INTRODUCING METAL-LIGAND GEOMETRIES THROUGH SCIENCE WRITING HEURISTICS AND MODELLING AND MODELLING SKILLS IN HIGHER EDUCATION

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ABSTRACT

This study investigated the efficacy of using Science Writing Heuristics (SWH) and Modelling and Modelling Skills (MMS) by students to predict the geometries of metal complexes. A case study design within the Model of Educational Reconstruction approach was used. The accessible population were all third-year chemistry students in the University of Education, Winneba (UEW)-Ghana with sample size of twenty-nine (29) students. The study involved students in a class of 5 groups, comprising 5-6 students each over eleven-week period. The findings among others, showed that students were able to understand, use and draw metal isomeric structures correctly because they were aided by the interventional strategies (SWH & MMS) adopted during the study.

Keywords: Educational reconstruction, efficacy, heuristics, modelling skills.

INTRODUCTION

Students use strategies in everyday life (embodied cognition) to guide their thinking and make decisions (Lakoff, 1990). Psychologists call these strategies 'Heuristics', which are defined as intuitive strategies to direct problem-solving and decision-making. Heuristics are neither laws nor rules that are accepted universally - they are supporting facts. The main objective of heuristics is not to find the 'truth' but find ways to move forward despite the lack of full information. The effectiveness of the SWH and MMS approaches have been reported in many international studies with regards to students' understanding of science concepts at different grade levels (Keys, Hand, Prain, & Collins, 1999; Hohenshell & Hand, 2006; Akkus, Gunel, & Hand, 2007; Schroeder & Greenbowe, 2008). Keys *et al*. (1999) in their research conducted studies on the influence of SWH activities on students' meaning making, conceptual change and reasoning.

Also, a minimum level of modelling ability or representational competence (Kozma & Russell, 1997) is required to use symbols to learn and understand chemistry. The use of models and modelling in teaching chemistry is a common practice that engages students to develop their own mental models of chemical compounds. However, despite this common use of models, studies have shown that students misunderstand the reasons for using models and modelling. Many secondary students view models only as copies of the scientific phenomena (Grosslight, Unger, Jay, & Smith, 1991) and their understanding of the role of models is frequently seen as being simplistic (Treagust, Chittleborough & Mamiala, 2003). Ingham and Gilbert (1991), in a similar research had stated that university students have limited experience with models, and only a small percentage of these students have an abstract understanding of model use in chemistry. In a cross-age study, Coll and Treagust (2001) described similar outcomes when undergraduate and postgraduate students tended to use simple teaching models learned in high school to explain chemical bonding. Gilbert, Boulter and Elmer (2000) intimated that models of every kind are used to communicate science outcomes, plan and implement its methods. Chittleborough and Treagust (2007) in a similar research concluded that students' abilities to use and interpret chemical models influence their ability to understand chemical concepts. These modelling skills should be deliberately taught, rather than being an incidental consequence of teaching of chemical concepts. Learners' acquisition of skills should be incorporated in instruction and be a given practice in the application of multiple representations of chemical compounds and their interactions. This study, believes that these basic concepts that we intuitively have in mind can be made accessible to students through conveying heuristic principles thus enhancing their conceptual understanding and drawing of metal isomeric complexes in coordination chemistry. The main conceptual framework used for the study was the Model of Educational Reconstruction (MER) – that is, how students' knowledge influence cognitive reconstruction (Duit et. al., 2012). Some researchers have used the MER to conduct studies into topics such as metal complex isomerism (Sam, Niebert, Hanson, & Aryeetey, 2016), coordination chemistry (Sam, Niebert, Hanson, & Twumasi, 2015), climate change (Niebert & Gropengiesser, 2013), evolution (Zabel & Gropengiesser, 2011), and a few others. These studies demonstrated a successful content oriented educational research through the MER principles.

The objectives for this study were to:

- Evaluate how students applied SWH & MMS upon introduction.
- Explore the effect of the intervention (SWH and MMS) on students' conceptions of metal isomeric complexes.

The study was guided by the following research questions:

1. What findings emerged from students' introduction to the SWH and MMS?
2. What was the effect of the intervention (SWH and MMS) on the students' drawings of the metal complex in the reconstruction process?

Methodology

The study was a case study using the Model of Educational Reconstruction (MER), approach as proposed by Niebert and Gropengiesser (2013). This approach was adapted in this study because it is a widely used research approach which seeks to improve content-specific learning and teaching. Furthermore, the research design was based on the MER due to its inherent ability to improve science teaching from secondary to higher education when adopted. The interpretive-qualitative methodology was used in this study to ascertain the depth of students' knowledge in metal-ligand geometries.

Population

Participants in the study were all third-year chemistry students in the University of Education, Winneba (UEW), who took the coordination chemistry course in the second semester of the 2014/2015 academic year. There were twenty-nine (29) students involved. The 29 comprised twenty-seven males and two females in the study.

Sample selection procedure

Purposive sampling was used to select 29 third year chemistry students for the study. According to Creswell, (2008), in this type of sampling, the researcher determines the type of participants who are appropriate for the study and select them. Based on this, the third-year chemistry students of the University of Education of Winneba were the accessible population for this study. They were randomly assigned to groups. The simple random technique was used by urging the participants one at a time to pick one coloured ball in a brown enclosed envelope. Each of the participants was to pick a coloured-ball and show it to the class. All those having the same coloured-balls were put in one group. Members in each group were then given specific tasks designed by the researcher, who served as the instructor for the course. This relationship enhanced easy administration and the collection of data for the study. In a class session, students were given a name of a complex to display graphically (draw). The metal name of the compound was *Tetraamminechloridonitrito-N-cobaltate(III)ion.* Students had challenges in transforming and moving their thoughts between 2-D and 3-D visualisations. These students' difficulties were corrected after the introduction of the interventional strategies adopted (SWH & MMS).

Instrumentation

With the purpose of the study in mind, it required that data be collected on

(i) students' drawings of metal isomeric complexes.
(ii) Pen and paper tasks

Validity of the main instrument

The main instrument was students' drawings as well as pen and paper tasks. To ensure the quality of the data analysis, all data were externally and consensually validated (Steinke, 2004) through discussion in the study group and crosschecked with other studies in the field of science education. Two experts in the field of inorganic chemistry validated the students' drawings independently. In this round of activity, the written (pen and paper tasks) responses were read several times, analysed and summarised independently by the two researchers. The agreement between the assessments was 70% and with the few cases of discrepancies, the researchers made a common assessment after discussions.

Results and Discussion

What findings emerged from the students' introduction to the SWH and MMS?

The SWH and the MMS were tools to help the students learn how to think conceptually and not to memorise. These interventional strategies were introduced to the students to enhance their competence of proposing metal isomeric structures and modelling geometries of metal complexes. Therefore, a simplified concept like geometrical structures of heuristic writing offered an intuitively useable system that was individually extendable beyond existing simple figures (lines, curves etc.) and enabled the students to connect to their prior knowledge. An example that guided the students in drawing the metal complex is displayed stepwise in *Activity 1*. The study herein considered an example in class that was given to the students to work on. They were guided in constructing the metal complex $[Co(NO_2)_6]^{3-}$ so that they would acquire the skills to do same. An example of the guided approach is shown in Activity *1*. This procedure was outlined in the students' instructional activity. The trainees were guided by the activity below:

Activity 1

1. Students must acquire a mode (central metal atom) with six-hole slot. *Hint: The choice of mode may differ if coordination numbers (the number of ligands) differ. For example, a five-member ligand complex may require a five-hole metal model slot as the central metal atom. This would be applicable for other squares and tetrahedral.* Draw this on a sheet of paper indicating the central atom as a point or dot.

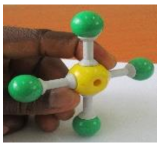
**The other three slots were unable to be captured by the camera*

2. Students, now put the first ligand (ligand 1) above or on top of the central atom. This may serve as the first axial atom of the complex. Draw this dimension to the dot or point stated in step one.

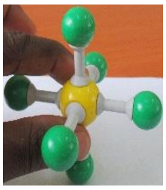
3. The students put the second ligand (ligand 2) below or beneath the central metal atom. This completes the axial dimension in the complex. Draw this dimension to join the dot below the metal atom.

4. Now, the students consider positioning the rest of the ligands in the equatorial region of the complex. Place the third ligand in the first slot (mid-section) of the complex. This formation begins the first equatorial sectional drawing on paper.

5. In the next step, the students place the fourth ligand opposite the third ligand in the equatorial section. Observe the picture below and continue drawing the diagram on paper as:



6. Students repeat step five, to place the fifth and sixth ligands in the equatorial section to complete the formation. Observe the picture below and draw the appropriate diagram.



Hint: Consider placing the appropriate charge on the complex after drawing the structure on the paper. Participants should consider the choice of ligand-colours. When ligands differ, your choice of colours must also be different.

7. The students name the structure in step six as an octahedral or a square bipyramidal.

The procedure for using the SWH & MMS was designed parallel in the instructor/students' activity-guide in Activity 2 (Figure 1).

Students observed the 2D-dimensional chart below and followed through the steps in that manner, as they drew on paper in Activity 2.

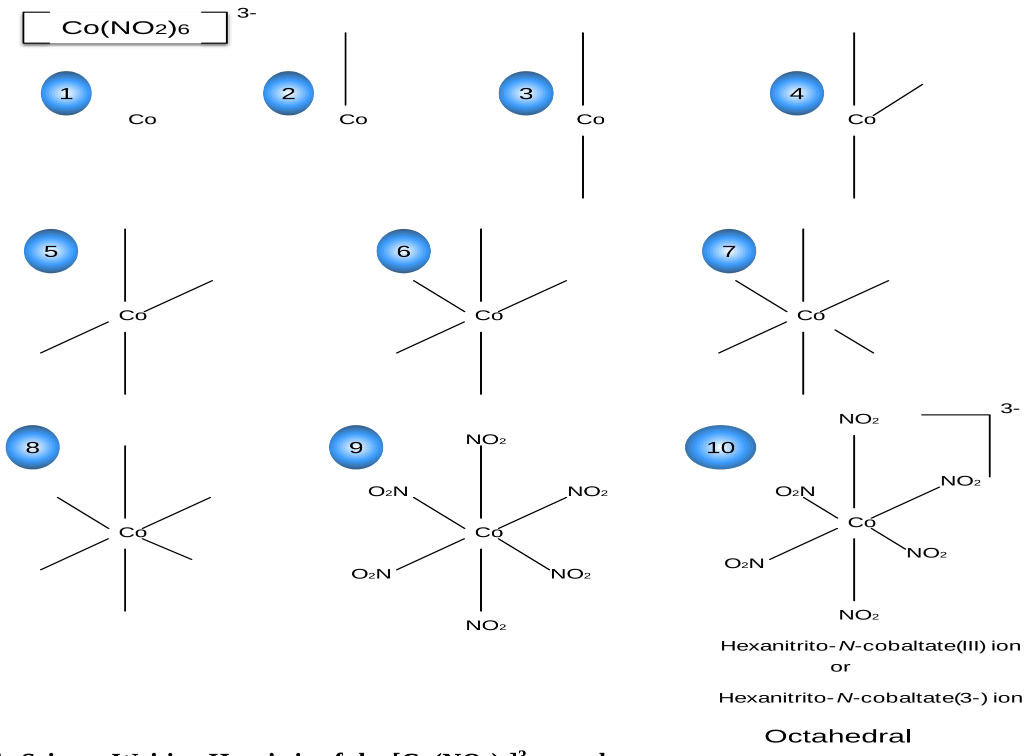


Figure 1: Science Writing Heuristic of the $[Co(NO_2)_6]^{3-}$ complex

From Figure 1, the structural drawings in chemistry was very important and necessary in understanding molecular geometries as asserted by Graulich, Hopf, and Schreiner (2010). With the idea from *Activity 1* in mind, using heuristic chemistry was a good strategy for understanding metal complex structures. The teaching of the SWH/MMS encouraged students to make pictorial representations of their ideas on paper, analyse and accessed them effectively. The data gathered from the *Activities 1* and *2* were used to answer the second research question.

What is the effect of the intervention (SWH and MMS) on the students' drawings of the metal complex in the reconstruction process?

This research question focused on the effect of the intervention on the students' conceptions of the selected aspects of the coordination chemistry topics. This was generated from the students' groups (evidence of understanding the topic, after interacting with the interventional tools) during the educational reconstruction process. The findings, among others showed that the students had conceptual understanding of the topic after engaging with the heuristic writing and the modelling skills. The formula of the complex compound was given to students to assess their understanding on its geometry. This was done after the students had experienced the Science Writing Heuristics (SWH) and the Modelling and Modelling Skill (MMS) instructional tools. Examples of the geometries that the students sketched for the $[CoCl(NO_2)(NH_3)_4]^+$ and $[CoCl_3(NH_3)_3]$ are shown in Figures 2 and 3 respectively.

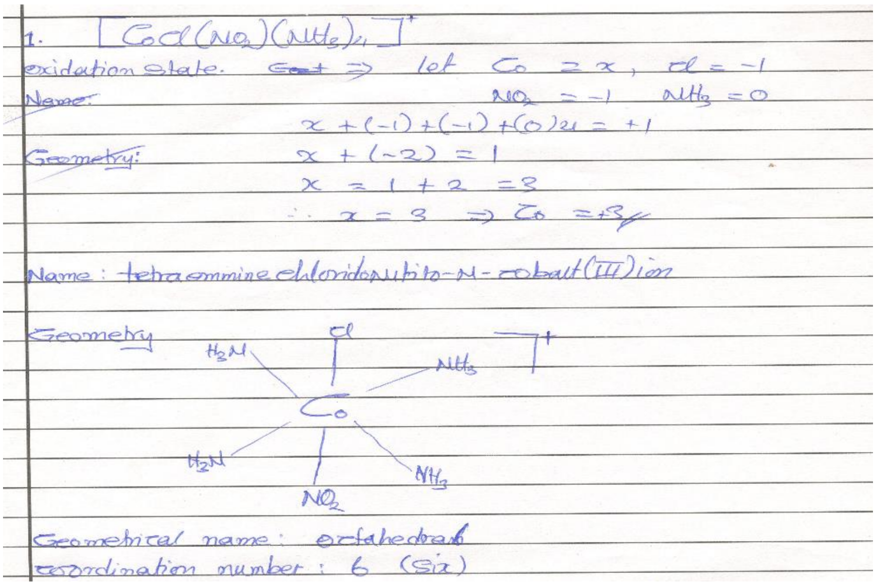


Figure 2: Group A's conception on the $[CoCl(NO_2)(NH_3)_4]^+$ complex

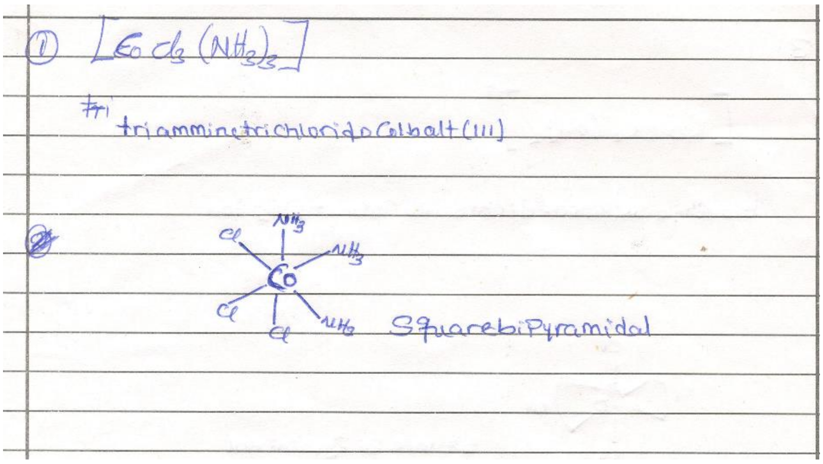


Figure 3: Group B's written example of the $[CoCl_3(NH_3)_3]$ complex

From Figures 2 and 3, the students' drawings showed an understanding of the geometries of metal complexes. The students' representations of the said figures showed that they now understood figures such as the octahedral and/or square bipyramids without any difficulty. Furthermore, students were able to mentally transform between two-dimensional (2-D) and three-dimensional (3-D) representations. It was not surprising that, the participants successfully viewed a 2-D diagram such as $[CoCl(NO_2)(NH_3)_4]^+$ correctly and were able to create a 3-D image from it. The study herein, reiterates that the SWH/MMS implemented urged the students to be able to form 3-D images by viewing 2-D chemical structures and mutually proceeded to rotate these 3-D images in their minds. Their views on chemical representations were not reliant on the surface features such as lines, numbers and colour as reiterated by Kozma and Russell (1997), but in high congruence with experts' meaningful basis for their conceptual understanding.

Students' abilities to use and interpret chemical models influenced their abilities to understand chemical concepts (Chittleborough & Treagust, 2007). The SWH offered the students intuitive useable systems that allowed them to extend their thinking beyond lines and curves and enabled them to connect their prior knowledge to scientific pictorial representations. This was a good strategy for understanding chemical behaviour as it provided the students the ability to explore geometrical structures as enshrined in the International Union of Pure and Applied Chemistry (IUPAC), 2005 recommendations.

CONCLUSIONS

Findings from the study among others showed that a learning environment with a presentation from the course instructor accompanied by hands-on-activities promoted students' participation in class. It was also found that students built better understanding of concepts more effectively when they are engaged to solve problems during class activities as practiced in educational reconstruction. In light of the fact that learning is a process that involves investigation, formulation, reasoning and use of appropriate strategies to solve problems, Science Writing Heuristics (SWH) and Modelling and Modelling Skills (MMS) were found to be effective in teaching the geometries of metal complexes at UEW. This was evident from the results found from this research.

RECOMMENDATIONS

Based on the findings from the study, it is recommended that Faculty members in the science education at UEW should adopt the heuristic and modelling skill approach and use them to teach for conceptual understanding and retention.

Workshops should be organised by the Science Education Faculty at UEW to emphasize and enlighten Lecturers and science educators, particularly on the importance of the heuristic and modelling skill approach of teaching. The Department of Chemistry Education of the University of Education, Winneba should embark on proactive programs targeted at incorporating or encouraging heuristic and modelling skill learning amongst Teacher Education College tutors during seminars organised by their outfit.

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