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THE INTERTEXTUALITY STUDY OF THE CONCEPTION, THRESHOLD CONCEPT, AND TROUBLESOME KNOWLEDGE ON REDOX REACTION

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Abstract

This case study has been employed to gather the intertextual linkage among conception, threshold concept, and troublesome knowledge in redox reaction. 21 respondents involved in this study were students from Grade X, XI, and XII. This study consists of four stages including case identification, data collection, holistic and embedded data analysis, and a report of meaning derived from the case. Through a Mental Model Diagnostic Test with Interview About Event (MMDT-IAE) instrument this study found 11 conceptions, 5 misconceptions, 4 threshold concepts, and 3 troublesome knowledge. In the context of redox reaction phenomena, the data shows intertextual linkage between conceptions, misconceptions, threshold concept and troublesome knowledge. According to the data, these four aspects may influence each other. Students are able to comprehensively explain redox reaction if they understand about elements/compounds nomenclature, are able to write chemical reactions, and are able to determine the main species of the element or compound involved in the reactions. Concepts about main species of elements/compound also have potentials to be a troublesome knowledge which need to overcome in order to reduce the complexity of determination of species in element and compound, interactions among the species and also the ability of each particles in releasing or attracting electrons.

Keywords: Conceptions, Intertextuality, Misconceptions, Redox reaction, Threshold concept, Troublesome knowledge.

1. Introduction

Students' comprehension of chemistry concepts can be represented by their ability to demonstrate a linkage among three level representation namely macroscopic, sub-microscopic and symbolic. These three level representations play an essential role during chemistry learning process which assist student to obtain meaningful learning and retain their conceptual understanding [1]. Students' ability to make an interrelationship is able to represent their mental model [2]. Therefore, teacher should prepare their teaching activities considerably by develop teaching and learning strategy, learning material, learning media, and rearrange the curriculum structure which is suitable to assist students in developing their intact mental model which could hinder the mismatch during learning process [3-6].

The process of teaching and learning strategy development begins with intertextual study related to the core concept including troublesome knowledge, threshold concept and students' conception. Troublesome knowledge is a concept which is hard and has potential to be an obstacle for the students when they are learning a certain concept [7], meanwhile threshold concept is a cognitive gate towards a new thinking way to achieve new domain which cannot be accessed previously. In general, the comprehension of a threshold concept is expected to involve a major transformation in the manner in which someone understands or interprets relevant systems and phenomena in a discipline [8].

Many research studies have been conducted to reveal students' conceptions regarding redox reactions. These studies have shown that many students have difficulties in constructing their understanding about redox reaction concepts which lead them to have misconceptions. This fact is due to the fact that redox reaction concepts are constructed by various abstract concepts which need a deep understanding in submicroscopic level. One of the studies conducted by Chiang [9] found that Grade 12 students have a better performance in explaining a dynamic process of redox reaction according to the release and bound of electron principle.

However, the number of studies related to threshold concepts and troublesome knowledge in chemistry education are still limited. Wiji and Mulyani [2] stated that there were 3 threshold concepts found in thermochemistry including the standard state, state function, and the extensive properties of enthalpy change. Park [10] found eight concepts identified as threshold concepts in science, namely the concept of mole, ideal gas law, periodic table, atomic structure, electron configuration, orbital, chemical bonding, and chemical equilibrium. Atomic structure is also a threshold concept in studying the atomic theory of quantum mechanics, spectroscopy, and bond theory [6]. In biochemistry, there are five threshold concepts consisting of steady state, biochemical pathway dynamic and regulation, the physical basis of interactions, thermodynamics of macromolecular structure formation, and free energy [11].

In linguistic studies, conception, threshold concept and troublesome knowledge of a certain concept can be viewed as texts. Intertextual correlation among these texts can result a more meaningful idea of a certain concept. For example, when a student did not understand a concept which act as a threshold concept, big possibility that student will experience misconception. In addition, if that student also did not understand a concept which act as troublesome knowledge. In this situation, the threshold concept can also play as troublesome knowledge [7].

Mental model diagnostic test has potentials to identify students' conception, threshold concept and troublesome knowledge. The types of diagnostic test which often used to reveal students' mental model are interview about event, predict-observe-explain, open ended question, two-tier, and semi-structured interview [12-20]. Among those type of diagnostic tests, the best technique is interview about event because it can investigate students' conceptual understanding in a greatest detail [21]. Besides, this technique also gives the students opportunity to evaluate the condition of a certain phenomenon/event given during the interview.

According to the abovementioned explanation, the general research problem is "how are the intertextual study among conceptions, threshold concept, troublesome knowledge about redox reaction using an interview about event model mental diagnostic test? This problem can be stated in the following research questions:

- How is the profile of students' mental model in the concept of redox reaction based on an interview about event model mental diagnostic test?
- What is students' conception, threshold concepts, and troublesome knowledge in redox reaction concept?
- How are intertextual relationship among conception, threshold concept, and troublesome knowledge in redox reaction?

2. Research Method

This study employs a qualitative research with case study method which consists of 4 stages: case identification, data collection, holistic or embedded data analysis, and reporting the meaning. This study examines students' difficulties in building understanding about redox reaction concept in terms of students' conception, threshold concepts, and troublesome knowledge. Mental Model Diagnostic Test with Interview About Event (MMDT-IAE) was administered to obtain intertextual correlation among those three aspects. The participants consist of 21 students from Bandung Indonesia which come from three different levels as shown in Table 1. All of the participants have an experience in learning redox reaction when they were in grade X.

Table 1. Distribution of students' education level.

Grade	Students' Code
X	S1, S2, S3, S4, S5, S6, S7
XI	S8, S9, S10, S11, S12, S13, S14
XII	S15, S16, S17, S18, S19, S20, S21

The MMDT-IAE was developed through several stages beginning with multiple representation analysis stage about redox reaction topic in General Chemistry handbook followed by analysis of basic competence from national Curriculum. Beside document analysis, this first stage also involved interview with teachers in order to gather information about they experience in teaching redox reaction and how did they find students' difficulties in learning redox reaction. These information become fundamental base to develop some indicators as a framework in developing interview question items. The items were validated by 8 chemistry and chemistry education experts followed by a trial stage. All validators stated that the instrument was valid with some minor revisions needed. The trial result also shows that the instrument is understandable.

The final version of Redox Reaction MMDT-IAE instrument represents two indicators such as students are able to demonstrate their understanding about redox reaction according to electron transfer principle and the change of oxidation number. The instrument consists of three types of questions: main questions, general questions, and probing questions. The overall stages of the instrument presented in Fig. 1. Redox reaction MMDT-IAE also consists of a number of questions which can reveal students' threshold concepts and also troublesome knowledge in redox reaction.

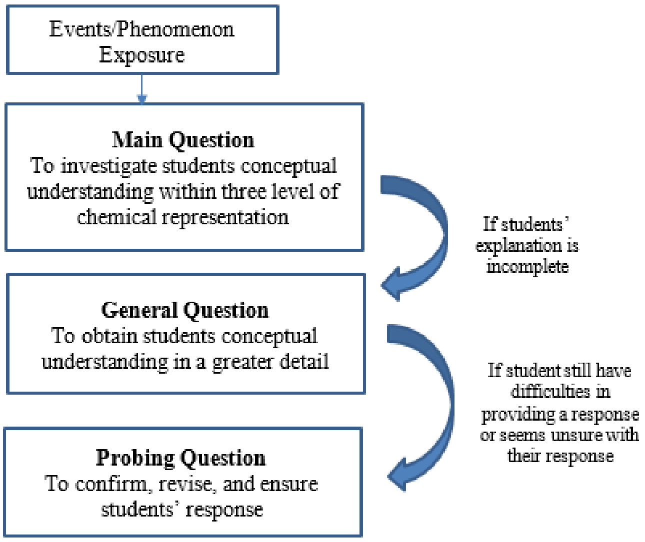

Fig. 1. The stages of MMDT-IAE instrument.

Data analysis was administered through four steps such as: transcribing, interpreting, depicting of students' mental model and investigating students' conceptions, threshold concept and troublesome knowledge. Students' mental models were categorized into four types as presented in Table 2. Threshold concept was determined by comparing the coherence between students' mental model type and their response to the questions for threshold concept while troublesome knowledge was determined by conducting an in-depth interview to the students whose mental model was categorized as an incomplete mental model.

Table 2. Types of students' mental model.

Type	Students' response criteria
Complete mental model	a. Students' explanation as a response to main question consists of three level representations b. Students' explanation covers three level of representation after guided by general questions and/or probing questions.
Partial mental model	Students' response has provided a correct concept but contain irrelevant explanation.
Mental model with misconception	Students' response provided conceptual explanations but still consists of consistent and repeatedly incorrect explanation.
Inconsistent mental model	Students did not respond or provided irrelevant and inconsistent response.

3. Result and Discussions

3.1. The profile of students' mental model in redox reaction

The result of MMDT-IAE shows that all students participants are able to mention correct reactants and products of each reactions as well as writing a chemical equation between magnesium and hydrochloric acid and also methane combustion. However, not all students are able to determine species which involved in a reaction and show the process of redox reaction using a change of oxidation number and electron transfer principle. Table 3 shows the distribution of students' mental model. According to Table 3, no students is able to provide an explanation as a response to main question which already consists of three level representations. Students need further guidance from general question or even probing questions to be able to provide a comprehensive explanation. This is in line with the results of Tsaparlis [22] review of Research on Student Misconceptions in Electrochemistry showing that numerous conceptual difficulties and misconceptions have been reported in the science and chemistry education literature about electrochemistry concepts such as redox equations.

Table 3. Type of student's mental model in redox reaction.

Type	Students' response criteria	Phenomenon: Mg(s) + HCl(aq)	Phenomenon: CH_4(g) + O_2(g)
Complete mental model	Students' explanation as a response to main question consists of three level representations	-	-
	Students explain redox reaction using the change of oxidation number and transfer electron principle and already consists of three level of representation after guided by general questions and/or probing questions.	S1, S2, S3, S4, S6, S7, S10, S12, S16	S1, S4, S7, S8, S9, S10, S11, S12, S15, S16, S17, S19
Partial mental model	Students explain redox reaction using the change of oxidation number and transfer electron principle and already consists of three level of representation but also consists of incorrect way in determining oxidation number of each species involved in the reaction.	S9, S13, S14, S15, S19, S21	S5, S6, S13, S21
Mental model with misconception	Students' response provided conceptual explanations but still consists of consistent and repeatedly incorrect		

Type	Students' response criteria	Phenomenon Mg(s) + HCl(aq)	CH4(g) + O2(g)
		Mg(s) + HCl(aq)	**CH_4(g) + O_2(g)**
	explanation. The variation of this mental model types is as follow:		
	The main components in HCl solutions are H_2 and Cl_2 ions.	S8, S11	-
	Chemical formula of magnesium chloride is MgCl	S17, S19, S21	-
	The main components in water are H^+ ions and O_2	-	S20, S14
	The main components in $MgCl_2$ solution are $MgCl_2$ molecule	-	S14
	The main components in CH_4 gas are ion C^{2+} and H_2	-	S5, S14
	Students were unable to show a redox reaction rate process	S5, S17, S20	S2, S3, S18
Inconsistent mental model	Students stated that redox reaction is a reaction which produce gas bubble.	S18	-

Six students out of 21 participants were able to present and develop a linkage among redox reaction concepts within 3 level of representation based on the reaction between magnesium and hydrochloride as well as methane combustion. The researchers indicated that for the construction of mental models especially on the submicroscopic level concepts, students' understanding of macroscopic and symbolic representations was very important because when the reality and the representations are misunderstood, they limit students' development of knowledge organization [18]. While according to Barke [23], in interpretations of chemical phenomena, students like to mix the macro level of substances with the sub-micro level of atoms, ions and molecules. For redox reactions students are doing this too: "one Cu2+ ion takes two electrons and is reduced to copper" - instead of "to one Cu atom"! Another difficulty seems to be the historical redox definition with the "oxygen transfer": this idea is so attractive that students argue mostly with oxygen participation instead of the transfer of electrons.

In addition, the finding also shows that there were 9 students who have complete mental model but only in one phenomenon. Most of the students found it easier to comprehend redox reaction concepts in a methane combustion phenomenon rather than magnesium reaction with hydrochloric acid. Students were able to examine the experiment provided, to predict the result of the reaction, to write a chemical equation, to determine each species involved in the reactions, to determine oxidation number, as well as to describe a change of oxidation number and electron transfer during the process of redox reaction. Figure 2 shows students' responses with complete mental model.

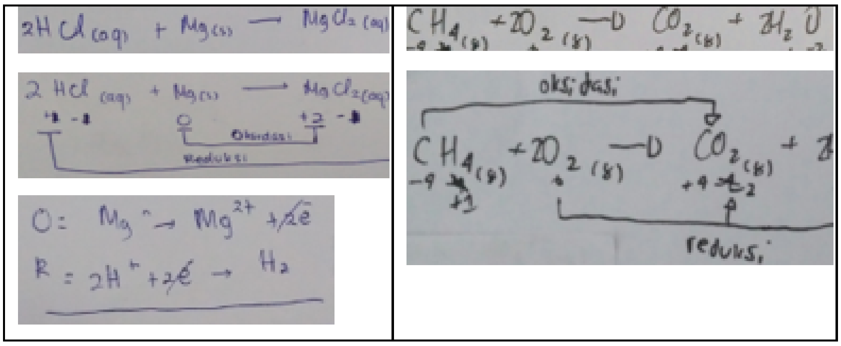

Fig. 2. Examples of students' responses with complete mental model.

Students with partial mental model are present in all Grade, 2 students from Grade X and each 3 students from Grande XI and XII. These students are able to explain redox reaction using a change of oxidation number principle as well as using electron transfer principle involving three level representations, but their often show some mistakes in determining the oxidation number of the species involved in the reaction. For example, students mentioned that oxidation number of Cl in $MgCl_2$ is -2, or oxidation number for C in CO_2 is +2, or oxidation number for O in H_2O is -1, oxidation number for O in H_2O is -4, and oxidation number for O in O_2 is -2. Figure 3 shows examples of students' false response in determining oxidation number. Brandriet and Bretz [24] also mentioned that several student misconceptions in oxidation reduction reactions and electrochemistry have been identified in the literature, including the notions that oxidation states can be assigned for molecules and polyatomic ions. Students not only incorrectly applied oxidation numbers, but they also failed to differentiate them from charges. Meanwhile, Cole et al. [25] stated that based on comments from student interviews, it appears that several students did not know the proper charges of the silver, copper (II), and nitrate ions in the oxidation reduction reaction between silver nitrate and copper metal.

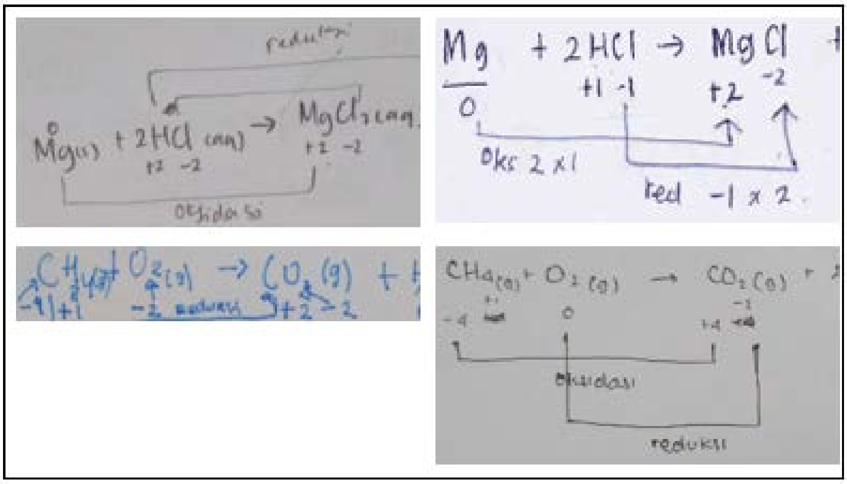

Fig. 3. Examples of students' responses with partial mental model.

Students' mental models with misconception were found in 8 students from three different Grades. 1 student from Grade X, 3 students from Grade XI and 4 students from Grade XII. Most of the students have misconception in determining main species of the element or compound involved in a reaction as well as in writing a chemical formula of a compound. Specifically, the misconception found related to the conception that main species in HCl are H_2 and Cl_2; chemical formula of magnesium chloride is MgCl; main species of water are H^+ ion and O_2; main species of $MgCl_2$ solution is $MgCl_2$ molecule; and main species of CH_4 gas is C^{2+} ion and H_2. In terms of the species involved in the reaction, Brandriet and Bretz [24] also found that only 31-33% of students answered correctly regarding the species involved in the oxidation reduction reaction between ferrous metal and a solution of cadmium sulfate. These results suggest that the students were better able to identify where the electrons transferred but struggled to describe the particulate process underlying the symbolic equation.

The result of this study also shows that there were 7 students with inconsistent mental model. Most of them cannot provide explanation of a given phenomenon. One student was unable to explain a reaction between magnesium and hydrochloric acid and methane combustion. Another student mentioned that redox reaction is a reaction releases gas. Some of this difficulty can be attributed to the triad nature of chemistry the interconnection between the macroscopic, particulate, and symbolic conceptual levels of the subject and the need for students to not only work proficiently at all three levels, but to also see and make connections among these levels [26]. Figure 4 shows students' responses with inconsistent mental model.

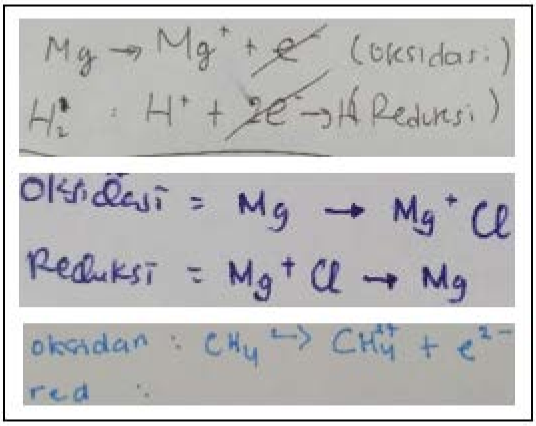

Fig. 4. Examples of students' responses with inconsistent mental model.

3.2. Conception, threshold concept, and troublesome knowledge

Further analysis of mental model leads to the identification of the quality of students' conception. Students may have a correct conception which suitable with scientist views or incorrect conception which unsuitable with scientific convention which is known as misconception. Students' misconception also can be identified if the incorrect explanations were consistently repeated by the students. When the oxidation reduction reaction is related to the structure and Behavior of the microscopic particles, the high school students' conception will be foggier. This is largely contributed by the lack of emphasis from the teachers' part on the correlation between oxidation reduction reaction and the said elements [14].

According to the profile of students' mental model in redox reaction of the reaction between magnesium and hydrochloric acid and also methane combustion, various type of students' conceptions had been identified. The correct conceptions found in Table 4 and misconception in Table 5.

Table 4. The conception on the redox reaction.

Conception	Description
Conception 1	The reaction of magnesium metal with hydrochloric acid solution produces a solution of magnesium chloride and hydrogen gas
Conception 2	The reaction of burning methane gas with oxygen gas produces carbon dioxide gas and water vapor
Conception 3	Magnesium has the chemical symbol Mg, while hydrochloric acid has the chemical formula HCl, magnesium chloride $MgCl_2$ and hydrogen gas H_2
Conception 4	Methane gas has the chemical formula CH_4, oxygen gas O_2, carbon dioxide gas CO_2 and water vapor H_2O
Conception 5	The chemical equation for the reaction of magnesium metal with hydrochloric acid solution is $Mg(s) + HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$
Conception 6	The chemical equation for the reaction of burning methane gas with oxygen gas is $CH_4(g) + O_2(g) \rightarrow CO_2(g) + H2O(g)$
Conception 7	The main species in a solution of HCl are H^+ and Cl^- ions; Mg metal is an Mg atom; $MgCl_2$ solution is Mg^{2+} and Cl^- ions; H_2 gas is a H_2 molecule
Conception 8	The main species in CH_4, CO_2 and H_2O gases are compound molecules, while in O_2 gas are elemental molecules
Conception 9	The reaction of magnesium metal with hydrochloric acid solution is a redox reaction because Mg species (oxidation number 0) has an increase in oxidation number to +2 in Mg^{2+} species, while H^+ species (oxidation number +1) has decreased its oxidation number to 0 in H_2 species.
Conception 10	The reaction of burning methane gas with oxygen gas is a redox reaction because the element C in CH_4 has an increase in its oxidation number from -4 to +4 in CO_2 compounds, while element O in O_2 has a decrease in oxidation numbers from 0 to -2 in CO_2 and H_2O compounds
Conception 11	The reaction of magnesium metal with hydrochloric acid solution is a redox reaction because Mg species changes to Mg^{2+} species by releasing 2 electrons, which are used by H^+ species to change into H_2 species

Table 5. The misconception on the redox reaction.

Misconception	Description
Misconception 1	The chemical formula for magnesium chloride is MgCl
Misconception 2	The main species in HCl solutions are H_2 and Cl_2 ions
Misconception 3	The main species in water are the H^+ and O_2 ions
Misconception 4	The main species in $MgCl_2$ solution is the $MgCl_2$ molecule
Misconception 5	The main species in CH_4 gas are C^{2+} and H_2 ions

Further analysis of these variety of students' conceptions were administered to obtain information about threshold concepts. The analysis for threshold concepts was supported by interview data with chemistry teachers and lecturers to get a depiction about concepts which become threshold concepts for redox reaction based on their teaching experience. The interview data informed that concepts assumed to be threshold concepts are nomenclature, chemical symbol or chemical formula, particle which composes matter, and electronegativity. These concepts were then confirmed to the students' perceptions and compare with their response to the questions in MMDT-IAE instrument. If students' perceptions are coherence with students' responses, then the concept is determined as a threshold concept.

The result of threshold concept analysis found that nomenclature, chemical symbol or chemical formula, particle which composes matter, and electronegativity are threshold concepts for redox reaction. Nomenclature become threshold concept because students have to be able to give an appropriate name to every species involved in a chemical reaction. The ability to determine correct name will lead the students to write chemical formula appropriately which assist them to determine the main species of a compound or elements involved in a reaction. This comprehension about determining the main species of a compound and writing the formula correctly will influence students' ability to determine oxidation number of an element or compound and also determine the species which release or accept electrons. Meanwhile, students' understanding about electronegativity is useful in deciding which element should has more priority in determining its oxidation number in its compound. Therefore, nomenclature, chemical symbol or chemical formula, particle which composes matter, and electronegativity are threshold concepts for redox reaction based on the change of oxidation number as well as electron transfer principles. Some threshold concepts need to be fully understood by students for the construction of correct mental models [6].

According to Perkins [27], troublesome knowledge consists of ritual knowledge, inert knowledge, conceptually difficult knowledge, alien knowledge, tacit knowledge, and troublesome language. Troublesome knowledge in redox reaction was determined by interview to the students whose mental model is categorized as partial mental model, mental model with conceptions or inconsistent mental model. Those students mentioned that their difficulties in learning redox reaction were resulted from the complexity of determining main species of an element or compound in their pure substance or in its solution. Besides, they also have difficulties in determining the result of the reaction.

This situation may lead students to further difficulties in determining the oxidation number of each species involved in the reaction. Thus, they also become unable to determine which species release and accept electrons in determining redox reaction based on electron transfer principle. In the phenomenon of reaction between magnesium and hydrochloric acid, the species involved in that reaction are abstract which cannot be seen by naked eyes, and this condition makes the student difficult in building their understanding about the reaction. This finding is in coherence with ritual knowledge as one of the types of troublesome knowledge which stated by Perkins [27]. Troublesome knowledge type ritual is the situation that students might be able to do the task with a superficial technique to get a result while actually they did not know the meaning of the complexity behind that task.

3.3. The intertextual linkage among conception, threshold concept, and troublesome knowledge

Students would be able to develop comprehensive understanding about redox reaction which covered three levels of representations if they were able to overcome the troublesome knowledge and pass through the existing threshold concept. If they were unable to do that they will be trapped in various kind of misconceptions. Students' comprehension about threshold concept will assist them to build conceptual understanding which they learn in a more effective way. Therefore, an incorrect understanding about threshold concept will lead to be a troublesome knowledge.

Intertextual linkage among conception, threshold concept and troublesome knowledge in redox reaction concept which represent by phenomenon of reaction between magnesium and hydrochloride acid and methane combustion presented in Fig. 5. Students are able to explain redox reaction in those two phenomena using a change of oxidation number as well as transfer electron principles if they were able to give a name to the compound, writing the chemical formula and chemical reaction and determining main species of the compound involved in the reaction (conception 9, 10, and 11). Therefore, chemical formula, nomenclature on chemicals, electronegativity, and elements/compound particles are the prerequisite concept to learn redox reaction. The concept about element/compound has potentials to be a troublesome knowledge since the process of determination of element and compounds, interactions between the existing species and species which release and attract electron involving complex thinking process. This is in line with Park and Light's [6] statement that the threshold concepts are related to the troublesome knowledge.

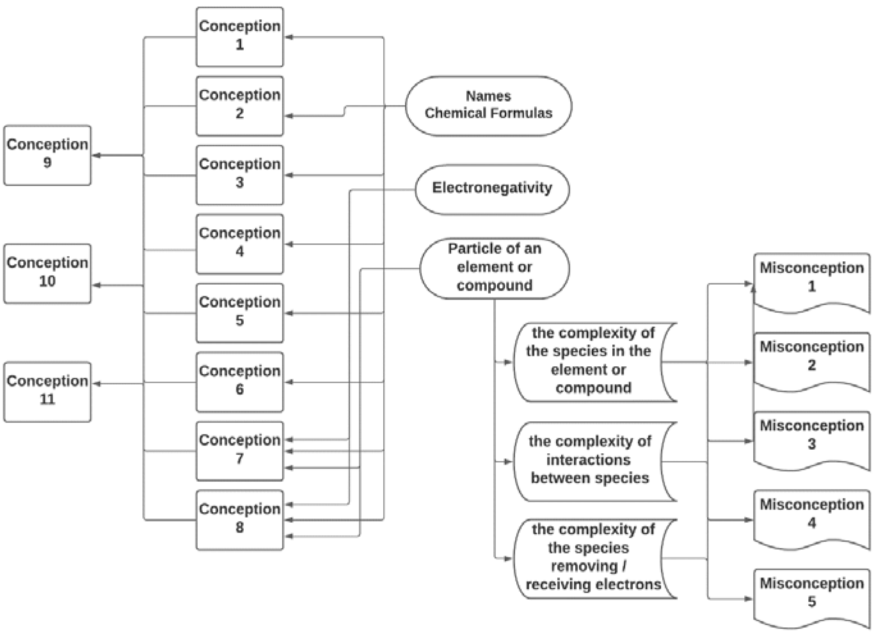

Fig. 5. The intertextual linkage among conception, threshold concept, and troublesome knowledge in redox reaction.

4. Conclusions

The mental models of students Grade X, XI, XII in redox reactions were distributed into 4 types, namely, complete mental model, partial mental model, mental model with misconception, and inconsistency mental model. Most of the students have complete mental model. They are able to explain redox reaction in macroscopic, submicroscopic, and symbolic level in a reaction of magnesium metal and hydrochloric acid and also the reaction of methane combustion. The result of mental model analysis shows that students pose correct conceptions, misconceptions, threshold concepts and troublesome knowledge. The intertextual linkage of those aspects represents that the aspects influence each other. The result also shows that students with complete mental model has proven that they have understand threshold concept and did not struggled with the troublesome knowledge and are able to construct the concept in a structured manner.

Although this study only involved 21 respondents, it was able to reveal the intertextual relationship between conception, threshold concept, and troublesome knowledge in redox reaction. This is valuable information for teachers in teaching the concept of redox reactions. Mastering threshold concepts in chemistry demands the construction of diverse cognitive elements, including implicit schemas that guide and constrain how students think about chemical substances and processes [8]. In this study, it was found that the constituent particles of an element or compound constitute a threshold concept that has the potential to produce troublesome knowledge, namely the complexity of existing species and their possible interactions. Research related to learning redox reactions by paying attention to troublesome knowledge and concept threshold needs to be done to maximize the conceptions formed in students and will reduce misconceptions that occur.

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