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THE MODEL OF EDUCATIONAL RECONSTRUCTION: SCIENTISTS' AND STUDENTS' CONCEPTUAL BALANCES TO IMPROVE TEACHING OF COORDINATION CHEMISTRY IN HIGHER EDUCATION

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ABSTRACT

The general knowledge of coordination chemistry, nomenclature and geometry was characterised by domain-specific students` conceptions as observed in this study. Based on the Model of Educational Reconstruction (MER), a clarification of coordination chemistry content structure was developed and made available for teaching. Generated conceptions from four (4) university-level science textbooks and students own ideas informed this clarification process. In this interpretive study, conceptual balances from scientists and fifteen (15) third year students of the University of Education, Winneba were brought into meaningful correspondences. Students` chemical drawings were analysed by qualitative content analysis and two (2) interventions adopted to be implemented in a subsequent study. Examples of how to bring students` conceptions vis-à-vis scientists` conceptions into balance have been discussed in this study.

Keywords: coordination chemistry, Educational Reconstruction, domain-specific, conceptual balances.

INTRODUCTION

Most students often 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 large variability of conceptions in students` knowledge at all levels (Rushton, Hardy, Gwaltney & Lewis 2008). For most topics taught in introductory chemistry courses, misconceptions have been identified through educational research studies. Some of these studies on students' misconceptions and alternative conceptions in chemistry include those by Andersson (1990) on matter and its transformations, Stavy (1995) on matter and its properties, Nakhleh (1992) on chemical bonding, Taber (2002) on bonding, and Hanson, Sam, and Antwi (2012) on hybridisation. However, not much work on coordination chemistry has been researched into, especially in West Africa and Ghana in particular.

Students' conceptions on science issues such as nomenclature and geometry usually differ greatly from scientific concepts. They are idiosyncratic, deeply rooted and often tenacious and can hardly be changed through instructional sequences, which were developed without an awareness of students' conceptions (Vosniadou, 2013). In order to change students' conceptions, their ideas have to be systematically related step by step to scientific concepts, and the misconceptions which arise at each step, clarified with respect to students' own naïve conceptions as a starting point (Duit, Gropengiesser, Kattmann, Komorek, & Parchman, 2012). This step-wise relation of scientific concepts alongside students' own unscientific conceptions would be in order to attain a content structure adapted to the students' previous knowledge. Such an approach would be used in this study as a guide for teaching and learning through the Model of Educational Reconstruction (MER). The process of interrelating and balancing understanding between authentic science view towards a certain subject matter and students' perspectives may be characterized as a form of reconstruction.

In this study, coordination chemistry would be used as an example to demonstrate how reconstruction of knowledge could be achieved by constructing a balance between what students perceive about coordination chemistry, vis-à-vis expert knowledge. This is the main assumption of the MER - how student knowledge influences cognitive reconstruction (Duit, Gropengiesser, Kattmann, Komorek, & Parchman, 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 Model of Educational Reconstruction (MER), (Niebert & Gropengiesser, 2013), has been adopted in this study because it is a widely used research approach, which seeks to improve content-specific learning and teaching as reiterated earlier. 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.

The MER as a research model identifies and interrelates three relevant research tasks of subject matter education: (1) clarification of science content, (2) investigation into students' perspectives, and (3) analysis, design and evaluation of learning environments. The third and latter task enables conceptual change in students. Nevertheless, all the three components which require clarification of content (in simple terms by a teacher), identification of students' own ideas and the design and evaluation of a favourable concept-based learning environment could be interplayed to ensure enhanced conceptual understanding and proper formation of scientific concepts. For example, in the educational reconstruction of coordination chemistry, (as would be employed in this study), scientists` and students' conceptions would have to be correlated in order to design effective teaching and learning activities as portrayed in Figure 1.

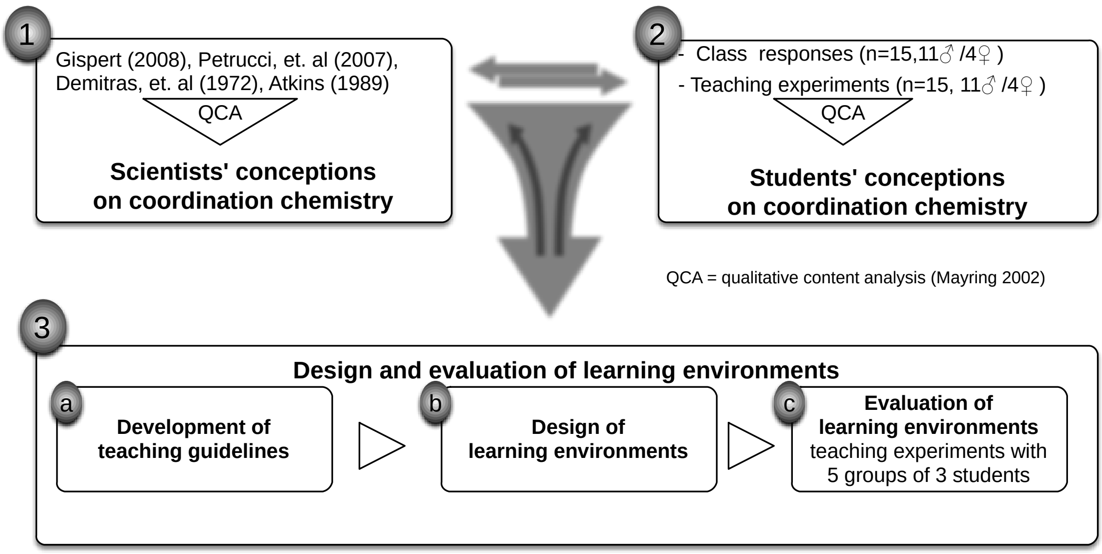

Figure 1: *Research design derived from the model of educational reconstruction* (Niebert & Gropengiesser, 2013)

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As presented in Figure 1, the key feature of this MER model shows the way in which all the three components have been brought together to influence educational reconstruction. The intimate interplay between clarification of science subject matter structure and investigation of students' perspectives is core for the model. From the Model, there is a dynamic research between what scientists believe and what students believe. After the dynamic research, an analysis is carried out to determine a point of congruence so that remediation could begin from there with ease. Investigations of students' perspectives should include issues of development of the constructed ideas towards the science point of view. It is therefore important to explicitly integrate a third component into the model of educational reconstruction, namely 'design and evaluation of learning environments' as shown in Figure 1. Designing a learning environment could mean developing an instructional unit, which could make it possible for a teacher to investigate both students' pre-instructional perspectives, and the development of these perspectives towards an intended science view. In this study, the model of educational reconstruction allowed to take into consideration the constraints of learning in real classroom situations.

The purpose of this study was to find a teaching strategy which would enable students gain an accurate, applicable knowledge base from which current International Union of Pure and Applied Chemistry (IUPAC) rules on naming coordination compounds (inorganic) and geometrical structures could be understood and employed in future. The main goal of this research was to adopt the well-known MER as a teaching strategy to improve the teaching of nomenclature and geometrical structures of coordination compounds in higher education.
Thus, we found it necessary to address these research questions:

1. What conceptions do scientists` and students` hold about coordination chemistry?
2. What interventional strategies would be employed to improve the teaching of coordination chemistry in higher education?

Methodology

In the educational reconstruction of coordination chemistry, scientists` and students' conceptions were correlated to design effective teaching and learning activities (see Figure 1). Scientists' conceptions were extracted (sub-model 1) from various scientific textbooks (Gispert, 2008; Petrucci, Harwood, Herring, & Madura, 2007; Demitras, Russ, Salmon, Weber, & Weiss, 1972; Atkins, 1989). Students' conceptions (sub-model 2) on naming of complexes and geometrical structures were sampled in a class on coordination chemistry in 5 groups of 3 students each over ten weeks. All students attended a level 300 course on coordination chemistry in a Ghanaian University. On the basis of analysis of students' and scientists' conceptions, we set up teaching guidelines (sub-model 3a) and learning environments that could operationalize the teaching guidelines (sub-model 3b). The learning environments were then evaluated in teaching sessions (sub-model 3c) in one semester for 10 weeks. The three components did not strictly follow each other but influenced one another mutually. Consequently the procedure was conducted step-by-step recursively.

In the study, students' and scientists' conceptions were analysed by qualitative content analysis (QCA) (Mayring, 2002), by developing categories in the following steps: (a) scanning students` drawings and editing them to improve readability, (b) rearrangement of statements/drawings by content, (c) interpretation of the statements/drawings, with an aim to understand in our own way the underlying conceptions, and (d) revision and final formulation of the categories. To ensure the quality of the data analysis, all data were externally and

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consensually validated (Steinke, 2004) through discussion in our working group and crosschecked with other studies in the field of science education.

Scientists` and students` perspectives on coordination chemistry: Nomenclature & Geometry

The conceptions that scientists and students have on coordination chemistry are presented from analysis of a section of selected data.

Scientists` perspectives

Due to a great number of complicated and structurally intricate complexes that might arise, scientists must have a systematic means of naming compounds in order to discuss them intelligently on a common platform. The Werner`s rule, with certain simplifying modifications, still serves as the basis for the present-day system of nomenclature, as recommended by the Inorganic Nomenclature Committee of IUPAC.
According to the former IUPAC rules:

Certain simple ligands have historically been presented by abbreviated forms such as fluoro, chloro, bromo, iodo, cyano.

Following the current rule these ligand names are now: fluorido, chlorido, bromido, iodido, and cyanido. (Gispert, 2008)

Arabic numerals are used to distinguish charges on atoms or groups of atoms while Roman numerals are used to indicate the (formal) oxidation state of atoms. (Gispert, 2008)

For example, a sodium tetranitratoborate(III) can now be written as sodium tetranitratoborate(-1).

Donor atoms of a ligand may be denoted by adding only the italicised symbol(s) for the donor atom(s) as proposed by some authors (Gispert, 2008; Petrucci, Harwood, Herring, & Madura, 2007; Demitras, Russ, Salmon, Weber, & Weiss, 1972; Atkins, 1989).

Examples could be thiocynato-*S* or nitrito-*N* etc.

When the coordination sphere contains an anion, the name of the central metal ends in –ate and Latin stem names of the metal are used. An example is *potassium hexacyanidoferrate(II).*
(Gispert, 2008; Petrucci, Harwood, Herring, & Madura, 2007; Demitras, Russ, Salmon, Weber, & Weiss, 1972; Atkins, 1989).

Identification of geometrical structures for these complex compounds requires the knowledge of standard rules. For example, in metal-ligand complexes where a central metal is bonded to two, three, four, five or six ligands the geometries of the resulting structures are portrayed below.

Metal-Ligand geometries:

- Two ligand groups: linear
- Three ligand groups: trigonal-planar
- Four ligand groups: tetrahedral or square planar
- Five ligand groups: trigonal-bipyramidal or square based pyramid
- Six ligand groups: octahedral or square-bipyramidal

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These propositions on how to identify and name shapes of metal-ligand were adopted from Petrucci, Harwood, Herring, and Madura, (2007).

A scientific conceptual example of a typical complex is presented below based on the extracted rule above:

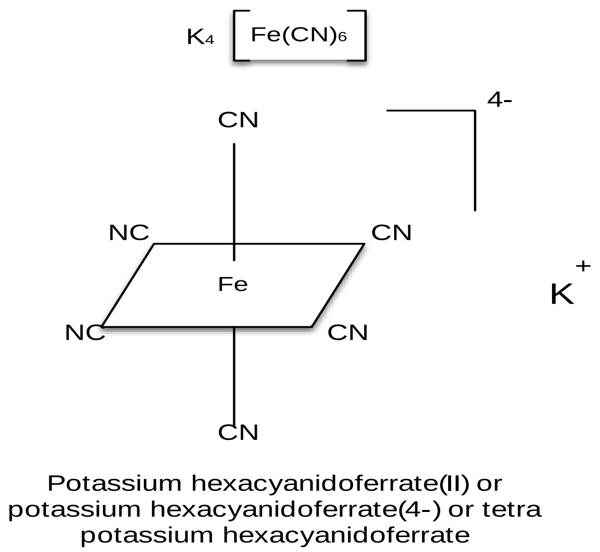

Figure 2: An octahedral structure of a typical complex

How students interpret scientists' views of complex compounds as discussed above will now be presented. This comparative analysis will lead to the emergence of congruence to facilitate the creation of a favourable environment to enhance concept formation and understanding of the said topic among learners.

Students` conceptions

Human beings express their conceptions through various symbols of speech and/or drawings. Therefore, students` expressions about acquired concepts in terms of statements/drawings are regarded as representations of their innate ideas (Niebert & Gropengiesser, 2013). In this study, participants were expected to translate their conceptions about coordination chemistry in symbolic form. This exercise was especially useful in assessing their understanding of nomenclature and geometry of given complexes. The drawings produced by students allowed the researchers to better conceptualize how some students interpreted the names and shapes of a few complex compounds. Examples of students' exercises on drawings of the geometry of octahedral structures are presented in Figures 3 and 4.

In the exercise, students' ideas about nomenclature and geometry were probed by presenting to them two concise problems to discuss. They were expected to write the name and draw the structure of the compound. However, as shown in Figure 3, a participant correctly found the oxidation number (Roman numeral) of the metal but wrongly wrote and drew the geometry.

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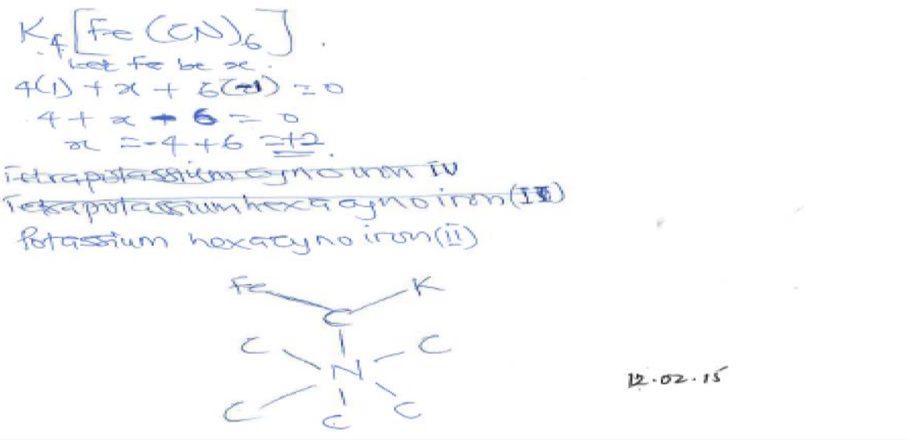


Figure 3: A student`s expression of the name and geometrical structure of a metal complex.

A second exercise required students to give the name and geometry of a given complex, hexanitrito-*N*-cobaltate(III) ion. A student`s interpretation of the exercise is displayed as Figure 4.

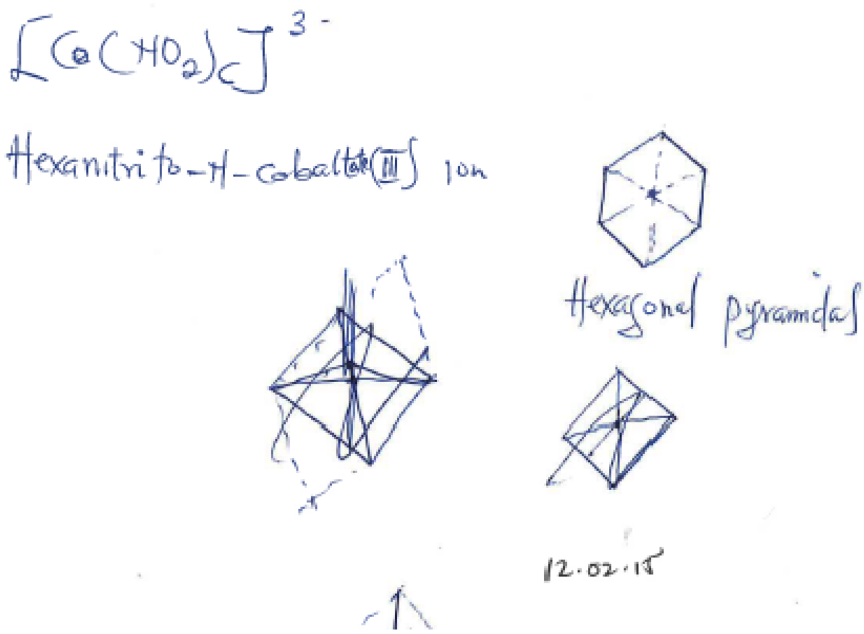


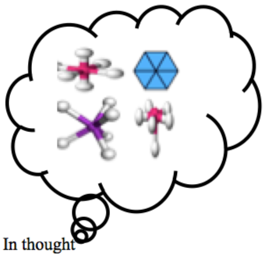
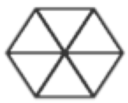
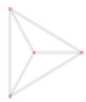
Figure 4: A student's geometry of the hexaxnitrito-N-cobaltate (III) ion complex

We see from Figure 4, that the student did write the name correctly but was unable to draw the corresponding geometry rightly. The student drew a hexagon and represented it as `hexagonal pyramidal`. Both the scientists' and students' ideas on the assigned exercise have been presented in a tabular form (Table 1) for easy analysis and interpretation.

Scientists` and Students` conceptual balances

An expression of scientists' ideas of the metal complex ($[Co(NO_2)_6]^{3-}$) as compared to that of students`, are interpreted and presented below.

Table 1: Table of Scientists` and Students' conceptual balances

CONCEPTIONS:	SCIENTISTS` CONCEPTIONS	STRUCTURED SEQUENCE Example: $[Co(NO_2)_6]^{3-}$	STUDENTS` CONCEPTIONS
CONCEPT	Octahedral: molecular geometry	Pure concept of Understanding	Hexagons, pyramids, squares, triangles.
SCHEME	`Rule of synthesis of the imagination, in respect of the pure figure in space`		The figure of possible experience
IMAGE	 In thought	No image for the thought of an object in general, but for particular object	 In thought
OBJECT PERCEIVED	 (Drawn Object) normal octahedral or square bipyramid	Any object as such (Object in general)	 (Drawn object) Hexagonal Pyramidal,  Triangular pyramid
PROJECTIONS (FACE (F), EDGES (E), VERTICES (V) n-GONS (N)	F=8, E=12, V=6 N=6		F=6 E=12, V= 7 N=6; F=4 E=6, V=4 N=3

In Figure 3, the student representation of the chemical formula showed a disregard for the IUPAC rules. As the conventional name for the complex is either Potassium hexacyanidoferrate(II) or Potassium hexacyanidoferrate(4-) or tetrapotassiumcyanidoferrate, the student gave the name as Potassium hexacynoiron(II). There are discrepancies in the ligand name and the Latin stem of the complex as stated by the student. That is, `cyno` instead of `cyanido` and iron for `ferrate`. The geometry stated by the student in Figure 3 does not portray an octahedral but 'seeming' bond lines of connecting atoms. According to Petrucci, Harwood, Herring, and Madura, (2007), metals surrounded by six ligands have octahedral or bipyramidal geometries. However, the geometry stated by the student in Figure 4 as hexagonal pyramidal gives the impression about the student`s difficulty in understanding higher figures such as octahedral and bipyramidal structures or geometries.

The process of understanding higher figures such as the octahedral and pyramidal figures is a learning difficulty, which involves mental transformation between two-dimensional (2-D) and three-dimensional (3-D) representations. Many students are not able to form 3-D mental images by viewing 2-D chemical structures and proceed to mentally rotate these 3-D images in their minds (Copolo & Hounshell, 1995). In order to successfully create a 3-D image by viewing a 2-D diagram, students are required to decode the visual information provided by

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depth cues used in the diagram (Shubber, 1990). These depth cues include the foreshortening of lines, relate sizes of different parts of the structure, representations of angles, and the extent to which different parts of the diagram overlap. Tuckey, Selvearatnam and Bradley, (1991) also found that some students cannot correctly identify depth cues, and even if they could, they may not be able to mentally track how depth cues change as a result of rotation. This makes mentally rotating chemical structures, as is required in coordination chemistry, difficult for students.

Koffka, (1935) stated that *`The whole is other than the sum of the parts`*. This he explained as an object having a shape, which could be different from the pieces (parts) it is made up of. He termed this phenomenon as 'Gestalt'. The 'Gestalt Effect' which is the capability of our brain to generate whole forms, particularly with respect to the visual recognition of global figures instead of just a collection of simpler and unrelated elements (points, lines, curves, hexagons), has been a scientific way of perceiving figures. This allows a breakup of the elements from the 'whole' situation into what it really is. From this study, students` conceptions were based on simple lines, points and figures as illustrated in Table 1.

In comparing the perception of experts (scientists) and novices (students) on a variety of chemical representations Kozma and Russel, (1997) reiterated that novices use only one form of representation and could rarely transform to other forms, whereas the experts transformed easily. Novices relied on the surface features, such as lines, numbers and colour, to classify representations, whereas experts used an underlying and meaningful basis for their categorization.

However from the embodied cognition framework (Johnson, 1987), this research considered these two facts:

- Symbol manipulation on its own cannot produce understanding.
- Symbols acquire their meaning only through embodiment.

Based upon this fact, this research seeks to reiterate embodied meaning as `grounded` symbols in argument. That is, some students` conceptions portray and point to the reason of bodily interactions with the environment (de Vega, Glenberg, & Graesser, 2008). It is not surprising that students express their thought with simple figures such as triangles, squares and lines, which are commonly experienced at the basic and high schools in Ghana. Olson, (1985) suggested that the act of composing writing/drawing involves all of the cognitive skills in Bloom`s taxonomy. Drawings, however, go beyond recall of information (a low order thinking skill) and enhance the development of students' higher order skills. Once a drawing assignment is posed, it requires students to clarify meaning, justify their ideas, clarify inconsistent perspectives and summarize progress toward solving the problem that together, provide higher-order level thinking. This implies that coordination chemistry content has to be well connected in order to give the students a broader basis for conceptual change through compositions and diagrammatic expressions.

Interventional Strategies adopted to improve Teaching

This research has identified two (2) key interventions which when adopted would improve the teaching of coordination chemistry and related content in higher education. The Researchers' assumptions have been based on their interpretation of students' work on IUPC naming and drawing of complex compound. The interventions which would be adopted to enhance the teaching of coordination chemistry would be modelling and modelling skills (MMS) and science heuristic writing (SHW).

Modelling and modelling skills (MMS)

According to Chittleborough and Treagust (2007), modelling ability is not necessarily innate, but a skill to be learnt. Students' modelling abilities with chemical representations must improve with instruction and practice. Generally, as modelling skills improve, so do students' understanding of the relevant chemical concept. A minimum level of modelling ability or representational competence is required to use these symbols to learn and understand chemistry (Kozma & Russel, 1997). The use of models and modeling in the new coordination chemistry teaching guidelines during the first two weeks of a semester would as a common practice engage students to develop their own mental models in representing correctly complex structures such as trigonal-bipyramidal and octahedral geometries.

Chittleborough and Treagust (2007) in their article concluded that students` abilities to use and interpret chemical models do influence their abilities to understand chemical concepts. These modelling skills should be deliberately taught, rather than be an incidental consequence of the teaching of chemical concepts. Learners` acquisition of skills should be incorporated in instruction, and students given practice in the application of multiple representations of chemical compounds and their interactions.

Science Heuristic Writing (SHW)

The SHW is a tool to help students learn how to think conceptually and not only to memorize. The ability of proposing geometrical structures or modelling chemical geometries into an existing mental scaffold through recognition plays a central role in chemical thinking. Therefore, a simplified concept like geometrical structures of heuristic writing might offer an intuitively useable system that is individually extendable beyond existing simple figures (lines, curves etc.) and enable students to connect to their prior knowledge.

Structural drawings in chemistry are important and necessary in understanding molecular geometries as asserted by Graulich, Hopf, and Schreiner (2010). The SHW encourages students to make pictorial representations of their ideas on paper/computer, analyze and access them effectively. Example of writing a metal complex is displayed stepwise in figure 5 below.

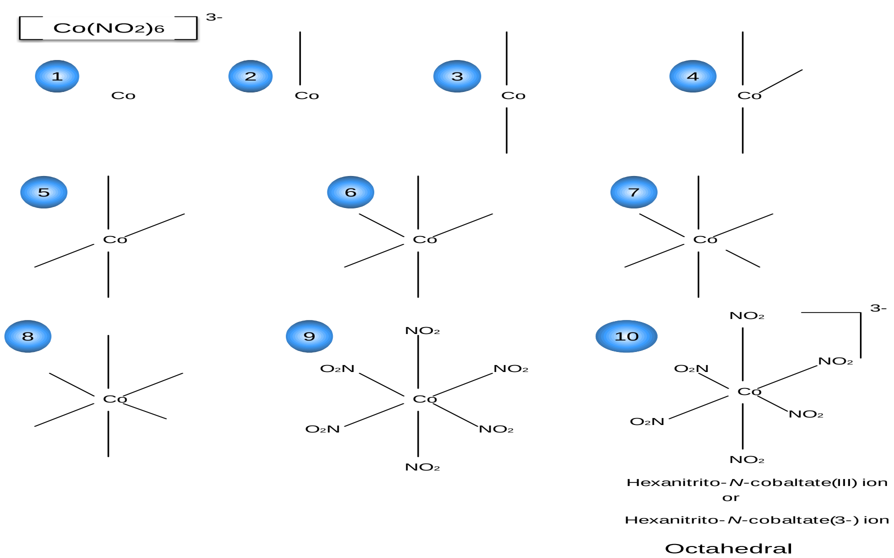

Figure 5: Scientific Heuristic Writing of a metal complex as portrayed in figure 4.

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With this idea in mind, using heuristic chemistry would not only be a good strategy for understanding chemical behaviour; but would also provide students the ability to explore and teachers to teach nomenclature and geometrical structures as purported by IUPAC.

CONCLUSION

The study explored the MER as a design to support teaching in higher education through scientists-students correspondences, using coordination chemistry. A comparative analysis of students' exercises in coordination chemistry, vis-a-vis that accepted by the scientific world showed many discrepancies. Students were found to be reasoning on the basis of lines and simple figures in drawing chemical structures such as $[Co(NO_2)_6]^{3-}$. Their reasoning abilities were found to be illogical and based on naïve conceptions and interpretations. Thus the use of MMS and SWH has been suggested as interventional strategies to remediate the situation observed in a Ghanaian university. These aforementioned interventions to support conceptual change would be implemented in a follow up study to assess how they will influence students' conceptual understanding about coordination chemistry. It is hoped that they will affect the students positively so that their interpretations of the geometry and names of complex compounds would improve.

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