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Study of the level of understanding of the student-teachers of physical sciences of the higher teacher training college of Yaounde on the notion of oxidation-reduction reaction in an acid medium.

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Abstract

This research aims to explore the level of understanding of future teachers of physical sciences on the nature of charge carriers exchanged when the oxidation-reduction reaction takes place in an acid medium and to identify the types of reasoning that led to the answers they propose. This is in order to know if they have the cognitive resources necessary to approach with their future learners the concept of redox reaction according to the reaction medium. To do this, 585 student-teachers of physical sciences (physics and chemistry) from the first and second cycles of the higher teacher training college of Yaoundé were interviewed between 2015 and 2021. The results obtained in this research show that 61.54% of student-teachers questioned can't identify the type of particles exchanged when the redox reaction takes place in an acid medium. This result leads us to conclude that most of the future teachers of physical sciences in Cameroon have a very low level of understanding of redox reactions in an acid medium and, therefore, do not have sufficient cognitive resources to help their future learners to better interpret oxidation -reduction reactions as a function of the reaction medium.

Keywords: *redox, exchanged particle, acid medium, level of understanding, type of reasoning and chemical equation.*

1. Introduction and problematic

Electricity occupies a very important place in the development of human beings in their daily lives, because it is used as a source of energy to operate household appliances, heat or cool homes, power televisions, telephones and computers, etc. It is also produced

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through chemical transformations during which electron transfers take place. These are redox reactions. A fundamental concept in the physical sciences, oxidation-reduction is taught at secondary and university level in Cameroonian education. It is introduced at the level of the third class (15 - 17 years old). But it is only from first grades in scientific series (17-19 years old) up to university level (for those who opt for a scientific course) that it is truly conceptualized and mobilized by learners. According to Cameroonian high school chemistry curricula [1], students are required to either:

- interpret the functioning of a battery, determine its polarity and its electromotive force;
- carry out oxidation-reduction assays and electrolysis of certain chemical compounds;
- to balance redox reactions using oxidation numbers;
- write and to balance half-reactions and to use half-equation method to balance redox reactions in aqueous solution and in acid or basic medium, then perform chemical calculations requiring a good understanding of oxidation-reduction concepts.

Unfortunately, we have found that learners as well as future teachers of physical sciences in high schools and colleges in Cameroon (especially those at the higher teacher training college of Yaoundé) experience considerable difficulty in carrying out these various tasks, reflecting thus a bad conceptualization of the concept of oxidation-reduction by the latter. These difficulties are confirmed by numerous studies in didactics that have been carried out around the world.

Garnett and Treagust (1992), Ogude and Bradley (1994), Sanger and Greenbowe (1997) and Bouraoui and Chastrette (1999) carried out research in Australia, South Africa, the United States and France and Tunisia respectively on the conceptions of pupils and students concerning the interpretation of the microscopic phenomena which take place during the operation of an electrochemical cell. The results obtained reveal that many learners do not conceive that an electrolyte solution is electrically neutral. For the latter, it is the free electrons in the electrolyte which conduct the electric current (Ogude & Bradley, 1994). In addition, learners conceive of the salt bridge as a passageway for electrons from one half-cell to another in a cell (Garnett & Treagust, 1992; Sanger & Greenbowe, 1997 and Bouraoui & Chastrette, 1999). Unfortunately, these erroneous conceptions of the learners on the role of the salt bridge persist until the university level (Bouraoui & Chastrette, 1999). This makes it difficult for learners to conceptualize and interpret electrochemical phenomena at the microscopic level, thus accentuating their difficulties in distinguishing the nature of charge carriers or particles exchanged when an oxidation-reduction reaction takes place. These results are corroborated by Ayina Bouni et al. (2012) who showed that 40 % of French science terminal students (17-18 years old) have difficulty understanding the circulation of electrons and ions respectively in the ohmic conductors and the electrolytic conductors of the battery. This result again confirms the significance of the students' difficulties in identifying the charge carriers and their respective sites of circulation when the battery is debiting.

Soudani et al. (1996), in France, assessed the achievements of first-year university students (scientific section) on the concept of oxidation-reduction and identified the sources of the difficulties they encounter in this process about before discussing this concept at the university level. The results obtained show that most of the students questioned are unaware of (or have forgotten) the concept of oxidation-reduction, the conceptual network associated with it and its field of application. The explanations for this observation would be the non-mastery of the language used in chemistry added to the difficulties in interpreting the phenomena of oxidation-reduction in aqueous solution and in acidic and basic medium, the ignorance of the meaning of the electrons present in the half-equations and the teaching of this concept at the secondary level essentially based on the electronic model.

Boulabiar-Kerkeni (2004) analyzed the way in which French pupils and students apprehend the concept of oxidation-reduction, and particularly the models for predicting the evolution of an oxidation-reduction system. The results obtained show that to predict redox reactions and their evolution, the learners questioned mobilize concepts such as the oxidizing or reducing power, the gamma rule or the model of reference potentials without however alluding to basic quantities such as chemical concentration and electron transfer. This shows that these learners do not have sufficient cognitive resources to better conceptualize basic concepts in chemistry such as chemical concentration, electron transfer, types of charge carriers involved depending on the type of chemical reaction.

Ferouni et al. (2012) conducted a study aimed at identifying the conceptions of moroccan pupils and students on chemical transformations, and more particularly, those of oxidation-reduction. According to the results obtained, learners find it difficult to write half-equations and balance equations of oxidation-reduction reactions; they do not always understand the meaning of the expression “transfer of electrons”; they struggle to distinguish between the charge carried by the ion and the stoichiometric coefficient when balancing the redox equations; finally, they have difficulty placing electrons in half-equation when negatively charged ions are present, regardless of the level of study. According to said research, these difficulties are closely linked to the lack of mastery by the learners of the basic concepts in chemistry (atom, electron, ion, molecule) and of the models used in oxidation-reduction. These results are confirmed by data from the survey conducted by Demircioglu et al. (2013) on the understanding of chemical equilibrium by chemistry learners which show a weak understanding of concepts in chemical equilibrium such as redox reactions by them.

Adu-Gyamfi et al. (2015) studied the conceptual difficulties faced by ghanaian students when balancing redox reactions with H_2O, OH^- and H^+ species. According to this study, most of the learners interviewed fail to conceptualize that the H_2O molecule is introduced in the balancing of oxidation-reduction reactions in acidic and basic medium to balance the number of oxygen atoms, rather than to dilute the system, as they think. Similarly, learners also fail to conceptualize that H^+ ions are not introduced into acid redox equations to neutralize OH^- ions, but to balance the hydrogen atoms in the system. The same is true in a basic medium, where the OH^- ions are not released in base form, but introduced to neutralize the H^+ ions present in the system. This shows that learners simply associate H_2O, OH^- and H^+ species with other learned concepts such as dilution and neutralization. This means that they struggle to

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[1] Order N^o 09/20/MINESEC of 24 January 2020 defining the study programs for the First, Lower and Upper Sixth grades of general secondary education.

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understand and explain the chemistry that goes with the introduction of these chemical species in the balancing of oxidation-reduction reactions in acidic and basic medium.

Nguessan (2016), in Côte d'Ivoire, assessed the level of skill development of physical science students (Bachelor 3 and Master 1) on redox. The results obtained show that the skills mobilized by the latter are not sufficient to solve problems in oxidation-reduction. In addition, they do not master the basic notions of oxidation-reduction and fail to apply the principles of oxidation-reduction to the different types of electrochemical cells. These results corroborate those obtained in the research of Bouraoui and Chastrette (1999); Soudani et al. (1996) and Ferouni et al. (2012). It is therefore necessary to mobilize other resources to make students efficient and effective in solving tasks involving redox and its conceptual framework.

Adu-Gyamfi and Ampiah (2019) explored the learning difficulties of ghanaian learners with redox reactions. From this research, students do not understand that during a redox reaction, it is the atoms of the reactants that transfer electrons and not those of the products; they fail to mobilize the concepts of oxidation state, ionic charge and electron transfer to conceptualize oxidized and reduced species; they do not apprehend that a positive charge indicates a loss of electrons, but no gain of electrons; they confuse the oxidation number and the ionic charge of the chemical species involved in redox reactions. All of these conceptual difficulties on redox reactions are due to the fact that learners are confused when it is necessary to use one of the four redox reaction models (oxidation index, electron transfer, type of carrier exchanged charges, addition and elimination of oxygen and the approach of addition and elimination of hydrogen) thus confirming the observation already made by Ferouni et al. (2012) in Morocco.

From the above, it appears that:

- across the world, learners struggle to conceptualize the redox reaction;
- this research mainly highlights the lack of understanding of the concept of electron transfer (the electron being the carrier of exchanged charges) as the source of difficulties when learning oxidation-reduction. Unfortunately, no study has been conducted to our knowledge to study the understanding of learners on the phenomenon of electron transfer (the nature of charge carriers, the number of charges exchanged, etc.) during an oxidation-reduction reaction , whatever the nature of the reaction medium;
- several of these studies suggest reviewing the teaching of electrochemistry, and more particularly that of oxidation-reduction because of the difficulties in learning and teaching it. Unfortunately, we also find like Goes et al. (2020) when they made a systematic analysis of scientific publications in science education on the concept of oxidation-reduction published between 2000 and 2019 that most of this research focuses its studies on learners. Hence the need to survey teachers in practice or in training in order to see if they have the cognitive resources necessary to properly address this concept with learners in their practice.

Taking into account these limits, our objective is to explore the level of understanding of future teachers of physical sciences of the higher teacher training college of Yaoundé on the nature of charge carriers exchanged when the oxidation-reduction reaction takes place in a medium acid. The question is whether they have the cognitive resources necessary to properly build the concept of oxidation-reduction reaction with the learners. To achieve our objective, the question we will seek to answer in this study is: what is the level of understanding of the student-teachers in physical sciences of the higher teacher training college of Yaoundé on the nature of charge carriers exchanged during an oxidation-reduction reaction in an acid medium?

2. Methodology

2.1. Data collection method

Our study was conducted with 585 student-teachers of physical sciences (physics and chemistry) from the higher teacher training college of Yaoundé between 2015 and 2021, i.e. 344 student-teachers of the first cycle (license cycle) and 241 student-teachers of the second cycle (master cycle). They all received lessons on oxidation-reduction reactions either in their secondary school course or in their university course. To study their level of understanding of the type of charge carriers exchanged during an oxidation-reduction reaction in an acid medium, the following question was asked to them:

How many charges are exchanged in the following reaction? Justify your answer.

$$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftarrows Mn^{2+}(aq) + 4H_2O(l)$$

Each respondent had 10 minutes to answer the question. The question has two levels and aims, on the one hand, to assess the ability of each student-teacher to identify the nature of the particles exchanged when the redox reaction takes place in an acid medium and involving several types of particles, namely ions , protons and electrons. On the other hand, it also aims to shed light on the types of reasoning that led to the answers they propose in order to identify whether these student-teachers questioned have the cognitive resources necessary to approach the concept of reaction with their future learners. redox depending on the reaction medium.

The expected correct answer is n = 5 electrons exchanged and to answer the question, you should know that:

- this equation is a redox half-equation and more particularly that of a reduction in an acid medium. It is in the form ox + ne$^-$ $\rightleftarrows$ red;
- the oxidant is MnO_4^- and the reducer Mn^{2+};
- the oxidizing/reducing pair (ox/red) is MnO_4^- /Mn^{2+} ;
- the number of charges exchanged is n in the equation not to be confused with Q, which is the quantity of electricity produced in coulombs (C) during electrolysis;
- the proton (H^+) indicates that this reduction takes place in an acid medium. Moreover, the proton is used to balance the hydrogen atoms and not to neutralize the OH^- ions as in the case of acid-base reactions;
- the ionic charges carried by the ions should not be confused with the electronic charges carried by the electrons, which are transferred or exchanged during such a chemical reaction.

2.2. Data analysis methods

Student-teacher responses were tabulated and analyzed following the categorical grid in table 1. This grid is inspired by the analysis technique used by Şen and Yilmaz (2017) when they studied the conceptual understanding of chemical bonding by Turkish secondary school students.

Table 1: ***Data analysis grid***

Type of responses	Levels of questions		Frequency (%)
	Suggested answer	Justification	

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Correct answer	Correct	Relevant	
False answer related to the presence of an alternative conception	Incorrect	irrelevant	
False answer related to a lack of knowledge or a bad conceptual arrangement	Correct	irrelevant	
	Correct/ no response	Lack of justification	
	incorrect / correct	Partially relevant	

According to this grid, an answer will be considered correct for a question, if the student answers the question correctly and he also gives a scientifically relevant justification. Otherwise, it will be considered false.

In the case of analysis of false answers, given that they may be due to several types of reasoning, only the criteria related to the presence of alternative conceptions in the learners' memory and to a lack of knowledge or to a bad arrangement concept have been taken into account. Thus, a false answer will be due to:

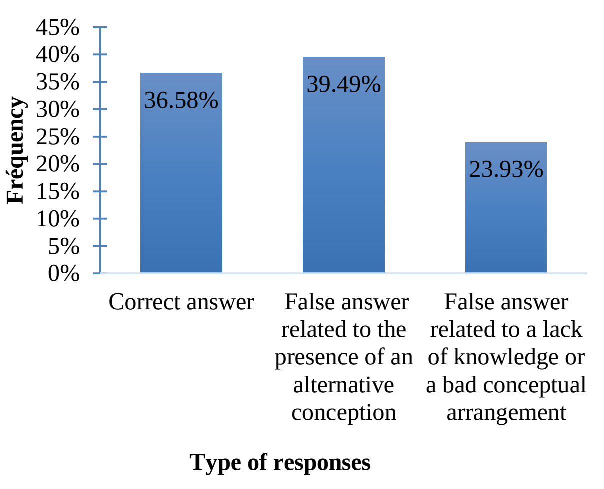
- the presence of an alternative conception in the memory of the participant if the answer he proposes is incorrect and the justification he proposes is also incorrect or irrelevant;
- a lack of conceptual knowledge if the participant gives a correct answer accompanied by an irrelevant justification. Similarly, a lack of knowledge will also be found if the participant answers the question correctly, but does not justify his answer. A lack of response to the question asked will also be attributed to a lack of knowledge, since we assume that the participants do not have the cognitive resources necessary to formulate an answer;
- a bad conceptual arrangement when the participant answers correct or incorrect, but gives an approximately correct justification in which he mismatches the chemical concepts he has learned.

Finally, the frequencies of the different item responses were calculated using the Microsoft Excel 2013 program.

3. Search results

The graph in Figure 1 gives the results of the evaluation of the participants' abilities to identify the type of particles exchanged when the redox reaction takes place in an acid medium and involving ions, electrons and protons.

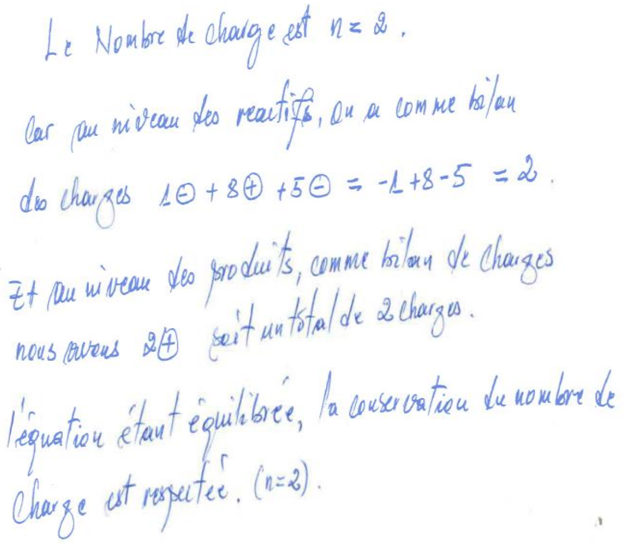
Figure 1: *frequencies of responses given by student-teachers questioned*



According to this graph, 63.42% of the student-teachers questioned give wrong answers to the question asked against 36.58% who answer correctly. That is 371/585 student-teachers who fail to correctly determine the number of electrons exchanged in the half-equation for the reduction of the permanganate ion (MnO_4^-) to manganese ion (Mn^{2+}) in an acid medium. Among the student-teachers who have difficulty in correctly determining the number of exchanged electrons required: 39.49% have completely erroneous conceptions (alternative) on the nature of charge carriers exchanged during a redox reaction in medium acid and 23.93% show a lack of conceptual knowledge about the notion of charge carriers or incorrectly arrange the scientific concepts they have learned in their answers.

Among the student-teachers who show the presence of alternative conceptions of the notion of charge carriers, more than 75% think that the number of exchanged particles is n = +2. They justify their answers by the fact that, in the proposed reduction half-equation, on the side of the reactants, we have a negative charge carried by the permanganate ion (MnO_4^-), 8 positive charges carried by the proton (H^+) and 5 negative charges from electrons (e^-). When we add these charges ((-1) + (+8) + (-5)), we obtain 2 positive charges equal to the number of charges on the side of the products (2 positive charges carried by the manganese ion Mn^{2+}) so that the proposed reaction equation is charge balanced, as shown in the excerpt from the copy given in Figure 2.

Figure 2: *Excerpt from the copy of a student of level 5, future teacher of physical sciences*



Le Nombre de charge est $n = 2$.
Car au niveau des reactifs, On a comme bilan
des charges $1\ominus + 8\oplus + 5\ominus = -1+8-5 = 2$.
Et au niveau des produits, comme bilan de charges
nous avons $2\oplus$ soit un total de 2 charges.
l'équation étant équilibrée, la conservation du nombre de
charge est respectée. ($n=2$).

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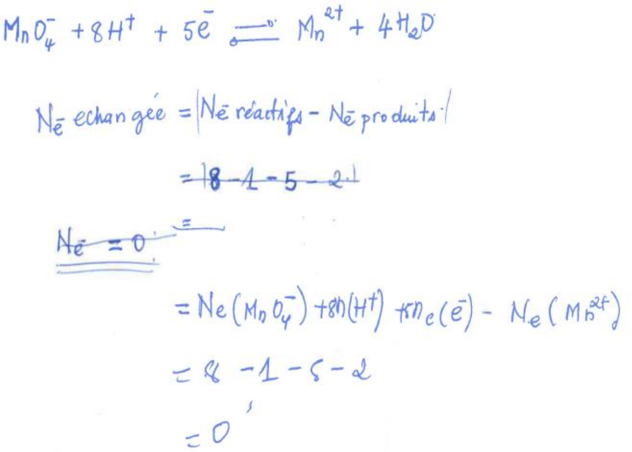
These results show that the student-teachers questioned struggle to distinguish between the charges carried by the ions and those carried by the electrons. They also do not know that the proton H^+ present in the half-reduction equation proposed to them simply indicates that the reaction takes place in an acid medium and that H^+ is also used to balance the hydrogen atoms of the system. Finally, they do not correctly mobilize the notion of electroneutrality and the equilibration of a chemical equation in this context.

Others (around 15%) think that there was no exchange of particles (n = 0). They in turn justify the answers they have proposed by making the difference between the sum of the charges of the products (+2) and those of the reactants (-1+8-5 = +2) as shown in the extract from the figure 3.

Figure 3*: Excerpt from the copy of a student of level 4, future teacher of physical sciences*



$MnO_4^- + 8H^+ + 5\bar{e} \rightleftharpoons Mn^{2+} + 4H_2O$

$N_{\bar{e}}$ echangée = $|N_{\bar{e}}$ réactifs − $N_{\bar{e}}$ produits$|$

~~= |8 − 1 − 5 − 2|~~

$N_{\bar{e}} = 0$

$= N_e(MnO_4^-) + 8n(H^+) + 5n_e(\bar{e}) - N_e(Mn^{2+})$

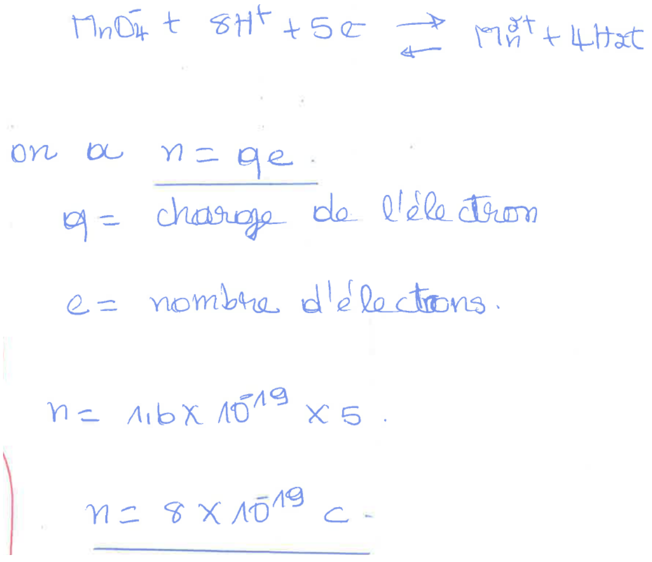
$= 8 - 1 - 5 - 2$

$= 0$

These results also reflect a poor mobilization of the concept of neutrality of a chemical reaction from the electronic point of view in the case of oxidation-reduction reactions.

Finally, 7% of student-teachers questioned who show the presence of alternative conceptions of the nature of carriers when the redox reaction takes place in an acid medium think that the number of charges exchanged n = qe = $5 \times 1.6 \times 10^{-19} = 8.10^{-19}$ *C* as shown in the excerpt from the copy of figure 4.

Figure 4: *Excerpt from the copy of a student of level 5, future teacher of physical sciences*



$MnO_4 + 8H^+ + 5e \rightleftharpoons Mn^{2+} + 4H_2O$

on a $n = qe$.

q = charge de l'électron

e = nombre d'électrons.

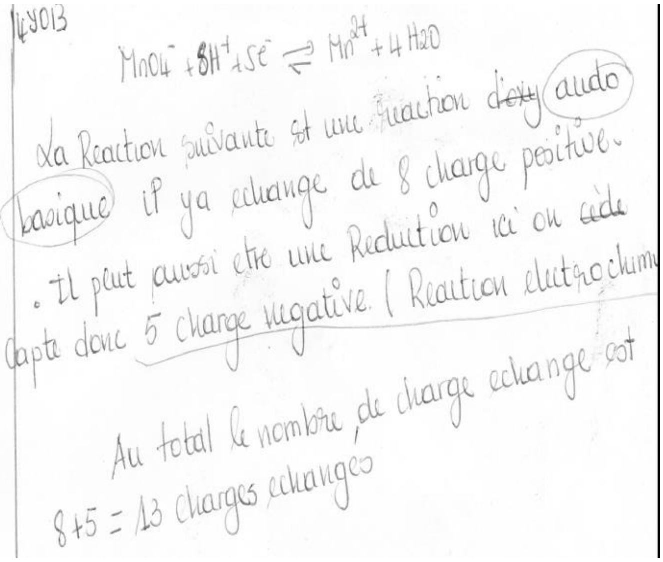
$n = 1{,}6 \times 10^{-19} \times 5$.

$n = 8 \times 10^{-19}$ c.

We note in this excerpt another conceptual confusion between the number of exchanged charges (n) and the quantity of exchanged charges (Q). We also note in this category of response, a poor conceptualization and mobilization of the notion of quantity of charges exchanged during a redox reaction by these student-teachers, because n = q/e and not n = qe as they think.

Regarding the student-teachers who mismatch the chemical concepts they have learned to incorrectly answer the question asked, more than 95% think that the number of charges exchanged is n = 13 as shown in figure 5. For them, the proposed chemical equation is simultaneously an acid-base reaction where there is an exchange of 8 protons (H^+) and a reduction reaction where there are 5 exchanged electrons. These results highlight a bad combination of the notions of redox and acid-base reaction to incorrectly **answer** the question posed.

Figure 5: *Excerpt from the copy of a level 3 student, future teacher of physical sciences*



4Y013

$MnO_4^- + 8H^+ + 5e \rightleftharpoons Mn^{2+} + 4H_2O$

La Reaction suivante est une reaction ~~doxy~~ auto basique il ya echange de 8 charge positive.

. Il peut aussi etre une Reduction ici on cède capte donc 5 charge negative (Reaction electrochim

Au total le nombre de charge echangé est 8+5 = 13 charges echangés

Finally, learners who show a lack of conceptual knowledge about the nature of charge carriers when the redox reaction takes place in an acid medium, offer various answers, namely: n = 2, n = 5, n = 0, but without the justify (more than 95%).

These results that we have just presented show that more than half of the student-teachers questioned have a very low level of understanding of oxidation-reduction reactions in an acid medium, whatever the level of study, because they are incapable of identify the type of particles exchanged when the redox reaction takes place in an acid medium. This low level of understanding is either due to the presence of alternative designs in the memory of the participants, or to a poor conceptual arrangement or to a lack of conceptual knowledge on the notion of charge carriers.

4. Discussion of the results

The results obtained as part of our research show that more than half of the student-teachers questioned (63.42%) have a very low level of understanding of oxidation-reduction reactions in an acid medium whatever the level. These results indicate that these future physical science teachers interviewed experience enormous conceptual difficulties in identifying the type of particles exchanged when the redox reaction takes place in an acid medium, despite the basic lessons they received in secondary school and then deepened in higher education on oxidation-reduction reactions. These results also agree well with those obtained by

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Garnett et al. (1994); Sudani et al. (1996); Bouraoui and Chastrette (1999); Boulabiar-Kerkeni (2004) ; Ferouni et al. (2012); Ayina Bouni et al (2012); Adu-Gyamfi et al. (2015); Dehon and Snauwaert (2015); Nguessan (2016); Adu-Gyamfi and Ampiah (2019) where the latter show that: pupils and students in physical sciences have difficulties in distinguishing the nature of charge carriers or exchanged particles when a redox reaction has place; they have difficulty interpreting oxidation-reduction phenomena in aqueous solutions and in acidic and basic environments; they have difficulty identifying the type of charge carriers involved in a redox reaction as a function of the reaction media; they have difficulty using the multiple information present in the reaction equation; and finally, they do not always understand the meaning of the expression “transfer of electrons” during a redox reaction.

Still according to these results obtained, several confusions and poor conceptual mobilizations probably due to preconceived ideas (alternative conceptions) and to the routine mechanisms of the resolutions of the problems developed during the learning were raised in these student-teachers who proposed false answers and irrelevant justifications. We have: the confusion between the charges carried by the ions and those carried by the electrons; the conceptual confusion between the number of exchanged charges (n) and the quantity of exchanged charges (Q) and the poor mobilization of the notion of electroneutrality and the equilibration of a chemical equation. Indeed, 85% of student-teachers questioned think that the number of exchanged particles $n = +2$ or $n = 0$ or $n = 8.10^{-19}$ C for the proposed reaction equation to be charge balanced. We also note a poor mobilization of the notions of oxidation-reduction reaction and acid-base reaction, because 15% of these respondents think that the number of charges exchanged is equal to 13. For them, it is simultaneously an acid-base reaction (where there is an exchange of 8 protons H^+) and a reduction reaction (where there is an exchange of 5 electrons). This thus reflects the ignorance of the meaning of the presence of the proton H^+ in the proposed redox equation, because the latter simply indicates that this reduction takes place in an acid medium. It is also used to balance the hydrogen atoms of the system and not to indicate the progress of an acid-base reaction according to the interviewees.

Among the confusions and the bad conceptual mobilizations that we listed previously, some like the confusion between the loads carried by the ions and those carried by the electrons; ignorance of the role played by the proton H^+ in the reduction equation proposed to them and the poor mobilization of the notion of electroneutrality and the equilibration of a chemical equation have already been identified among secondary school learners and some students by Ferouni et al. (2012); Adu-Gyamfi et al. (2015) ; Adu-Gyamfi and Ampiah (2019). This shows that the conceptual difficulties encountered by learners when faced with certain scientific concepts such as oxidation-reduction persist throughout the school and academic curriculum. They are automated by the latter and they are almost impossible to deconstruct despite the lessons they receive, because we find them in the experts, who are in this case, the future teachers of the physical sciences. These future teachers having already automated these difficulties and it is very likely that they favor the construction and the automation of the same conceptions in their future learners. These results are also in agreement with the results obtained by Taber (2001) and Ouasri and Ravanis (2020) who showed that unlike other scientific fields, learners arrive in chemistry class with fewer preconceptions. Because they really weren't in direct contact with the chemical notions that will be studied. Even as this does not simplify the problem of learning in chemistry, the conceptions are therefore developed by the latter by the way they give meaning to what is presented to them in class and in connection with their previous knowledge. In chemistry, these conceptions come exclusively from previous teaching or learning, thus generating a poor understanding of the scientific theories that they must acquire.

Thus, we recommend that chemistry teachers’ pay more attention to the vocabulary they use in class to avoid any conceptual confusion or possible confusion with everyday language. We also invite them to use new learning techniques based on the results of the neurodidactics of science, such as the conceptual prevalence model (Potvin, 2013; Potvin, 2018) which is a very promising avenue for overcoming the difficulties of learning in chemistry (Dunbar et al. 2007; Malenfant-Robichaud, 2018).

More specifically, the model of prevalent conceptions suggests that teachers stop fighting alternative conceptions of learners, because the results of research in the neurodidactics of science (Houdé, 2007; Dunbar et al. 2007; Masson, 2012; Thibault, 2013; Houdé, 2014; Dehaene, 2018; Malenfant-Robichaud, 2018) show that these conceptions persist and coexist with the new knowledge learned in the brain throughout life. To do this, teachers must provide, from the outset, the basics of scientific knowledge that we want to see emerging in learners so that they very quickly enter the race with their preconceived ideas of them. Thereafter, it is a question of training the learners to recognize the circumstances in which they should resist using their preconceived ideas and routine mechanisms of resolution of the problems developed during the learning for the benefit of the use of the scientific knowledge learned and adapted to the circumstance.

5. Conclusion

The results obtained in the context of our research show that more than half (63.42%) of the student-teachers questioned (future teachers of physical sciences) have a very low level of understanding of oxidation-reduction reactions in an acid medium whatever the level. Like secondary school students, they experience enormous conceptual difficulties in identifying the type of particles exchanged when the redox reaction takes place in an acid medium, despite the basic lessons they received in secondary school and then deepened in higher education on redox reactions.

This shows that most physical science teachers do not always have the cognitive resources to help learners better conceptualize the notions they want them to acquire. Thus, the conceptual difficulties identified in said research could therefore serve as a basis for developing training devices aimed at facilitating conceptual change in order to further improve the understanding of oxidation-reduction phenomena.

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