Didactic and epistemological study of the difficulties of studying redox concept in secondary education (Morocco)

Karima Mounchide [1], Oussama Azaroual [2], Mounia Cherki [1], Karima El Bouqdaoui [1*]

1: Laboratory of Health and Environment, Faculty of Sciences Ain Chock, Casablanca, Morocco
2: Laboratory of Theoretical Physics, Faculty of Sciences Dar El Mahraz, Fez, Morocco

*elbouqdaouik@gmail.com

ABSTRACT

The concept of redox presents difficulties in its teaching and learning. The purpose of this research is to make a double epistemological and didactic analysis of the achievements of two hundred and fifty Moroccan students of scientific sections on this concept and to locate the difficulties they encounter in this regard. The didactic analysis is based on the content set by the curriculum; and the epistemological analysis is carried out through a questionnaire on the knowledge, understanding and application of this concept during the school year 2019/2020.

The results showed that redox reactions are only taught in the 1st year of the baccalaureate, whereas in the 2nd year, students use the basic concepts of redox already seen. Most of the students questioned are unfamiliar with the concept of redox, the conceptual network associated with it and its application. Indeed, learning about redox centered on the electron transfer model does not allow the learners to make the link between electron transfer and the transfer of hydrogen and oxygen. Also, the percentages obtained show that the students are far from mastering all the basic notions related to this topic.

The main difficulty was related to conceptual difficulties. Students had great difficulty in differentiating between the terms oxidant and reductant, and reduction and oxidation, as well as in identifying the equations of redox reactions. This leads us to think about the use of mnemonic models suitable for these purposes, and especially to propose to the teachers a training based on new approaches (TPaCK) to improve and facilitate the learning of this kind of concept through the creation of adequate digital teaching resources.

Key words: redox, didactic, epistemological, questionnaire survey, model

INTRODUCTION

Redox reactions are a key concept in most secondary school chemistry and biochemistry curricula (Soudani et al., 2000); phenomena such as photosynthesis in plants, human respiration, combustion and corrosion of metals are examples of redox reactions (Bendall et al., 1995; Cournac et al., 2000; Bokma et al., 2008). These examples highlight the importance of learning about redox reactions in both their natural and technical applications. The concept of redox is widely covered in secondary and university education. A better understanding of this concept requires the knowledge of some basic concepts related to general chemistry: atom, electron, acid/base, chemical reactions (Amamm, 2018). On the other hand, redox reactions have also been identified as one of the most difficult concepts to learn and teach (Soudani & Cros, 1998; De Jong, & Treagust, 2002; Boulabiar-Kerkeni, 2004; Österlund et al., 2010; Chiang et al., 2014; Adu-Gyamfi et al., 2015; Nguessan, 2016; Österlund & Ekborg, 2009). This explains the numerous studies that have focused on the difficulties in the assimilation of the redox concept by secondary school students (Jong & Treagust, 2002; Udo, 2011; Chiang et al., 2014; Dewi et al., 2019; Osterland & Ekborg, 2019; Adu-Gyamfi et al., 2019). Some of these difficulties have been attributed to shortcomings in initial teacher education (Rollnick & Mavhunga, 2014). Shulman (1986) introduced the concept of pedagogical content knowledge (PCK) which is supposed to help reconstruct a body of theoretical knowledge and pedagogical practices to make the concept understandable for effective teaching (Shulman, 1987). PCK is part of the Technological Pedagogical Content Knowledge (TPACK) model which has been adopted in many teacher education and professional development to study and understand specific learning activities and environments (Mishra et al., 2002; Koehler & Mishra, 2005; Archambault & Crippen, 2009; Doering et al., 2009; Graham et al, 2009; Harris et al., 2009; Shin et al., 2009).

In order to identify the problems that arise in the learning of the redox concept among students, we carried out a double epistemological and didactical analysis. The didactic analysis was based on the content set by the Moroccan school curriculum, while the epistemological analysis, was based on a questionnaire that focuses on the knowledge, understanding and application of this concept during the academic year 2019/2020 with 250 students of the second year of the Moroccan baccalaureate (science section).

METHODOLOGY

The Moroccan school curriculum of physical sciences was analyzed in the broad lines based on the content and precisely on the topic of redox. In this study, we used the frameworks of reference of the college and secondary physical sciences proposed by the Ministry of National Education. 250 students in the second year of the Moroccan baccalaureate participated in this study, which was conducted in accordance with institutional research ethics. Anonymity and confidentiality were strictly maintained.

For this study we used an anonymous unrated questionnaire (see Appendix), consisting of:

- Closed-ended binary choice questions where there are two alternative answers of yes/no followed by a justification.
- Closed-ended multiple choice questions where the respondent must choose one or more answers. The questions were specific to the knowledge, understanding and application of redox concepts.

The statistical analysis is based on descriptive statistics (percentages, means) and the graphs were made using Microsoft Excel 2019.

RESULTS

The Moroccan School Curriculum

The curriculum analysis showed that physical and chemical sciences are introduced in college education from the first year, while the concepts and laws of chemical reactions are only introduced in the 2nd year of college. The basic concepts of atomistics are covered in the core curriculum and 1st year undergraduate. It is limited to presenting the Bohr model and the Lewis model. In the 1st year of the baccalaureate, redox reactions are only taught in experimental sciences for two 2-hour sessions and in mathematical sciences for 5 hours. In the second year, the students use the basic concepts of redox already seen in the first year for two 2-hour sessions.

Several objectives have been set by the curriculum which aim to have an idea of the students' ability to define the redox reaction, to know the notions of oxidant and reductant, to determine redox couples, to write and balance half-equations and balance equations and to calculate the oxidation number to identify a redox reaction.

Data Collection Knowledge

A part of the questionnaire was dedicated to the definitions that represent a fundamental aspect of the understanding of the redox concept. These questions concerning the notions of redox reaction, oxidant and reductant were asked separately. The results show that the percentage of correct answers is 55.20%, the percentage of incorrect answers is 38.2% and the questions without answers present a percentage of 6.6%. The percentages of the answers to the knowledge questions are presented in figure 1. These results show that 51.5% of the students defined the redox reaction as an electron exchange reaction and 31.8% students answered that it is an electron and proton exchange reaction. While, 89% of the students recognized the definition of oxidizer and only, 40.60% of these students managed to choose the proposal that defines the reductant.

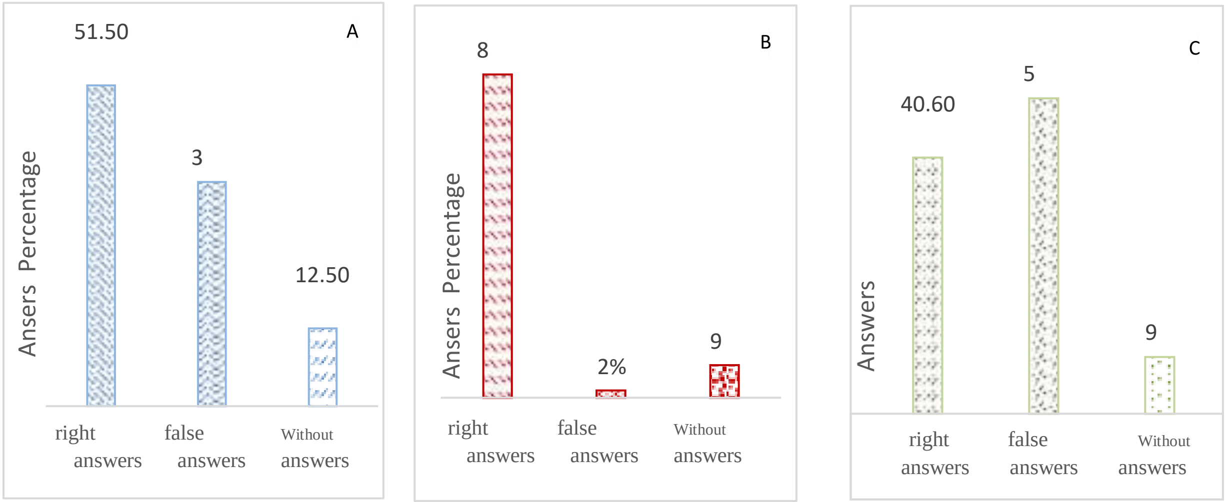


Figure 1: **Percentages of responses for definitions, (A) Redox, (B) Oxidant, (C).**

Understanding

The comprehension questions are based on the recognition of the oxidant and the reductant of a redox couple (Q4), the recognition of what is reduced (Q5a) and what is oxidized (Q5b) and the writing of the half equation (Q6). The results show that the percentage of correct answers is 46.8%, the percentage of incorrect answers is 37.5% and the percentage of unanswered questions is 15.65% (Figure 2).

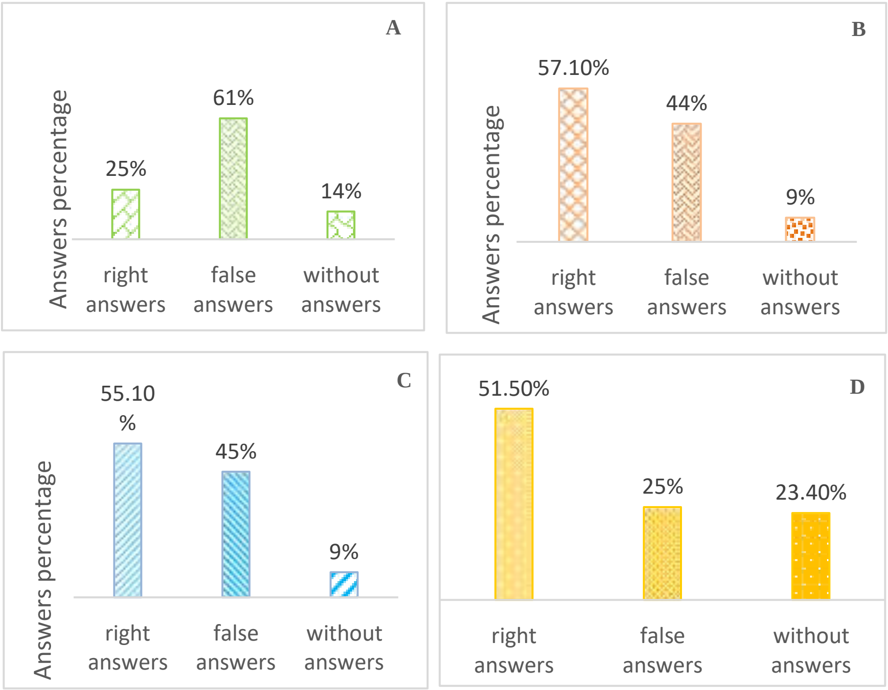


Figure 2: **Answers to the comprehension questions: (A) knowledge of the redox couple, (B) recognition of what is reduced, (C) recognition of what is oxidized, (D) writing the half-equation.**

The analysis of the results shows that 53% of the students answered simultaneously that the oxidant is reduced and the reductant is oxidized, whereas, 4% of the students answered that the oxidant is reduced and 2% the reductant is oxidized. However, 51.5% of the students were able to choose the correct half-equation of a redox couple and only 25% of the students identified the oxidant and the reductant of a redox couple.

These results indicate that 50% of the students have a poor understanding of the concept of redox.

Application

The equations used in the questionnaire were taken from the 1st year baccalaureate textbook. The results show that 21.4% of the answers are correct, 36.32% of the answers are incorrect and 42.18% are without answers.

- Identification of the redox reaction, the oxidizing agent and the reducing agent

Table 1 represents the answers concerning the identification of the redox reaction.

The results show that 80% of the students have difficulties in identifying a redox reaction among other proposed reactions. Indeed, equations 1 and 2 represent redox reactions for 33.5% of the students; they justified their choices by the presence of charges in the elements of the equation. Only 20% of the students chose equation 3 as a redox equation but without giving any justification.

Table 1: **Answer to the identification of the redox reaction.**

	Equations	Yes	No	Without
1	$Na^{2+} + OH^- + H_3O^+ + Cl^- \rightarrow Na^{2+} + Cl^- + 2H_2O$	16%	44%	40%
2	$NH_3 + H_2O \rightarrow NH^{4+} + OH^-$	17.50%	42.50%	40%
3	$O_2 + 2H_2 \rightarrow 2H_2O$	20%	40%	40%
4	$4Na + O_2 \rightarrow 2Na_2O$	2%	58%	40%

Additional redox equations were presented to the students to identify the oxidizing and reducing agent. The results are shown in Table 2. These results show that 74.17% of the students have difficulties in identifying the oxidizing agent and 90.6% are unable to identify the reducing agent.

Table 2: **Results of responses regarding the identification of the oxidizing and reducing agent**

Questions	**Correct answers**	**Wrong answers**	**No answers**
Questions 8, 9, 10 and 11 Identification of the oxidizing agent in the following reactions: Al_3^{2+} + Fe → Al + Fe^{3+} 2 Ag + (aq) + Zn(s) → 2 Ag(s) + Zn^{2+}(aq)	26.5% 25%	34.37 % 35%	39.80% 40%
Identification of the reducing agent in the following reactions: 2 Ag+ (aq) + Zn(s) → 2 Ag(s) + Zn^{2+}(aq) Zn(s) + Cu^{2+}(aq) → Zn^{2+} (aq) + Cu(s)	9.37% 8%	37.5% 30%	53.1% 62%

- Writing of half equation and redox reaction

Redox pairs were presented to the students to choose the writing of the half-equations and the redox reactions. The results are shown in Table 3.

Table 3: **Answers to writing half-equations and redox reactions**.

Questions	**Correct answers**	**Wrong answers**	**No answers**
Questions 12 and 13 Choice of the correct writing of half equations of the following redox couples: Al^{3+} (aq)/Al(s) H_2O_2(aq)/H_2O(l)	30,25% 30%	29,43% 29,4%	36,30% 40,60%
Questions 14 and 15 Choice of the right redox reaction writing between : I_2(aq)/I^-(aq) and Fe^{3+}(aq)/Fe^{2+}(aq) $Cr_2O_7^{2-}$(aq)/Cr_3^+(aq) and Fe^{3+}(aq)/Fe^{2+}(aq)	14,1% 17,18%	42,8% 29,68%	43,70% 53,10%

The analysis of the results shows that 30.25% of the students are able to recognize the half-equations of the proposed redox couples. Whereas, between 14.1% and 17.18% recognized the proposed redox reactions and only 21.4% answered the application questions.

The analysis of the percentages of unanswered questions shows an increase from knowledge to applications. This means that 42,18% of the learners are unable to mobilize their knowledge to solve problem situations already treated in class. These results report that the students have a weak understanding on the conceptualization of the notion of redox.

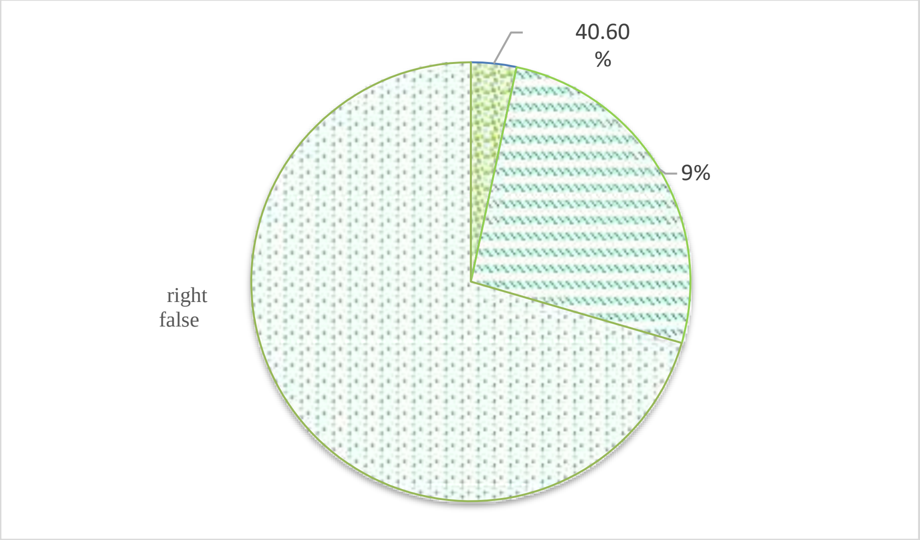


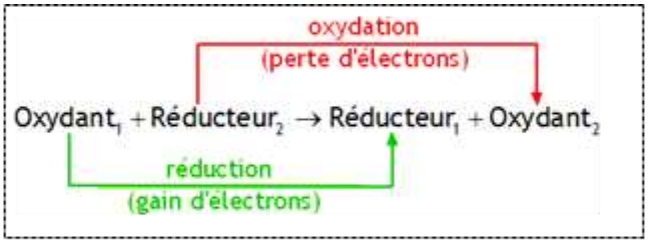
Figure 3: **Percentage of unanswered questions.**

Modeling Redox Phenomena

The model of the redox concept should provide elements for designing an alternative teaching approach that allows students to link the experimental with the symbolic.

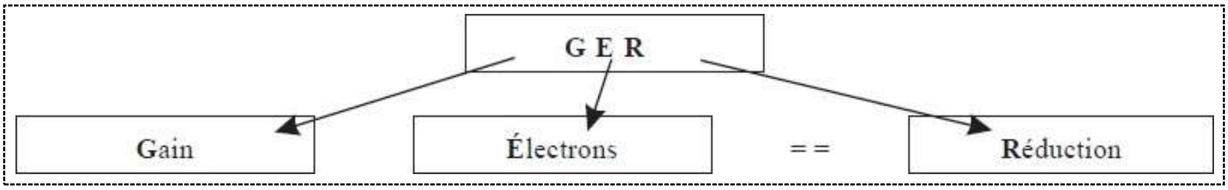
To motivate students and give meaning to the concepts covered, the use of everyday phenomena makes the learning situations meaningful. The first oxygen transfer model allows the direct identification of the nature of chemical reactions that exist in our closest environment (combustion reactions, respiration, photosynthesis, rust,...)((van Driel et al., 1998).

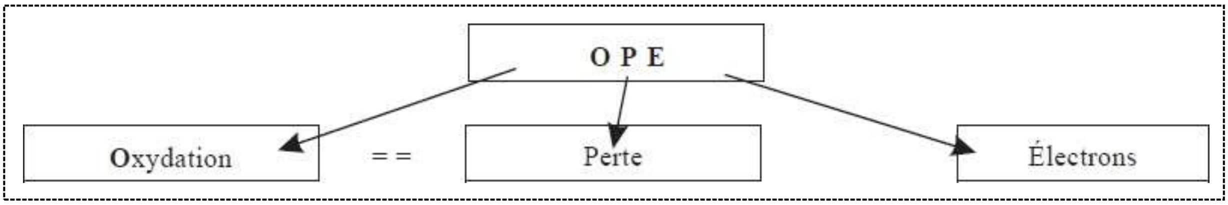
The teacher will then help them model redox phenomena in terms of electron transfer. The oxidation number model will be presented as a generalization of redox and will encompass the other models...



Mnemonic model

Mnemonics could help students to remember the definitions of redox in terms of electron transfer. We cite here only two examples:





The two terms attributed to the two notions oxidation and reduction mean respectively: the term "GER" represents the peak of Ger: a peak in the Pyrenees south of the Aubisque pass and of 2613 m of altitude, and the word "OPE" in architecture is the hole drilled in a wall to place a beam (van Driel et al., 1998).

This type of model must be adapted to the educational system in question because the small words used must have a meaning that is easy to remember. Its effectiveness does not guarantee a thorough understanding of the concepts targeted by all categories of learners.

Model for The Integration of ICT In Education: TPaCK

The current teaching/learning of redox is organized in such a way as to plunge the student directly into situations of abstraction. It would be much better to get students to model than to teach them "ready-made" models; thus allowing them to learn to reason and conceive.

A good teacher training should deal independently with : Disciplinary Content, Pedagogy and Technology. In Quebec, Mishra and Koehler (2006) have provided a conceptual model of teachers' knowledge of the integration of technology. This model, called TPaCK (Technology, Pedagogy and Content Knowledge) (Figure 4), aims to better train teachers in the use of ICT. It presents an interesting structure for understanding teacher support by showing how technology creates new dynamics in the teaching and learning process, providing a solid foundation for effective and quality integration of technology in their teaching practices (Abbitt & Klett, 2007).

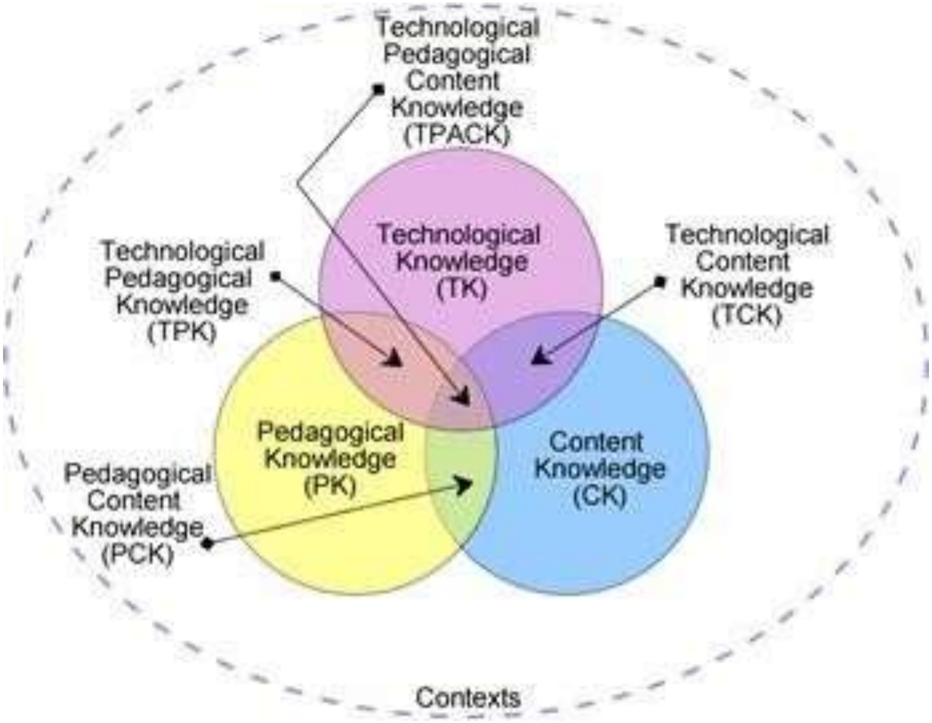


Figure 4: **Technology Educational Content Knowledge (Mishra & Koehler, 2006)**

Investment in continuing teacher education programs on redox reactions could be a solution to accompany the development of hands-on experience-based PCK (Mamlok-Naaman et al., 2018). Strategies based on the realization of analog and numerical models to enable teachers to address the three levels of representation: macroscopic, submicroscopic and symbolic (Sherri Miller, 2008).

The knowledge of redox reactions can be developed with the teacher's experience. The improvement of PCK is directly related to the other two areas TCK and TPK, so the integration of technology allows the development of interactive teaching tools that can help teachers to make the concept understandable by suggesting to use experimentation with a more investigative approach (Luciane et al., 2020).

DISCUSSION

In the Moroccan school curriculum, redox reactions are taught in the $^{\text{first}}$ year of the baccalaureate and serve as a basis for the study of photosynthesis in the $^{\text{first}}$ year of the baccalaureate, as well as the study of electrochemical cells and cellular respiration in the $^{\text{second}}$ year of the baccalaureate. The questionnaire used in this study is made up of questions that are specifically based on Knowledge, understanding and application. These three elements are among the cognitive objectives of physical sciences (Bloom, 1975). In order to assess the learners' knowledge of the questions on definitions. 89% of the learners defined oxidant and only 40% defined reductant which means that 60% of the learners have an independent representation of oxidation and reduction. Only 51.5% of the students chose the electron transfer model to define the redox reaction despite the fact that the interpretive model used for secondary education in Morocco is essentially based on the electronic model. This is in agreement with the results of Soudani (1996; 1998) and Nguessan (2016) who showed that learners are far from acquiring the basic notions related to redox concept. From these results, it can be concluded that the students have not properly assimilated the basic notions necessary to acquire the concept of redox. A lack of mastery of these basic notions by the students leads to a poor understanding of the concept of redox. This is evident from the comprehension results, which showed that 75% of the students could not identify the oxidizing and reducing agents of a redox couple. As well as 47% of the learners were unable to identify the agent that will be reduced and the agent that will be oxidized. These results are similar to the results of Ojokuku and Amadi, 2010. These results indicate that students have a low understanding on the conceptualization of redox. This is due to language barriers among learners, who have difficulty relating electron loss to oxidation, when the reaction does not involve the element oxygen (Herron, 1975; Shehu, 2015). This creates conceptual errors in learners that lead to epistemological barriers. Shehu (2015) and Gil-Pérez et al., (1990) have also shown that misconceptions can lead to epistemological barriers.

The majority of students (80%) did not identify redox reactions. In addition, 33.5% of the students chose acid-base reactions as redox reactions based on the presence of charges in the elements of the equation. Medimagh & Bouguerra found that learners associated the presence of charged entities with electron exchange. Only 20% of the students chose reaction (3) and 2% chose reaction (4) but without giving any justification. This meant that these learners do not recognize oxygen as an oxidant and therefore the presence of oxygen in a chemical reaction is not a redox reaction (Shehu, 2015). On the other hand, the learner thinks that electron transfer is the general definition of redox phenomena. This leads to an epistemological barrier which is due to the fact that the teaching/learning of redox is almost based on the electron transfer model while the concept has four epistemological models (Olson, 2010; Udo, 2011).

The translation of chemical transformation into chemical equation by using symbols is a major difficulty for learners (Mzoughi-Khadhraoui & Dumon, 2012). For the writing of half equation and balance equation, the percentage of incorrect answers vary between 69.75% and 82.8%. Between 74.17% to 90.6% of learners are unable to identify the oxidizing agent and the reducing agent in balance equations. These low results are due to the confusion of the terms oxidizing and reducing agent from the theoretical and operational point of view. This confirms that the concept of redox is not mobilized by the students.

The teacher can help learners to model redox phenomena in terms of electron transfer. In addition, mnemonics that could help students retain the definitions of redox.

Investment in continuing professional development programs focused on redox reactions could be a solution to accompany the development of educational content (PCK) based on practical experience.

By extending the PCK model to include technological knowledge (TK), the TPACK framework illustrates three additional interactions between these knowledge domains: Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK) and Technological Pedagogical Content Knowledge (TPCK) (Koehler & Mishra, 2005; Mishra & Koehler, 2006).

This changing relationship has implications when considering approaches to teaching educational technology in a teacher preparation program. As pre-service teachers develop a broader view of the role of technology in education, improving their technological skills becomes relevant to their discipline and likely to work well in their future classrooms (Luciane et al., 2020).

CONCLUSION

The difficulty of assimilating the concept of redox based on electron transfer models does not allow learners to make the link between electron transfer and the transfer of hydrogen and oxygen, encountered in chemistry and biochemistry, the results of our study confirm this confusion in the majority of the target category whether it is at the level of definitions or identification of this type of reactions.

The assimilation of redox concepts during the secondary school course should be evolutionary based on experience and the use of appropriate digital teaching resources.

The integration of information and communication technology for teaching (ICT) into the Technology and Pedagogical Content Knowledge (TPACK) framework provides a valuable framework for structuring teacher preparation and the ways in which technology creates new dynamics in the teaching and learning process. These distinct constructs can be better used as formative and summative measures to reveal the impact of teacher preparation experience on the factors that lead to effective technology integration by preservice teachers. The utility of the TPACK framework can be extended to provide a pedagogical knowledge-based numerical model that can effectively fill gaps in the redox construct encountered by the categories surveyed.

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APPENDIX

This survey is for you, the high school students. It aims to assess your knowledge of the Corona virus and whether you are aware of the seriousness of this infection. Are you?

☐ A boy

☐ A girl

How old are you?

What is your grade level?

☐ Common core

☐ 1st year bachelor

☐ 2nd year baccalaureate

1-A redox reaction is :

☐ an electron exchange reaction.

☐ a proton exchange reaction.

☐ an exchange reaction of electrons and protons.

2-Choose the correct statements:

☐ An oxidant is a chemical species capable of giving up one or more electrons.

☐ A reductant is a chemical species capable of giving up one or more electrons.

☐ An oxidant is a chemical species capable of gaining one or more electrons.

☐ A reductant is a chemical species capable of gaining one or more electrons.

3-During a redox reaction :

☐ The oxidant is oxidized

☐ The oxidant is reduced

☐ The gearbox is reduced

☐ The reductant is oxidized.

4- Among the following reactions, identify those which correspond to a redox:

1- $Na^{2\,+} + OH- + H_3O^{+} + Cl^{-} \rightarrow Na^{2+} + Cl^{-} + 2H_2O$ yes no

Why?

2- $NH_3 + H_2O \rightarrow NH^{4+} + OH^{-}$ yes no

Why?

3-$O_2 + 2H_2 \rightarrow 2H_2O$ yes no

Why?

4- $Na + O_2 \rightarrow 2Na_2O$ yes no

Why?

5- Determine which compound or ion is the oxidizing agent in the following reaction: $\mathbf{Al_3^{2+} + Fe \rightarrow Al + Fe^{3+}}$

- ☐ Fe
- ☐ Al
- ☐ Fe^{3+}
- ☐ Al^{3+}

6- Determine which compound or ion is the oxidizing agent in the following reaction: $\mathbf{2\,Ag + \,(aq) + Zn(s) \rightarrow 2\,Ag(s)^{+}\,Zn^{2+(}aq)}$

- ☐ Ag
- ☐ Ag^{+}
- ☐ Zn
- ☐ Zn^{2+}

7- **Identification of the reducing agent in the following reactions**:

$\mathbf{2\,Ag + (aq) + Zn(s) \rightarrow 2\,Ag(s) + Zn^{2+}(aq)}$

- ☐ Ag^{+}
- ☐ Zn(s)
- ☐ Ag
- ☐ Zn^{2+}

8- **Identification of the reducing agent in the following reactions**:

$\mathbf{Zn(s) + Cu^{2+(}aq) \rightarrow Zn^{2+}\,(aq) + Cu(s)}$

☐ Zn

☐ Cu^{2+}

☐ Zn^{2+}

☐ Cu

2- **Check off the correct entry for the half-equation of the H2O2(aq)/H2O(l) couple**:

☐ H_2O_2(aq) + e- →H_2O(l) + O-(aq)

☐ H_2O_2(aq) + 2H+(aq) + 4e- →2H_2O(l)

☐ H_2O_2(aq) → 2H2O(l) + 2H+(aq) + 2e-

☐ H_2O_2(aq) + 2H+(aq) + 2e- →2H_2O(l)

3- **Check off the correct entry for the half-reaction of a redox couple** Al3+ (aq)/Al(s) :

☐ Al (s) + 3e- → Al3+ (aq)

☐ Al^{3+} (aq) + 3e- → Al(s)

☐ Al (s) + 2e- → Al3+ (aq)

☐ Al^{3+} (aq) → Al(s) + 3e-

4- Check off the correct entry for the redox reaction between I2(aq) and Fe2+(aq). The pairs involved are : I2(aq)/I-(aq) and Fe3+(aq)/Fe2+(aq).

☐ I_2(aq) + $Fe^{2+(}$aq) →Fe^{3+}(aq) + I^-(aq).

☐ I_2(aq) + $Fe^{2+(}$aq) → Fe3+(aq) + 2I^-(aq).

☐ I_2(aq) + 2$Fe^{2+(}$aq) →2Fe3+(aq) + 2I-(aq).

☐ I_2(aq) + $Fe^{2+(}$aq) → Fe3+(aq) + 2I^-(aq).

5- What are the redox couples involved in the following reaction? $Cr_2O_7^{2-(}$aq) + 6$Fe^{2+(}$aq) + 14H^+(aq)→2$Cr^{3+(}$aq) + 6$Fe^{3+(}$aq) + 7H_2O(l)

☐ $Cr_2O_7^{2-}$(aq)/Cr^{3+}(aq) and H^+(aq)/H_2O(l)

☐ $Cr_2O_7^{2-}$ (aq)/$Cr^{3+(}$aq) and Fe^{3+}(aq)/Fe^{2+}(aq)

☐ Cr_3+(aq)/$Cr_2O_7^{2-}$ (aq) and Fe^{3+}(aq)/Fe^{2+}(aq)

☐ H^+(aq)/H_2O(l) and Fe^{3+}(aq)/Fe^{2+}(aq)