TEACHER TRAINEES' ALTERNATIVE CONCEPTIONS ABOUT SOME ASPECTS OF COORDINATION CHEMISTRY: A CASE STUDY AT THE UNIVERSITY OF EDUCATION, WINNEBA-GHANA

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ABSTRACT

Students' alternative conceptions of some aspects of coordination chemistry namely nomenclature and geometry, geometrical isomerism, bonding and colours in complexes differ greatly from scientific concepts. This study investigated the causes of students' alternative conceptions and how they express these conceptions in coordination chemistry. A case study design within the Model of Educational Reconstruction (MER) approach was used. The access population were all third-year chemistry pre-service teacher trainees in the University of Education, Winneba (UEW)-Ghana with sample size of fifteen (15) students. A pre-test administered at the beginning of the study in a class of 5 groups, comprising 3 students each over eleven weeks showed that students had alternative conceptions about some aspects of coordination chemistry. The students' alternative conceptions were derived from two-tiered questions, written tasks and inorganic formulae of some coordination chemistry complexes. The results among others indicated that the causes of the students' alternative conceptions emanated from their inability to distinguish between 2D and 3D visualisation and the misunderstandings of some inorganic chemistry terms. The study recommended that the coordination chemistry content at UEW has to be well connected in order to give the students a broader basis for conceptual change through meaningful interventional approaches such as Science Writing Heuristics (SWH) and Modelling and Modelling Skills (MMS).

Keywords: Alternative conceptions, conceptual change, heuristics, modelling skills.

INTRODUCTION

Most students perceive the study of chemistry to be difficult for many reasons mainly because of its specialised vocabulary and seemingly abstract features. Wandersee, Mintzes and Novak (2005) reiterated that in spite of chemistry teachers' best efforts in teaching chemistry, learners do not easily grasp the fundamental ideas covered in class. Although some smart students give apparent correct answers to questions in class, they only use the correctly memorised words and naive explanations (Hanson, Twumasi & Antwi, 2015).

In most cases, students consider chemistry as a tough, demanding and difficult course. A greater number of research studies investigating students' conceptual understanding of basic chemical concepts revealed a great variability of conceptions in students' knowledge at all levels (Rushton, Hardy, Gwaltney & Lewis, 2008). For most topics taught in introductory chemistry courses in our tertiary institutions, alternative conceptions have been identified via educational research studies. Some of these studies on students' alternative conceptions and pseudo-conceptions in chemistry, include those conducted by Andersson (1990) on matter and its transformations, Stavy (2008) on matter and its properties, Nakhleh (1992) on chemical bonding, Taber (2002) on bonding, and Hanson, Sam, and Antwi (2012) on hybridisation. However, to the best of the reseachers' knowledge no work on coordination chemistry has been done in West Africa and Ghana in particular.

Students' conceptions of some aspects of coordination chemistry such as nomenclature and geometry, isomerism, bonding and colours in complexes usually differ greatly from scientific concepts (Sam, et. al., 2015). In this study, coordination chemistry was used as an example to demonstrate causes of the students' alternative conceptions and how these conceptions were expressed. This is the main assumption of the MER - how student knowledge influences cognitive reconstruction (Duit et. al., 2012). Some researchers have used the MER to conduct studies into topics such as climate change (Niebert & Gropengiesser, 2013), the principles of vision (Gropengiesser, 1997), cell division (Riemeier & Gropengiesser, 2008), 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 was to:

- Identify the causes of the students' alternative conceptions in nomenclature and geometry, isomerism, bonding and colours of metal complexes.
- Investigate how these alternative conceptions were expressed by the students.

The study was guided by the following research questions:

1. What are the causes of the students' alternative conceptions about the selected aspects of coordination chemistry?
2. To what extent are these alternative conceptions expressed by the students?

Methodology

The study is a case study using the Model of Educational Reconstruction (MER), approach (Niebert & Gropengiesser, 2013). This was adapted in this study because it is a widely used research approach, which sought to improve content-specific learning and teaching. The research design was based on MER due to its adoptability to improve science teaching from secondary to higher education - a strategy that builds upon a successful research design and elevates it into university contexts (UEW).

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 15 students involved; eleven males and four females in the study.

Sample selection procedure

Purposive sampling was used to select 15 third year chemistry pre-service Teacher Trainees 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.

Instrumentation

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

(i) Pre-test (students' conceptions) from two-tiered test in class.
(ii) Pen and paper tasks and students' drawings from the classroom process.

Validity of the main instrument

The main instrument was test (pre-test items). To ensure the quality of the data analysis, all data were externally and consensually validated (Steinke, 2004) through discussion in the research group and crosschecked with other studies in the field of science education. Two experts in the field of inorganic chemistry validated the test items 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 90% and in few cases of discrepancies, the researchers made a common assessment after discussions.

Results and Discussion

What are the causes of the students' alternative conceptions in nomenclature and geometry, isomerism, bonding and the colours of metal complexes?

This research question, focused on the causes of the students' alternative conceptions about the selected aspects of the topics under consideration. The findings indicated that, there were considerable alternative conceptions associated with the selected topics. The causes of the students' alternative conceptions on the selected themes on coordination chemistry were specified in this study as:

1. Curriculum indecisions;
2. 'Commonsense reasoning': that is *heuristics*;
3. Inappropriate use of language;
4. Inadequate prerequisite knowledge; and
5. Inability to visualise and transform dimensions

The study is of the view that, a careful attention to some of these issues could lead to significant improvements in students' understanding. The summary which follows, highlights the root causes of these alternative conceptions that were generated from the study.

1. Curriculum indecisions.

The re-analysis of the scientific books showed some inconsistencies of the aspects used in the study (Sam et al., 2016). On the aspect of nomenclature, only Gispert, (2008) used the current rules for naming coordinated complexes by International Union of Pure and Applied Chemistry (IUPAC, recommendations, 2005). The recommendations made by IUPAC on nomenclature and geometries in 2005 were not considered by the students. The study was of the view that the students were not aware of these new recommendations. This revealed that students' conceptions were often inconsistent with the scientific conceptions they were expected to learn. These and other evidences, which has clearly been shown in the study, points to the fact that they did not acquaint themselves with scientific updates and recommendations that influenced subsequent learning. This study established that, lack of prompt curriculum decisions by reviewers and developers, made the students to develop different conceptions in naming complexes and this led to resistance in conceptual change.

2. 'Commonsense reasoning': heuristics.

The study was based on the hypothesis that, one of the causes of students' conceptual difficulty to understand some aspects of coordination chemistry resulted from lack of application of 'commonsense' (Viennot, 2001) analogy. In this study, most of the students hardly characterised the approach of heuristics. However, the use of patterns of reasoning, especially unconsciously following-up and applying other alternatives in problem solving was absent. The heuristic use was to control how and where to look for information when the students were posed with problems, when to stop the search, and what to do with the results.

3. Inappropriate use of language.

The use of language in a scientific context has been identified in several studies as a potential cause of students' conceptual difficulties (Garnett, Garnett & Hackling, 1995). This study hereby reiterates therefore that the language of science is difficult to learn and even to understand it terminologies. Scientific nomenclature was more or less a foreign language for the students, as most of them were frustrated when trying to relate chemical names with corresponding Latin names, such as plumbate, argentate and aurate etc. This study clearly not only agrees with Niebert and Gropengiesser (2013), that the use of language is a window into students' conceptions but also a conduit that creates different mental pictures for different group of participants in research.

Another cause of the students' conceptual difficulty in coordination chemistry established by this study was terminology conflict. It was realised that some organic chemistry courses had already introduced students to a variety of the discipline specific terms of which the participants were already aware about and using them in the course of the study. Common examples of such unique terms were functional groups/substituents (as ligands), stereochemistry/chirality, and conformers (equatorial/axial) designations. From this study, the students improperly assimilated these terms into their explanations and vocabulary, misapplying their use in some instances in the representational discussion sessions. The presence of terms from other chemistry disciplines in justification seemed to indicate that students were not considering differentiating the subdisciplines of chemistry.

4. *Lack of prerequisite knowledge.*

The lack of appropriate prerequisite knowledge was another factor that aided students' conceptual difficulty as the new concepts were introduced. For example, students' inadequate understanding of chemical formulae, formation of compounds, bonding and hybridisation were likely to have experienced considerable difficulty in topics such as nomenclature and geometry, isomerism and exhibition of metal colours. This study hereby agrees with Ausubel's (1968) proposal that, the most important single factor influencing learning is what the learner already knows. It is therefore clear in this study that more emphasis be placed on students' prior knowledge, prior instruction and the extent to which the participants had acquired prerequisite knowledge in other related courses.

5. *Inability to visualise and transform dimensions*

Model and modelling confusion witnessed in introductory chemistry as Taber described, resulted from formal learning environments (Taber, 2002). In this regard students' inability to visualise and transform 3D models to 2D models represented a major area of difficulty in developing a sound conceptual understanding of the coordination chemistry course. Another difficulty this study acknowledged was the rapid transfer between what was described as the three levels of thought: the macroscopic, sub-microscopic and symbolic forms. From the study, for the students to have good conceptual understanding into the coordination chemistry course, they were required to operate across these three levels of thought successfully (Johnstone, 1991). From the research evidence available at this stage, it was useful to point out to the students the different ways of thought and what clearly formed the links across these levels appropriately.

To what extent are these alternative conceptions expressed by the students?

This research question was focused on generating the students' ideas about the aspects of the topics in coordination chemistry under consideration. This afforded the researchers the opportunity to identify the students' alternative conceptions and remediate them appropriately. The alternative conceptions expressed by the students in coordination chemistry has been structured on the following topics: ***Nomenclature and geometry, Geometrical isomerism, Bonding and colours.***

Nomenclature and Geometry

Some studies have documented students' alternative conceptions on nomenclature, hybridisation and geometry (Sam, et. al. 2015; Hanson, Sam & Antwi, 2012; Taber, 2002). Table 1 collates alternative conceptions documented from this study. The alternative

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conceptions on nomenclature and geometry have been grouped into these broad areas: The nature of central metals and ligands; oxidation states of central metals; the central metal and the way ligands are arranged; central metals in different coordination spheres. Table 1 indicates students' alternative conceptions in nomenclature and geometry.

Table 1: Students' alternative conceptions on nomenclature and geometry

Students' alternative conceptions: Nomenclature and geometry
The nature of central metal and ligands
1. Size of metals
A central metal is 'micro' in size.
A central metal is lighter enough to be outweighed.
A central metal is small piece but invisible as complex ion.
2. Oxidation states of central metals
The oxidation state of the metal is the charge on the coordination sphere.
The coordination sphere can be assigned an oxidation state and this equals the charge on the sphere.
The oxidation state of a metal outside the coordination sphere never affects it.
3. Complexes are composed of all central metal atoms and ligands.
4. Ligands have macroscopic properties (they are stretchable).
5. All ligands have the same weight.
6. Ligands are alive. Alive because they move.
The central metal and the way ligands are arranged.
7. There is considerable space between metals and ligands in the coordination sphere.
8. Metals are arranged in a disorderly manner rather than an orderly fashion.
Metals and ligands occur in homogenous masses in the coordination complex.
Central metals in different coordination spheres.
9. Metals and ligands may have different sizes, shapes and weights depending on the complex ion.
Metals and ligand bonds become longer as the coordination sphere reduces.
Two or more metals can exist in the coordination sphere.

DISCUSSION

From Table 1, some alternative conceptions may arise from students confusing the interpretation of common language with specific scientific language (Gkitzia, Salta & Tzougraki, 2011). In everyday language, the word 'micro' is perceived as a small but visible piece of solid substance. In the area of chemistry, however, the students loosely used this term at the sub-microscopic level to describe atoms, molecules and ions. Conception 1 arose from the students, thinking that all the central metals involved in coordinating with ligands are ionic. According to Gispert (2008), metals complexes are grouped as being:

(1) Cationic complex,
(2) Anionic complex,
(3) Neutral complex, and
(4) Coordinate complex; depending on their oxidation states.

ability to assign oxidation states is also an important factor in the identification of the charge on the metal complex. Typical alternative conceptions of the students in conception 2 were the association of the oxidation states on the coordination sphere with the central metal in the sphere. Using different definitions of redox reactions caused problems for the students in an attempt to identify the states of the metals in the complexes. This study found that the students considered four definitions. These were:
(1) oxygen addition or removal;
(2) hydrogen addition or removal;
(3) electron transfer; and

(4) changes in oxidation states; as related from previous electrochemistry courses. The first three of these did not work in all instances, when the students tried to use them in the algorithmic calculation of the oxidation states for the metals. The metal oxidation states could be identified with certainty when students are familiar with the individual states of atoms (ligand) or molecules that compose the complex (De Jong & Treagust, 2002).
Tsaparlis (2009) found that students were likely to hold conceptions that were consistent with common errors found in science textbook illustrations. The researchers noted that students interpreted diagrams of relationships in textbooks qualitatively and globally and were unable to distinguish between the diagrams and the models they represented. Hence, the students, were likely to have formed alternative conceptions about the spacing between ligands and the central metals, conceptions, 3, 4, 5, 7, 8 and 9 (See Table 1).

Perhaps some of the students were aware that the nucleus of some cells was one or two molecules thick, since the nucleus controlled the activities of the cell and molecules consisted of atoms. In conception 6, students had the notion that ligands were alive. This was a fundamental source of confusion between ligands (atoms) and biological cells. There was a thought that atoms were alive because they were at times substituted or replaced in chemical reactions. The students therefore brought this view to instruction as part of their culturally acquired 'non-scientific' knowledge. Students too often thought objects were endowed with human or animal features (Gkitzia, Salta & Tzougraki, 2011). Most of the alternative conceptions identified in Table 1 were associated with students' difficulty in visualising matter.

Geometrical isomerism
From the observed difficulties students experienced in developing an acceptable understanding of the nature of the central metal atom and the concepts of oxidation states of central metals atoms and the way the ligands were arranged in a coordination sphere, it was therefore not surprising that they also had difficulty in understanding the concepts associated with geometric isomerism. A two-tier test item (Chandrasegaran, Treagust & Mocerino, 2005) was used to establish alternative conceptions held by the participants. These alternative conceptions on geometric isomerism have been expressed in Table 2.

Table 2: Students' alternative conceptions on geometric isomerism

Students' alternative conceptions: Geometric isomerism
Metal-ligand geometries
1. The numbers of ligands may/not equal the coordination number.
2. The numbers of ligand around the metal may/may not determine the shape of the geometry.
Bond Polarity
3. Provision of electron pair by ligands in some coordinate bonds.
Shape of coordination sphere
4. Shape is due to cis/trans effects as 'seeming' lines.
5. Shape is due to formation of squares and triangles.
6. Bond polarity determines only the metal-ligand geometry

Table 2, provides the possible causes of the students' alternative conceptions. Namely,
(1) students' inability to transform models between two dimensions; and
(2) students' inexperience in developing acceptable shapes around central metals within coordination spheres.

This is evident in conceptions 2, 4 and 5. In Table 2, it was also not surprising that students had difficulty in understanding concepts associated with coordinate bonding and (geometry) structure as reiterated in conception 3. In conception 6, some students predicted the shape of the geometry by considering only the repulsion of bonding electrons pairs around the ligands. A few of them, however viewed the repulsion between non-bonding electron pairs while others thought that bond polarity determined the geometry of the metal complex. All these indicated the degree of confusion the students encountered in understanding covalent bonding and coordinate bonding.

Bonding and colours

The researchers focused on the findings of this study and stated that, similar findings had been reported by Hanson, Sam and Antwi, (2012) and Taber (2002). Table 3, gives a summary of these alternative conceptions held by the students.

Table 3: Students' alternative conceptions on bonding and colours

Students' alternative conceptions: Bonding and colours
1. Hybridisation may create an avenue for ligands to form coordinates bonds
2. Any type of ligand (weak or strong field) determines the colour produced by the complex.
3. All ligands cause splitting of metal orbitals the same way.

From Table 3, one of the causes of the students' alternative conceptions on bonding and colours was their inability to perceive colours. Students were unable to distinguish between absorbed and reflected colours. They viewed the colours of metal complexes as the colours imparted by the ligands attached to the central metal atoms. Hadenfeldt and Neuman (2014) noted that, because phosphorus is yellow students think that the atoms are yellow and also the atoms exhibited same characteristics as the substance. Conceptions 2 and 3 reflected this assertion. In conception 1, the students were unable to remember that in hybridisation process, the number of orbitals is conserved. For example, if three orbitals are mixed to form hybrid orbitals, then three hybrid orbitals are formed. This typifies conception 1.

CONCLUSION

The study among others concludes that students had varieties of alternative conceptions about the topics of coordination chemistry and needed self-reflection within the learning process. It was also found out that students' views on nomenclature and geometry, geometric isomerism, and bonding and metal colours had to be given maximum consideration and attention in a way each of the views is presented, for a successful construction of the content structure for instruction.

RECOMMENDATIONS

Educational restructuring will offer a kind of platform or environment for reflection so that students would be able to examine their alternative concepts in the light of new authentic information. Thus, opportunities should be given to students to revisit their own naive or alternate ideas, revise them, understand and relate the concepts appropriately, and restore to new scientific conceptions in more integrated trend. Lastly, selected aspects of the coordination chemistry content have to be well connected in order to give the students a broader basis for conceptual change through Science Writing Heuristics (SWH) and Modelling and Modelling skills (MMS).

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