfi, Ampiah and Appiah (2017) attributed students' difficulties in writing structural formulae of hydrocarbons to their inability to identify the number of carbon atoms in parent chains, formula of functional groups, positions of substituents, use of di, tri and tetra prefixes, and number of multiple bonds. They alluded these challenges to students' inabilities to experience reality, and lack of teaching and learning resources that do not conform with IUPAC's basic strategies. Their earlier study revealed that only 39.2% of Ghanaian students wrote the formula of 2-methylpropan-1-ol as $(CH_3)_2CHCH_2OH$ and displayed it in 2D, using the IUPAC nomenclature system (Adu-Gyamfi, Ampiah, & Appiah, 2013). The Chief Examiner (CE) of national examination in chemistry, from 2015 to 2018 explained in reports that the number of candidates who answered questions on organic Chemistry were remarkably low and performed poorly due to incorrect application of principles that underlie the IUPAC nomenclature. (West African Examinations Council, 2015-2018). Candidates also exhibited poor differentiation between aliphatic and aromatic hydrocarbons. Engagement with first-year students of the University of Education, Winneba (UEW) revealed that they also had challenges with the characterisation and symbolisation of monocyclic organic compounds. They could not answer pre-laboratory questions that required them to draw and label names of monocyclic hydrocarbons, which calls for research and possible review of the learning environment. Most reviewed literature presented centred on activities with High school students. This study, however, filled the gap and adds on to academic knowledge by engaging first-year undergraduate students of UEW. These students were chosen because they were pre-service teachers who were in training for professional teaching in High schools upon graduation.

Purpose of the Study

The study aimed to use molecular models to enhance university of Education, Winneba (UEW) students' concept and process skills in interpreting, identifying, naming and illustrate the structures of some monocyclic compounds through hands- and minds-on activities. The overarching objective was to use the models to help students to apply mental models to interpret concepts about monocyclic organic compounds with comprehension.

Research Questions

The study was be guided by the following research questions:

1. What difficulties do students demonstrate when they interpret, identify, name and represent structures of monocyclic organic compounds?
2. How would the use of molecular models impact on students' process and concept skills when they interpret, identify, name and illustrate structures of monocyclic compounds?
3. What are students' perceptions about molecular models as having the capacity to equip them with required skills to interpret, identify, and present monocyclic compounds?

Theoretical framework

The theoretical framework for this study was based on constructivism. The constructivist learning and teaching perspective represents a shift from viewing learners as responding to external stimuli to seeing learners as "active in constructing their own knowledge through social interactions" (Bruning, Schraw, Norby, & Ronning, 2004). In constructivist perspectives, learners actively develop knowledge through experience as they learn through cognitive processes to understand the world around them. Constructivism is best understood in terms of how individuals use information, resources, and help from others to build and improve their own mental models and problem-solving strategies. This sharpens one's cognitive development for acquiring higher-level intelligence. Examples of constructivist learning models are experiential learning, self-directed learning, discovery learning, inquiry training, problem-based learning, and reflective practice (Hanson, 2020). Knowledge construction often happens in a social interactive setting through the mediation of individuals. Constructivism modifies the role of teachers, so that they facilitate knowledge construction, rather than produce facts for students to reproduce. This constructive interventive approach was adopted to aid students to interpret, identify and draw monocyclic organic compounds.

Methodology

Research Design

The study adopted a case study design which used action research to develop a systematic, inquiry approach towards positive change (Frabutt, Holter, & Nuzzi, 2008). Mills (2011), defined action research as the process of studying a school situation to improve its educational process and provide practitioners with new knowledge and understanding about how to resolve identified problems. By implication, it helps teachers to develop new knowledge directly related to their pedagogical repertoire, promote reflective thinking, put them in charge of their craft, reinforce the link between practice and student achievement, foster an openness toward new ideas and learning, and give ownership to effective practices. In this study scientific molecular model kits were employed in a first-year chemistry class to boost practice and enhance students' interpretation and illustration of monocyclic compounds. Students' concept and process skills were identified through a pre-test which results were addressed with the molecular models as interventive tools and their acquired skills evaluated through a post-test.

Population, Sampling and Data Collection Procedures

Research population is a well-defined collection of individuals or objects that have similar characteristics (Mills, 2011). The study population was all first-year chemistry students in UEW. According to Cohen, Manion and Morrison (2017), purposive sampling is the selection of a sample based on the judgment of their typicality. This study used purposive sampling to select 103 undergraduate chemistry major students for the study. The sample was the only group who were reading CHE 121 (Introduction to Organic Chemistry) and had been identified in their first semester of the academic year to have misconceptions in their understanding of basic organic chemistry principles. These participants consented to be part of the study, which was explained to them before its start, and signed consent forms. The instruments for data collection were students' exercises, tests, observation and questionnaires. Tests (Appendix A) and exercises were administered to students to measure their prior knowledge and processes used in the interpretation and representation of monocyclic compounds. A similar test, herein called the post-test (Appendix B) was administered at the end of the study to find out the effectiveness of the intervention. A 4-point questionnaire instrument (Appendix C) with a reliability of 0.79 was used to collect students' perceptions on the use of the interventive molecular models because it had the capacity to collect information from respondents within a short time. The options included 'Strongly Agree (SA)' which scored 4 points, 'Agree (A)' with 3 points, 'Disagree (D)', 2points and 'Strongly Disagree (SD), one point.' Each respondent ticked appropriate options that applied to their case. An observation schedule (Appendix D) was used to obtain information on how the use of molecular models influenced their process skills and attitudes during the learning process because 'observation' has advantages over other qualitative data collection methods when the focus of research is on understanding processes, roles and behaviour (Walshe, Ewing, & Griffiths, 2012). The questionnaires were pre-tested on first year organic chemistry minor students as they shared similar characteristics with the sample. The coefficient for responses in the pilot study was 0.79 which was supported by Aryl, Jacobs and Razavieh's (2002) coefficients of reliability.

Students' three-week exercises were analysed, after which they were interviewed to ascertain the veracity of identified challenges. They were identified to have difficulty in interpreting the names and structures of aromatic hydrocarbons due to low conceptual understanding. A 20-item pre-test was administered to assess evidentially, the extent of students' difficulties. The total score for the test was twenty (20). Scores were collated and analysed. After the findings from the pre-test, an intervention was designed to engage students in activities that could improve their conceptual understanding and processing skills. The topic on cyclic compounds was divided into five activity-lessons where organic molecular models were used as tools to improve students' understanding. Each interventive lesson, as shown in Table 1, lasted 120 minutes.

Table 1: Five-Week Plan of Activities

Week	Topic Treated
0	Introduction to modelling techniques (using alkanes and alkenes)
1	Application of IUPAC rules to monocyclic compounds
2	Interpreting, identifying and naming of alkyl substituents
3	Modelling of monocyclic compounds with different structural formulae
4	Modelling and naming of monocyclic compounds using IUPAC rules.
5	3-D and 2-D representations of monocyclic compounds.

Interpreting, identifying, and representing organic compounds is rule-governed (Taber, 2002). This implies that certain skills and processes are followed in identifying and representing monocyclic compounds, which are formed when atoms combine to form a ring. Examples of such governing rules that were followed are presented as 'steps' in lessons 1 and 2.

Step 1: The parent name was determined by counting the number of carbons in a ring.

Step 2: The prefix *cyclo*– was added to the parent name.

Step 3: Alkyl group substituents were named as for straight chain hydrocarbons.

Step 4: The position of the alkyl group(s) on the ring was determined.

a. For a ring with only one attached alkyl group, the position was always carbon 1.

b. A ring with more than one alkyl group attached was numbered to obtain the lowest sum of numbers. If there were two groups, the number '1' was assigned to the first alkyl group alphabetically, then the shortest distance to the second substituent was counted. With three or more substituents, a set of numbers that gave the lowest sum was determined. Figure 1 was named as 1-ethyl-2-methylcyclohexane and not 1-ethyl-6-methylcyclohexane.

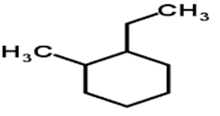


Figure 1. A monocyclic compound with substituents

c. If the sum of numbers was identical in either direction around the ring, then the count was towards the second group alphabetically on the ring as in Figure 2 (1-ethyl-3-methyl-5-propylcyclohexane).

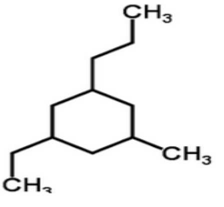


Figure 2. A cycloalkane with multiple substituents

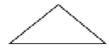
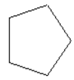
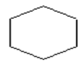
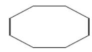
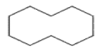
Step 5: A complex ring was named as a substituent on an alkane chain. The rules from Steps 1 – 4 changed, and so called a cycloalkyl group.

Step 6: When a ring was attached to another ring the larger ring became the parent compound.

These basic steps were applied to help in naming monocyclic compounds (Aryeetey, 2018).

Students were then introduced to the accessories in the molecular model kit after which they engaged in several hands-on activities, using knowledge acquired from the stepwise rules acquired, to illustrate (represent) compounds on paper (2D) and model them in 3D. After required skills were acquired through hands-on they were presented with a chart (Table 2) to guide them in further activities.

Table 2: Nomenclature guide to some cyclic compounds

No. of carbon atoms	Cycloalkane	Molecular Formula	Basic Structure
3	Cyclopropane	C_3H_6	
5	Cyclopentane	C_5H_{10}	
6	Cyclohexane	C_6H_{12}	
8	Cyclooctane	C_8H_{16}	
10	Cyclodecane	$C_{10}H_{20}$	

Further on, students were able to derive the general formula for the cyclic compounds $C_nH_{(2n)}$ and $\mathbf{C_nH_{2(n-m)}}$. During the remaining weeks cyclic compounds were always modelled before naming or illustration.

A post-intervention test was administered to assess students' conceptual gains. The results obtained from the tests were grouped and analysed descriptively. Inferential statistics like t-test (confidence level of 95%) were determined to establish the statistical difference between students' performance at the pre- and post-intervention stages. Data collected from the questionnaire and observation checklist were also analysed.

Results and discussions

RQ1: What difficulties do students demonstrate when they interpret, identify, name and illustrate structures of monocyclic organic compounds?

In order to find out students' difficulties in identifying, representing (illustrating) and naming monocyclic compounds, a pre-intervention test was administered and analysed as presented in Table 3.

Table 3: Mean score of students in the pre-test

Test	N	Min	Max	Mean	SD
Pre-test	103	1	16	8.88	4.05

From Table 3, majority of the students were not able to score up to half of the overall score (20 marks). Analysis of students' answers revealed their inability to identify, interpret and illustrate given structures and formula of monocyclic compounds among other organic compounds. Some of the difficulties identified included their inability to identify the parent ring for compounds with monocyclic alkyl substituents, inability to identify the starting point for a cycle of carbons, draw monocyclic compounds with two or more substituent groups, or arrange substituents alphabetically. For example, more than half of the students could not name Figure 3 (1-ethyl-3-methylcyclohexane).

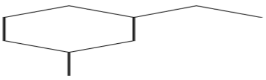


Figure 3. A monocyclic compound with alkyl substituents

Figure 3 was named by some students as 3-methyl-1-ethylcyclohexane and others as 3-ethyl-1- methylcyclohexane. They could not figure out the substituent group that should take precedence. Some identified the correct starting position but could not name the substituents alphabetically. Majority misapplied the IUPAC rules, as Adu-Gyamfi, Ampiah and Appiah (2013) reported about their sample who lacked conceptual application of the IUPAC rules. Findings from this current study also supports that of Wu and Shah (2004) who found that chemistry students have difficulty in writing structural formulae of organic compounds. From observation, students failed to construct valid structures of organic molecules as the number of carbon atoms in structures increased, because their abilities to show correct displayed (2D and 3D) representations fell significantly (Aryeetey, 2018).

A summary of observed difficulties that the first-year undergraduate chemistry students of UEW demonstrated included inability to:

– Identify the parent chain or monocyclic compounds with monocyclic alkyl substituents;
– Demonstrate the skills to identify first carbon for monocyclic compounds with two or more substituent groups;
– Exhibit and apply knowledge to separate numerals from numerals and from words using commas and hyphens respectively;
– Indicate bonds positions;
– Exhibit the process skill for arranging substituents alphabetically;
– Give preference to functional groups; and
– Apply the IUPAC rules.

RQ 2: How would the use of molecular models affect students' process and concept skills when they interpret, identify, and illustrate monocyclic organic compounds?

A comparison of students' pre- and post-intervention scores in Table 4 is an interpreted quantitative summation of gained cognitive skills that enabled enhanced performance in the post-intervention assessment.

Table 4: Comparison of students' scores in pre-test and post-test

Test	N	Min	Max	Mean	SD
Pre-test	103	1	16	8.88	4.05
Post-test	103	7.5	20	17.47	3.67

The observed improvement could be attributed to the molecular models that were employed as their cognitive and process skills were enhanced. According to Chittleborough and Treagust (2007) concrete models help students to practice and gain the required process and cognitive skills as models and modelling are explanatory tools that could relate targets to analogues as well as allow for prediction, testing and evaluation of ideas. The guided lessons enabled students to understand vocabularies used in the IUPAC rules. The focus was to guide students to name, write and represent organic structural formulae graphically or through models. The group work was to enable bright students assist weak ones through socialisation. Some of the IUPAC rules were applied with understanding, and demonstrated through students' abilities to draw distinguishing structures for cycloalkenes and cycloalkanes as shown in Figure 4, with explanation.

Cycloalkene cycloalkane

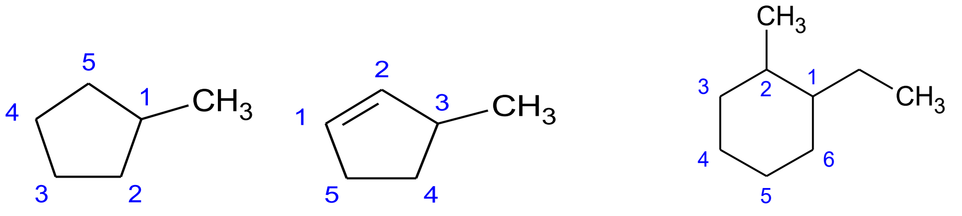
Figure 4. Structural representations of monocyclic compounds without substituents

They also represented cyclic compounds with substituents and identified the alkyl chains as shown in Figure 5.

3-methylcyclopentene methylcyclopentane

Figure 5. Mwonocyclic structures with substituents

They demonstrated how a carbon chain is numbered appropriately and substituents named alphabetically as in Figure 6.



Methyl cyclopentane 3-methylcyclopentene. 1-Ethyl-2-methylcyclhexane

Figure 6. Appropriately numbered carbon atoms

The challenges that students exhibited when drawing named compounds reduced since they modelled structures before drawing. This observation is supported by Stull, Hegartey, Dixton and Seieff's (2012) findings, that students who sketched during simulation activities developed mental models and so produced more accurate illustrations of scientific models. It was found that if models were made available to students as they performed diagram translation tasks, they acquired the needed skills early and performed well in representing structures. Dori and Barak (2001) also found that models, as visual tools in inquiry–based learning enhanced students' understanding of organic compounds. Models discouraged rote memorization of structures in this study as students performed mental transformations and visualizations from two-dimensional states to three-dimensional states and recalled them with ease, as observed by Cody, Craig, Loudermilk, Yacci, Frisco and Milillo's (2012) and Wu and Shah's (2004). It was observed that students with difficulties in writing prefixes and arranging substituents in alphabetical order in the current study mastered the skills for doing the expected through modelling and application of the IUPAC rules. The improvement in performance suggests that modelling is an effective tool for teaching the identification and representation of organic compounds. Its interactive nature enabled students to develop mental models of organic structures as their skills at drawing and naming compounds increased. They wrote correct formula for organic compounds and represented them structurally as the models enhanced their spatial ability. Thus, a statistically significant difference was observed between the two tested performances as evident from paired sample t-test of the pre-test and the post-test in Table 5.

Table 5: Paired sample t-test analysis of pre-test and post-test

Test	N	Mean	SD	t-value	p-value
Pre-test	103	8.88	4.05	-17.29	0.000
Post test	103	17.47	3.67		

From Table 5, statistical significance difference exists between students' performance before and after the implementation of the intervention. This could be from the dexterity that students demonstrated in displaying structures in 3D with molecular models and their adept skills at illustrating desired structures in 2D formats. The observed improved concept and process skills could thus, be attributed to the molecular models that were the only new tools introduced into the lesson, as Dori and Barak (2001) also noted.

The molecular models were effective as they helped students to develop skills to process information for cognitive change constructively.

RQ3. What are students' perceptions about molecular models as having the capacity to equip them with skills to interpret and illustrate monocyclic organic compounds?

A summary of students' perceptions on a 4-point Likert scale about how molecular models influenced their ability to identify and represent organic compounds is presented in Table 6.

Table 6: Students' perceptions on the influence of model models (N = 103)

S/N	Items	Mean	SD
1.	Deepening of conceptual understanding of bonds formed by each carbon and ability to display it gained	3.51	0.71
2.	I can apply the IUPAC principles for naming and modelling of substituents	3.43	0.77
3.	Skill to identify the longest carbon chain easily gained	3.50	0.87
4.	My skill in the process to indicate correct positions for substituents improved	3.52	0.68
5.	I can identify the best positions to number carbon atoms		
6.	I enjoyed the use of the molecular models	3.38	0.91
7.	The model equipped me with skills to interpret, identify and represent structures of monocyclic compounds	3.45	0.75
8.	The molecular models made lessons more engaging and interactive	3.56	0.78
9.	Use of the model improved my ability to collaborate with colleagues	3.49	0.71
10.	Provision of effective visualisation of extended structures	3.39	0.75
11.	Modelling of cyclic compounds equipped me with skills to represent monocyclic structures with understanding	3.31	0.78
	Mean score	3.45	0.77

From Table 6, all responses were rated highly (mean of 3.51; SD = 0.72) to indicate students' perceived skills for interpreting and identifying monocyclic compounds. This could be due to the perception that modelling increased reality and reduced rote learning. This suggests that modelling must necessarily be taught and learned. In related studies Stull, Hegarty, Dixon and Stieff (2012) and Aryeetey (2018) found that students who struggled with symbolization acquired representational competence after engaging with models. Students in the current study reported that they were able to apply the IUPAC rules effectively and identify the best long carbon chain and correct positions of substituents; after engaging with the models. They agreed that 'models' subtly increased their skills in identifying, naming and representing organic compounds. They admitted the interactive nature of the models, how easy and enjoyable it was to use, and the provision for effective visualisation of extended structures. They perceived that the inherent collaborative nature of the models led to peer teaching that motivated them to commit to interactive engagements with attention.

It was observed that about half of the class were not enthused about the hands-on activities with the models during the first interventive lesson, but interest increased to about 75% in the second lesson. The few who showed disinterest admitted that they were slow in acquiring the skills to display compounds in 3-D, using the models. Difficulties were overcome after an online tutorial and completed assigned tasks by the third week. Students engaged in constructive whole class discussions but were also observed to make independent initiative, which helped with their conceptual gains. From observation, students' cognitive understanding increased as their skills to model structures also increased and were engaged collaboratively during the activity-packed lessons. This encouraged peer teaching and motivated students to share ideas with colleagues. A summary of students' impressions on the use of molecular models was that they perceived that they gained the needed process and concept skills to draw (illustrate) and name illustrated monocyclic compounds after engaging with the chemical models. They perceived that the models:

– Made learning real and reduced abstract learning
– Made learning enjoyable
– Enhanced understanding and application of IUPAC rules to depict structures
– Were interactive and easy to use
– Improved their ability to share ideas with colleagues
– Deepened their conceptual understanding on the type of bond formed by each of the hydrocarbons and ability for display
– Equipped them with skills to interpret, identify and represent structures of monocyclics
– Equipped them with skills to identify the longest carbon chains
– Enhanced their abilities to share ideas

It could be summarised from the findings that the application and practice with models was necessary for the students to become proficient with representing or illustrating structures of monocyclic compounds and to gain deeper understanding of underlying concepts. The importance of this study is that it demonstrates how the ability to model impacts on students' mental models of organic compounds. The models developed students' thinking processes as they showed high order thinking processes about monocyclic organic compounds by using the models to test assumptions, predict and evaluate their ideas, develop mental pictures, and transfer between 2D and 3D models. Students should, therefore, use models, at least in the beginning stages when they are first developing their understanding and representations of 3D molecular structures.

Conclusion

The study investigated the effectiveness of using chemical models to enhance first-year chemistry students' ability to identify, interpret, name and draw monocyclic organic compounds at the University of Education, Winneba. The study revealed that students did not possess the appropriate conceptual or process skills to make representations when diverse organic compounds were presented to them before the intervention; however, after the intervention, they perceived that their skills for interpreting and representing structures of monocyclic compounds improved. Their abilities to use and interpret models influenced their abilities to understand underpinning concepts. This suggests and affirms that allowing students to construct knowledge (Hanson, 2020) through the use of molecular models and constructive modelling activities has the potential to facilitate the identification, naming and representation of monocyclic compounds, as confirmed by a statistically significant difference in students' conception and acquisition of process and concept skills. The models were perceived to enhance their visualisation and retention capacities. The analysed questionnaire revealed that students had positive attitudes toward the use of molecular models and acquired the necessary skills which they attributed to ease of use and inherent interactive nature of the molecular models. The study further revealed that as students practiced the use of the models, their interest increased symmetrically with their conception and acquisition of skills, which they considered enhanced their conceptual understanding.

It is recommended that for conceptual growth to occur and to avoid the formation of misconceptions, students must be engaged in collaborative, constructive hands-on activities (Bruning, Schraw, Norby, & Ronning, 2004) that will enable them to construct their own authentic knowledge. Besides that, modelling skills should be taught instead of making it a supporting tool for teaching concepts.

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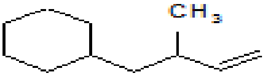
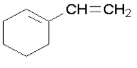
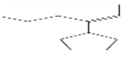
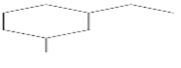
APPENDIX A
PRE-TEST

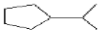
Name the following cycloalkanes and cycloalkenes using the IUPAC system.

a.


b.


c.


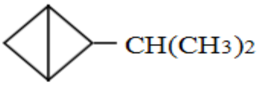
d.


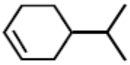
e.


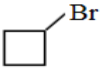
2. Draw the following structures using the IUPAC system of nomenclature
1,2-dimethylcyclohexane
1-cyclopropyl cyclopropane
1-isopropyl Cyclohexane
3,3-Dimethyl-1,4-cyclohexadiene

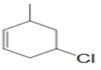
APPENDIX B
SAMPLE POST-TEST

1. Name the following compounds using the IUPAC system of nomenclature.

a.


b. 

c. 

d. 

2. Draw the following structures using the IUPAC system of nomenclature.
a. 1,3-dimethylcyclobutane
b. 1-cyclopropyl-2-cyclohexane
c. l-chloro-2-methylcyclopentene
d. 3-cyclobutyl-3-methylpentane

APPENDIX C

Questionnaire on the usefulness of the molecular models.

Items	Strongly Agree	Agree	Disagree	Strongly Disagree
1.Modelling of compounds deepens conceptual understanding of the type of hydrocarbon bonds				
2.Effective application of IUPAC rule for naming and modelling monocyclic compounds with alkyl substituents				
3.Longest carbon chain could be identified easily				
4. Improvement in ability to indicate the correct position for substituents.				
5.Using the molecular models was enjoyable.				
6.Molecular model kit enhances understanding				
7.Molecular models made lessons more interactive.				
8.Use of model improves ability to share ideas.				
9.Molecular models provide effective visualisation				
10.Understanding improved with modelling of cyclic compounds before structural representation				

APPENDIX D

Observation schedule

S/N	Items	Yes	No
1	Pay attention in class		
2	Work well with colleagues		
3	Participate actively in discussion		
4	Take independent initiative		
5	Enjoy use of the molecular models.		
6	Discouraged and abandon work when obstacle is encountered		
7	Name modelled cyclic organic compounds		
8	Follow the IUPAC rules in naming and writing cyclic compounds.		
9	Approach new assignments with sincere effort		
10	Ask relevant questions during lessons		

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