Research Article

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Investigation the Association Between the Moroccan High School Chemistry Program and Students' Reasoning

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Abstract

In this study, we discuss the achievements of learners and their abilities to mobilize these achievements in solving complex and everyday life situations. For this purpose, we analyzed the institutional guidelines for the teaching of chemistry, in particular redox transformations and some related concepts. Then, we developed a test targeting two categories of items: the first category covers epistemic aspects while the second goes over the mobilization of redox knowledge in everyday life. This test was administered to a sample of high school students. The results of this empirical research indicate that these learners only master some fragmented knowledge and therefore they cannot mobilize it in an integrated way in everyday situations. The analysis shows that the majority of the difficulties identified can be interpreted by a poor appropriation of chemical concepts related to the microscopic structure of the substance. The difficulties encountered could stem from the structure of the program recommended in the curriculum and the methods of assessing learning. Indeed, our content analysis reveals that the didactic transposition operated for the conceptualization of the concepts related to chemical transformations rather favors the memorization of declarative and procedural knowledge. Moreover, the construction of knowledge follows a linear and not a spiral progression. The current research explores these empirical findings and proposes implications for content progression, learning and assessment of learning.

Keywords: *achievements, concepts, teaching of chemistry, redox knowledge, microscopic structure, spiral progression*

1. Introduction

In recent years, Morocco has embarked on a wide-ranging reform of the curriculum for the teaching of physics and chemistry in the secondary cycle. This curriculum describes the aims of the teaching, the different pedagogical approaches, the targeted competences, the contents to be taught and the organization of the secondary cycle programs. This 6-year cycle is composed of the middle cycle (3 years of study) giving access to the qualifying secondary cycle (high school) sanctioned by the baccalaureate diploma which allows learners to continue their higher education.

Regarding the challenge of these reforms adopted by Morocco, the acquisition of knowledge by learners as well as the development of disciplinary and transversal skills is mentioned. The aim is to develop the learner's ability to mobilize a range of resources in solving a problem, preferably related to everyday life. The development of these skills is supposed to be based, among other things, on modelling activity and experimental practice while adopting an investigative approach. This choice is motivated by the will to give more meaning to learning and not to be limited by the development of declarative and procedural knowledge in learners, but also to the ability to mobilize this knowledge in contextualized situations that give meaning to the knowledge acquired. However, we did not find detailed research assessing the skills that learners can mobilize to solve real-life situations, in high school chemistry teaching.

In terms of learning achievements related to chemistry education, students are expected to master skills related to epistemological knowledge, practical areas, scientific process and development of transferable skills (Reid & Shah, 2007). Transferable skills can be used to solve complex problems in everyday life. However, this type of task can be very difficult. Indeed, these problems often require the integration of several concepts and knowledge that may concern different areas of the same discipline or different disciplines. In this context, Campbell et al (2022) observed such difficulties in students unable to integrate thermodynamic concepts to interpret transformations in organic chemistry.

With the same concerns and given our role as trainers of future teachers, we have noticed in recent years that most of trainee teachers do not have a good mastery of the basic concepts of chemistry. They know only few examples of applications of chemical transformations in everyday life. Yet these trainees have an initial university education of at least three years.

These findings also apply to the chemistry teachers in a recent experiment (Mennani et al, 2023). The results of this study reveal that teachers in Moroccan high schools have epistemological difficulties related to the knowledge to be taught and are unable to mobilize the appropriate knowledge to solve practical chemistry problems.

Based on these observations, our research is based on an epistemological and didactic analysis of the contents to be taught in chemistry, focusing on the structure of these contents, as well as on the learners' achievements in relation to the fundamental concepts, in particular the concept of redox. we have tried to highlight the logics that structure these contents, their supposedly spiral progression as well as the evaluation methods. We conducted a reflection on the articulation between these components in order to have the maximum information on the degree of the coherence of the curriculum.

The results of this study will help those responsible for educational policy to reflect critically on the choices made regarding the content to be taught, its progression and the methods of evaluating the knowledge acquired.

2. Literature Review

For several countries, the Moroccan curriculum insists that programs should be developed using a spiral approach as introduced by Bruner (1977). This approach advocates that the progression in complexity should be carried out progressively, taking into account the cognitive development of the learner. It also suggests that the same concept is addressed several times in the learning process. Such non-linear progression ensures that learning takes place over the years. For example, in the UK, in order to avoid fragmentation of ideas, a new chemistry course has been built around the theme of chromatography. Students are first required to master the basic experimental processes, and then the skills are revisited several times, with increasing complexity. The emphasis has been on the theory and the various applications of chromatography in all areas of chemistry (Campbell et al., 2022).

The analysis of the curriculum and the content to be taught requires an examination of the conceptual content and the practical applications of chemistry in everyday life. The notional content is broken down into several types of knowledge: declarative knowledge, procedural knowledge and strategic knowledge (Sahdra & Thagard, 2003; Yilmaz et al., 2012).

Using natural and technical phenomena as practical examples during teaching has become essential to give meaning to learning. In this context, Broman and Parchmann (2014), King (2012), Millar (2004), Stowe et al., (2020) and Stowe and Cooper (2019) raise the issue of the links between the objectives of chemistry teaching and their concrete practical applications in everyday life. The knowledge of concepts is important, but how is the student enabled to mobilize them in contextualized situations is even more important (Cooper, 2018). These concepts are previously subjected to the process of didactic transposition, in which scientific knowledge is transposed by program designers to make it easily teachable, taking into account especially the cognitive development of learners (Chevallard & Bosch, 2020). This transposition could then have implications on how knowledge is taught (Atalar & Ergun, 2018; Bosch & Gascón, 2006; Lundberg & Kilhamn, 2018). As a result, a distinction must be made between programmed content and the knowledge actually acquired by learners (Sun et al,.2021). We will analyze this external transposition in the redox program, and we will identify its impact on the knowledge to be taught.

The construction of knowledge in chemistry requires the mobilization of concepts that can be linked to the microscopic structure of substance, on the one hand, and to a macroscopic description of observable events and measurable quantities on the other (Johnstone,1993).

A chemical transformation can be modelled microscopically by chemical symbols, describing the arrangement of atoms and the bonds between them. This transformation can also be modelled macroscopically by the same symbols. Both of these modellings can be learning barriers for learners (Taber, 2013). For example, with regard to the reaction equation:

$2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g)$, De Jong and Van Driel (2004) found that many students had difficulties in relating its meaning to the macroscopic and microscopic levels.

The learner can only grasp these chemical transformations if he/she is able to mobilize the chemical properties deduced from the microscopic structure of entities and the underlying concepts (Taber & Bricheno, 2009; Talanquer, 2011). In this context, an empirical study (Cooper et al., 2018) faced difficulties by university learners who were unable to mobilize chemical properties inferred from microscopic structure to predict melting and boiling points of certain compounds. Another empirical study found that many students have difficulty drawing Lewis structures, despite the fact that these structures provide an understanding of many chemical properties of materials (Cooper et al., 2010). According to these authors, these difficulties are related to the structure of the program on the one hand, and the method of assessment of learning on the other. Learners were unable to relate microscopic structure to macroscopic properties because they have not been taught to do so and do not have a structured knowledge base comparable to that of a chemical expert (Cooper et al., 2012).

To solve complex situations, an expert is able to mobilize a range of highly organized and coherent knowledges in an integrated way (Bransford et al, 2000). As a result, teaching must introduce methods to the learner that are based on scientific practices that allow the acquisition of a well-articulated, coherent and contextualized range of knowledges (Cooper, 2018). In contrast, teaching that relies on methods that result in the acquisition of fragmented knowledge promotes insignificant learning (Novac, 2010; Sevian & Talanquer, 2014). As a consequence, learners learn formulas and definitions by rote and are unable to mobilize them in an integrated way in situations, other than those adopted when teaching the knowledge in question.

For example, to acquire the reasoning of an expert in organic chemistry, learners need to reason mechanistically and causally about how the reaction takes place. This reasoning is built up during the learning process, starting with the study of an acid-base transformation that has to be described microscopically using causal reasoning (why the reaction occurs). This transformation is modelled by an arrow curve that describes the result of the electrostatic interaction between a free doublet of a base B and a less bound proton of an acid A (Cooper et al., 2016).

The construction of any knowledge in a coherent and integrated way must be the answer to a constructed problem, during which the learner is required to overcome epistemological obstacles underlying the teaching-learning objectives (Makhene, 2022; Mayer, 1977; Mayer, 2011; Yeşiloğlu &

Köseoğlu, (2020). The problem in question aims at tackling a conceptual difficulty, linked to the learners' conceptions (Becker & Cooper, 2014; Butler et al, 2015; Soeharto & Csapó, 2021). The knowledge to be constructed must also be contextualized in order to give more meaning to learning. Also, the use of problem-solving activities based on investigation can contribute to and consolidate the acquisition of skills in the scientific approach. These practices allow students to acquire the reasoning of an expert. In this perspective, and under the guidance of the teacher, learners are invited to construct the problem and to think about the elements of its resolution (Cooper, 2018).

On their part, Cooper et al (2013) recommend that knowledge should be constructed with a supported progression that allows the learner to acquire highly coherent skills from which to make predictions about the properties of the material. However, typical assessments should be avoided as they can mask the difficulties students have with basic concepts. The learner is able to apprehend new knowledge after destabilizing his explanatory system. To do this, the teacher must take into account the conceptions, ways of thinking of the pupils as well as the epistemological obstacles of the discipline taught. He/she must accompany and support them to establish a new cognitive balance based on correct conceptions (Babakr et al, 2019; Kuhn, 1979; Fosnot, 2013; Fosnot & Perry, 1996; Mayer, 2008). However, studies conducted by Cooper (2018) have shown that the above-mentioned teaching methods remain insufficient or even useless if particular attention is not paid to the structure of the program and the way it is evaluated.

Based on the results of previous studies, we conducted our research with the aim of analyzing of the program of chemistry in general and redox in particular targeting middle and high school learners. The content to be taught is the result of an external transposition carried out by the program designers and should follow a spiral progression. we were particularly interested in the consequences of this didactic transposition and the structure of the program on the knowledge acquired by the learners. We based the analysis on the topic of redox, as this subject is very important in terms of scientific knowledge and applications in everyday life.

In this paper, we have tried to answer the following questions:

1. How is the concept of redox introduced into the curriculum?
2. With what reasoning do learners model chemical transformations?
3. How do high school learners, trainee teachers understand the content of the chemistry curriculum?

In order to answer the research questions, we relied on the following two hypotheses:

First hypothesis: The structuring and articulation of disciplinary knowledge related to the concept of redox in the program is neither relevant nor in harmony with the spiral progression.

Second hypothesis: the knowledge and teaching activities selected by the program designers are not effective for the scientific education of the learners. At this level, we would like to point out that our research attempts to establish the actual state of chemistry teaching with the aim of identifying possible dysfunctions.

3. Research Methodology

3.1 Aims of research

This study was initially focused on the analysis of the program of chemistry in general and redox in particular targeting middle and high school learners. The documentary analysis focused on the content to be taught and the assessment of learning. The content to be taught is the result of an external transposition carried out by the program designers and should follow a spiral progression. We were particularly interested in the consequences of this didactic transposition and the structure of the program on the knowledge acquired by the learners. To this end, we carried out an evaluation, using an open-ended questionnaire, whose objective was to identify the conceptions and reasoning of learners at the baccalaureate level (3rd year of high school). These respondents should solve theoretical and real-life situations. These situations are in line with the knowledge recommended in the high school chemistry program.

A cross-sectional study of these different analyses would make it possible to establish the actual state of chemistry teaching at high schools and to identify possible dysfunctions.

3.2 Student Participants

In order to explore the reasoning and knowledge mobilized by learners when solving theoretical and everyday problems, a written questionnaire was administered to 120 learners (76 girls and 44 boys). Before collecting the data in the secondary schools, the researchers met the teacher of each class (4 classes in total). Discussions focused on how to effectively involve and motivate the respondents, as well as how to stimulate their interest and curiosity. They were asked to explain their ideas and reasoning in detail. The learners (aged between 17 and 18) were at the end of their third year of secondary school and were chosen to solve the theoretical and contextual chemistry tasks. They were enrolled in the mathematical sciences option. In general, the best-performing learners choose this option. They can then go on to scientific engineering schools or medical schools. The learners came from four different high schools: two private schools in El-Jadida, in the Casablanca region, and two state schools in Marrakech. We made these choices in order to minimize the effects of teacher and social class. These respondents should be motivated by the fact that they are generally used to solving questionnaires thanks to their participation in the national chemistry, physics and mathematics olympiads. As a result, these students had the time to take part in the interview and were able to explain their reasoning orally. The conditions for completing the questionnaire were specified to them by their teachers (anonymity, not taken into account for the assessment). After the written test, we asked each teacher to nominate ten learners (TL) to take part in interviews aimed at obtaining in-depth information about their reasoning.

3.3 Instruments and data collection- Procedure

Between January 2022 and April 2023, a "paper and pencil" questionnaire was administered to respondents, who were asked to answer the questions for approximately one hour. This questionnaire, which is the research tool, consists of 11 items, all open-ended questions.

The research questionnaire:

Q1: Explain why water is an acid-base amphoteric? Justify your answer based on microscopic interpretation, then give its corresponding pairs.

Q2: When CH4 gas is bubbled through water, is there an acid-base reaction between the water and the CH4? Justify your answer.

Q3: Microscopically model the transformation between ammonia NH_3 and water H_2O.

Q4: Water is a redox amphoteric. Justify your answer with the redox half-equations and based on microscopic interpretation.

Q5: Write the balance equation for the reaction modelling a transformation, if it occurs, between: a) Cl^- and Br_2 b) I^- and Br_2. Justify your answer.

Q6: The electrolysis of a Sulfuric acid solution is carried out using copper electrodes? draw the electrical circuit, specifying the anode and cathode, and then write the possible redox half-equations at each electrode (the sulphate ion is chemically inert in this case)

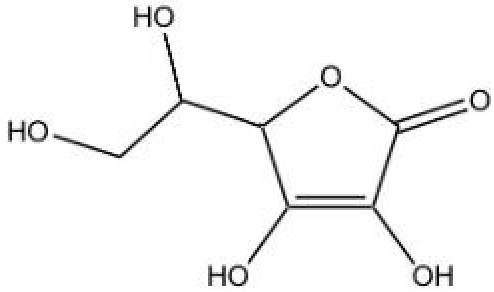
Q7: Is dissolved oxygen a stronger oxidizing agent than water? Justify your answer.

Q8: Give the active constituents of two antiseptic oxidizing solutions, specifying their Ox / Red pairs.

Q9: Consider the following balance equation $2H_{2(g)}+O_{2(g)}\rightarrow 2H_2O_{(l)}$: is it a redox transformation? If so, can it be used to generate electricity? Explain. Is it a forced or spontaneous transformation?

Q10: In the food industry, ascorbic acid is used as an antioxidant. Explain why? Use the semi-developed formulae and then write the half-equation which models the oxidation of the organic function carried by carbons 2 and 3 (C2-ene diol function):

Q11: On bleach labels, it is stated: "In contact with an acid, it releases a toxic gas, that is highly dangerous to health. This solution must be stored in opaque containers." Explain chemically in a detailed way these two indications



The first 7 questions cover the epistemic aspect of the various concepts in the chemistry program. The remaining questions deal applications of the redox concept in everyday life recommended in the redox program. To answer these questions, the respondents should mobilize the following resources: the electronegativity of a chemical element, the evolution of chemical properties in the periodic table of elements, microscopic modelling of chemical transformations, the nature of a chemical bond, the laws that allow the prediction of a chemical transformation, acid-base transformations, redox transformations and their applications in everyday life. These concepts are presented in the program in the order given above.

To design the questionnaire, we used the skills form recommended in the science curriculum, certain baccalaureate exams, the chemistry program and textbook. Before being administered to the participants, the test was reviewed, adjusted and improved by several high school teachers and teacher trainers.

A week before the day of the test, we organized a meeting with the learners in each class and their teacher. We explained the aim of the project and the knowledge to be mobilized. We insisted that they had to detail their reasoning.

The interviews with each group (TL) lasted around 50 minutes. We asked them to comment on the questionnaire, particularly if they were familiar with this type of tasks, and then to explain their reasoning orally.

3.4 Analysis

The analysis of the respondents' reasoning focused on answers that were inadequate with the knowledge recommended in the program as well as on correct answers. We compared these two categories of answers to an expert's answer. Then we deduced the most recurrent reasoning.

The interviews with the (TL) enabled us to identify the main causes of these erroneous and incorrect responses. Both first authors described and interpreted the learners' responses. They identified the different knowledge mobilized by the respondents to answer the questionnaire.

4. Results of different analyses and discussion

4.1 Results of the redox program analysis

4.1.1 Structuring and progression of the content of the redox concept

The chemistry program is composed of three rubrics which are the content to be taught, the proposed activities and the knowledge in the form of abilities.

Table I (Appendix-1) represents the content to be taught in redox during the 3rd year of middle school, the 2nd and 3rd years of high school.

The content is the result of an external transposition made by the program designers.

In the 3rd year of secondary school, the program introduces the study of the structure of an atom and the formation of ions as a result of a loss or gain of electrons. The notion of chemical reaction is consolidated by the study of the oxidation of iron, its Fe^{2+} ions and aluminum by the oxygen in air. The concept of oxidation is addressed for the first time and modelled by the fixation of oxygen by a metal. The program also introduces the notion of acidic and basic solutions, besides their actions on some metals and their effects. These transformations of metals into ions are modelled by chemical equations without introducing the concept of redox by electron transfer. The identification test of some ions is also a subject of study.

From a reading of the contents assigned in the topic of redox, we note that the progression of learning is rather linear than spiral, as stipulated in the curriculum, which could favour a constitutes a partitioning of contents. Indeed:

- The model of oxidation based on the transfer of oxygen programmed in middle school has not been taken into account in high school. Moreover, the reaction between iron and oxygen in a humid environment leads to the formation of rust, which is a link between the middle school and high school programs. However, the program has ignored this important paragraph. We recall that the interpretation of the formation of rust calls for the principle of operation of a battery, which is a teaching objective in high school.
- We have also noticed the absence in the high school program of the study of the oxidation of metals by acid solutions. Though, the 3rd year middle school program recommends the study of the action of this solution on iron, copper and aluminum.
- The concept of redox based on electron transfer was introduced in high school just after the study of acid-base transformations. The redox couples of water are not directly recommended by the program, although the learners' prerequisites are more than sufficient for them to understand that water is an amphoteric redox substance. While in the acid-base theme great emphasis has been placed on water as an amphoteric acid-base substance, without any indication of the possibility of an interpretation based on the concepts related to the microscopic structure. Regarding these concepts, they are recommended in the chapter that precedes that of acids and bases. We recall that water as a solvent " houses " all the transformations in aqueous solutions, it can act through its physical properties due to the fact that it is polar and can act through its chemical properties due to its character that it is acid, base, oxidant and reducer. This global vision relating to these properties of water is entirely absent in the program.
- The notion of electronegativity and its evolution in the periodic table of chemical elements has not been reinvested either in the study of an acid-base or redox transformation or in the prediction of the spontaneous direction of this type of transformation. In particular the redox transformation between a halogen and a halide ion.
- Our analysis revealed that the different modelling activities in the set of programs are based solely on the writing of redox half-equations, on the balance equation using symbols that describe only the macroscopic registers. Moreover, no capacity has been taught or assessed in relation to the microscopic register. Causal and mechanistic reasoning are virtually ignored in the chemistry program.

Analyses of the program, the assessment syllabus and some baccalaureate examination papers have revealed that the cognitive abilities mobilized by the learner to carry out the tasks proposed belong only to the lower taxonomic level. There is a wide range of cognitive abilities such as: writing the redox half-equations, deducing the balance equation, identifying the oxidant or the reducer of a redox couple, recognizing the anode and the cathode, and carrying out an advancement table in order to calculate the quantities formed or transformed. The absence of higher order skills such as:

analyzing, interpreting, arguing, synthesizing, or proposing an experimental protocol to verify a hypothesis. It is these latter abilities that can develop disciplinary and cross-curricular skills.

4.2 The relevance of teaching activities to everyday life and social practices

In the 3rd year of middle school, the program proposes discovering experimentally the conditions that favor the oxidation of iron in the air, and that causes the formation of rust. It is a study that deals with a phenomenon of everyday life, which gives meaning to the learning. On the other hand, the program for the 2nd year of high school only recommends knowing some examples of reducers and oxidants in everyday life such as ascorbic acid, bleach, hydrogen peroxide, oxygen O_2 and hydrogen H_2. However, the importance of using these examples in learning situations has not been emphasized, as well as the didactic strategies for their realization. Furthermore, the analysis revealed that this content to be taught is not accompanied by any skills or abilities to be developed and assessed. In fact, these concrete examples would make learning more meaningful and motivate learners more. Indeed:

- Oxygen, which is a main oxidant in our atmosphere, is responsible for the oxidation of a large number of metals and foods. In aqueous solution, it is involved in the O_2/H_2O couple. Dihydrogen is a reducing gas that belongs to the redox couple: $H^+(aq)/H_2$ or H_2O/H_2. Both gases are used in the fuel cell and are taught in the 3rd year of high school.
- Ascorbic acid or vitamin C is a reducing agent used as an antioxidant in canned foods. It is involved through its redox couple $C_6H_6O_6/C_6H_8O_6$. This acid contains several organic functions, in particular the alcohol function, which can be oxidized into a ketone. Moreover, the oxidation of alcohols is taught in the 2nd year of high school. This progression is hidden in this program.
- Bleach is a powerful oxidant, its aqueous solution is an antiseptic thanks to ClO^- ions, which belong to the ClO^-/Cl^- and ClO^-/Cl_2 couples. The hypochlorite ions ClO^- are reduced by water in a very slow transformation. For this reason, bleach must be stored in opaque containers and must not be mixed with acidic solutions, as chlorine, a gas that is very dangerous to health, is released, as follows:

$$ClO^-(aq)+Cl^-(aq)+2H^+(aq) \rightarrow Cl_2(g)+H_2O(l).$$

These examples could be integrated into the teaching of chemistry in order to provide a more meaningful learning experience. However, it is noted that no detailed indication has been given in the syllabus about these applications of the redox concept.

In addition to the epistemological aspects related to the integration of these concrete examples, their treatment would allow the learners to become aware of their chemical effects and their conditions of use.

To sum up, in response to research question 1, we consider that the recommended program does not explicitly reflect the objectives of the curriculum. Indeed, its structure and the type of assessment do not contribute to the development of learners' skills. As a result, learning may remain superficial.

5. Results of the Questionnaire

5.1 Results of the theme related to the epistemic aspect

The analysis of the questionnaire reveals that most of respondents have little knowledge of the aspects related to the conceptualization of the different concepts of the program. A large majority answered incorrectly to the items dealing with epistemological aspects. Very few participants in the study mobilized their knowledge in an integrated way based on the scientific arguments of an expert. All four teachers of these interviewees stated that teaching should be problem-based, the resolution of which requires the mobilization of interconnected knowledge.

However, the baccalaureate exams only require procedural knowledge which is fragmented. We have observed that this questionnaire has stimulated the interest and motivation of the respondents. They have stated that the tasks in the questionnaire were interesting because they were structured around their knowledge and context. They have asked us for the answers to these tasks.

In question Q1, the respondents should explain microscopically why water is an acid-base amphoteric and then give its corresponding pairs based on the microscopic properties of the molecule H_2O. Learners should rely on Brönsted's definitions and then use the fact that the H-O bond is polar and therefore the hydrogen element can be attacked by a base. Furthermore, the H_2O molecule has a free doublet according to the Lewis diagram, and through this free doublet, the water molecule can fix an H^+ proton.

59 respondents considered that the molecule H_2O is an acid-base amphoteric because; for some, it is a solvent and for others it is a law. However, all the respondents gave the acid-base pairs of water in a correct way, by writing the following half-equations: $H_2O + H^+ \leftrightarrows H_3O^+$ and $H_2O \leftrightarrows H^+ + HO^-$.
41 respondents answered as follows: water is an acid-base amphoteric because its pairs are H_3O^+/H_2O and $H_2O\ /HO^-$, because $H_2O + H^+ \leftrightarrows H_3O^+$ and $H_2O \leftrightarrows H^+ + HO^-$.
20 others justified their answer as follows: water is an acid-base amphoteric because it has a pH=7, since it can react with itself in the following way: $H_2O + H_2O \rightarrow H_3O^+ + HO^-$.

We find that the learns used faulty reasoning that relied on a macroscopic description, not a microscopic one. This reasoning informs us that these learners were unable to rely on the microscopic structure of H_2O to predict its acid-base properties, because they did not correctly understand the utility of what they were learning. Otherwise, the learning was meaningless to them and therefore they just memorize the acid-base pairs of water. The discussion with the (TL) revealed that the assessment of their learning during their training was mainly based on a macroscopic description of the chemical transformations in which water is involved as an acid or base. We can say that their chemical conceptions related to the water molecule are limited to its couples H_3O^+/H_2O, $H_2O\ /HO^-$, and not to its microscopic structure as an angular molecule with its +, - poles and the resulting chemical properties.

In question Q2: When CH_4 gas is bubbled through water, is there an acid-base reaction between the water and the CH_4? Justify your answer, respondents should explain their reasoning based on microscopic properties and the acid-base ampholytic character of water. With this detailed question, we wanted respondents to be able to mobilize and provide as much relevant information as possible. Our aim was to identify the subjects' reasoning process and their ability to mobilize relevant resources.

Participants in the study should use reasoning that relies on properties related to molecular structure to predict an acidic or basic property of a substance. They should also use causal reasoning: water has the property of being acidic and basic, but the molecule CH_4 cannot be an acid because the C-H bond is covalent.

All respondents answered as follows: $CH_4 + H_2O \rightarrow CH_3^- + H_3O^+$

This is a macroscopic description of a reaction whose transformation is impossible from the acid-base point of view. Presumably, the learns during their studies was based on transmissive teaching, which only aims at mastering declarative and procedural knowledge.

The participants did not use either the concept of electronegativity or the notion of the least bonded hydrogen in a polar bond. Therefore, for them, every molecule that contains hydrogen is automatically an acid. They do not rely on the content recommended in the program and do not use expert reasoning.

Cooper (2018), and Cooper et al., (2016) have found these misconceptions among university chemistry students. they recommend that teaching should incorporate a structured and interconnected progression of ideas, which will allow students to rely on the microscopic properties of matter to predict its chemical reactivity.

In question Q3: Model microscopically the transformation between ammonia NH3 and water H_2O. Explained microscopically why. Respondents should use the Lewis diagrams of NH_3 and H_2O, showing the free doublet of the element nitrogen and a mobile hydrogen of the water molecule, and by a curved arrow the interaction of this free doublet with the mobile hydrogen should be illustrated (causal reasoning)

First category of answers: 85 respondents gave the following balance equation, without explanation: $NH_3 + H_2O \rightarrow NH_4^{+} + HO^{-}$.
Second category of answers: 35 respondents proposed the following two half-equations: $NH_3 + H^{+} \leftrightarrows NH_4^{+}$; $H_2O \leftrightarrows H^{+} + HO^{-}$ and then the equation: $NH_3 + H_2O \rightarrow NH_4^{+} + HO^{-}$.

The first category of answers illustrates a macroscopic modelling of the transformation between NH_3 and water H_2O and not a microscopic modelling.

The second category of answers only illustrates a mathematical breakdown that does not describe the microscopic modelling of the transformation.

The discussion with the (TL) revealed that they are used to writing only the acid-base or redox half-equations and then the balance equation of the transformation. In other words, they do not use reasoning that relies on the microscopic register to predict macroscopic properties.

During the discussion, we asked them to draw the Lewis diagrams of NH_3 and H_2O so that they could predict the microscopic interaction between these two reactants. It became clear that the task asked of the respondents was complicated

for them. It seems that they are not used to constructing relationships between microscopic and macroscopic properties and yet these microscopic properties are recommended in the program. This could be explained, as stated by the respondents, by the fact that during their training, the formative evaluation focused on macroscopic aspects to the detriment of microscopic ones. As a result, not all respondents were able to model the reaction between NH_3 and H_2O microscopically.

The findings from the analysis of the answers to the above questions could be the consequence of the structure of the program. Indeed, a break between the different contents can be noted, which is reflected in the absence of reinvestment of concepts related to the microscopic structure of matter in the chapters on acid-base and redox transformations.

In Question 4: Water is a redox amphoteric. Give the redox couples of water, justifying your answer with the redox half-equations and based on a microscopic interpretation.

Suggestions from 90 learners: H_2O is a liquid, not a solid, so it cannot be a reducing agent. H_2O is an uncharged liquid, so it cannot be an oxidant.
30 of those questioned proposed the following pairs: H_3O^{+}/H_2O and $H_2O\ /HO^{-}$, water only has acid-base properties.

These results show that the teaching-learning process does not take into account the learners' misconceptions and seems to rely exclusively on methods that favour the acquisition of fragmented knowledge.

The discussion with (TL) showed that during the teaching-learning process, teachers directly propose the redox pairs of water without any justification or explanation. The task is to write the redox half-equations only.

In sum, the majority of the subjects in the experiment do not know the redox couples of water or are completely unaware that it is a redox amphoteric. This is likely to be a result of the structure of the program and the dominant style of assessment of learning that focuses on fragmented knowledge and macroscopic aspects. In fact, during high school training, learners are only expected to write the redox half-equations and the balance equation from the redox pairs that are provided. The redox pairs for water are not directly recommended by the program.

In question Q5: Write the balance equation of the reaction modeling a transformation, if any, between a) Cl^- and Br_2 b) I^- and Br_2, learners should use the oxidizing power rankings for halogens, knowing that electronegativity increases from bottom to top in the periodic table. Thus, halogens can oxidize halide anions. Therefore, Br_2 cannot react with Cl^- but Br_2 can react with I^-.

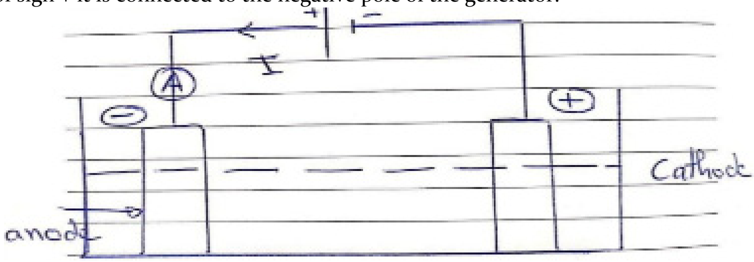
All the respondents have proposed the following equations:
$2Cl^- \leftrightarrows Cl_2+2e^-$; $Br_2+2e^- \leftrightarrows 2Br^-$: $2Cl^- + Br_2 \rightarrow Cl_2 + 2Br^-$
$2I^- \leftrightarrows I_2+2e^-$; $Br_2+2e- \leftrightarrows 2Br^-$: $2I^- + Br_2 \rightarrow I_2+2Br^-$

We quote the explanations of (TL): « *Since the chemical equations are balanced so they correspond to chemically possible transformations.* »

Based on the discussion with these learners and their statements, we deduced that during learning and formative assessment, learners in high school are asked to balance the redox half-equations without discussing the possibility of the evolution of the chemical transformation. Concerning the prediction of a given transformation, all the respondents do not rely on any method that would allow them to predict its spontaneous direction. However, the recommended high school program suggests knowing the evolution of electronegativity in the halogen column, without mentioning its role in the study of a redox transformation or in predicting the spontaneous direction of this transformation.

In question Q6: The electrolysis of a Sulfuric acid solution is carried out using copper electrodes. Draw the electrical set-up, specifying the anode and cathode, and then write the possible redox half-equations at each electrode (the sulphate ion is chemically inert in this case), the learners should make a list of the reactants likely to react and then use the redox couples: Cu^{2+}/Cu; H^+/H_2 and O_2 / H_2O. Then they should write the half-equation for the reduction of H^+ ions at the cathode, and the half-equations for the oxidation of Cu and H_2O at the anode. They should also model these possible transformations on the electrodes in the presence of a generator.

All the learners wrote only one redox half-equation which is $Cu \leftrightarrows Cu^{2+} + 2e^-$.
Concerning the modelling of these transformations, all the learners drew the below diagram and proposed the following wrong answers:
The anode is a - sign electrode, it is connected to the positive pole of the generator. The cathode is an electrode of sign + it is connected to the negative pole of the generator.



During the discussion, the learners stated that the anode always has a (-) sign and the cathode always has a (+) sign. They all defended this reasoning because they had learned it during their training. They did not understand during their training that only the electrodes of a generator are polarized. We present here the words of a high school student on the process he/she is used to in order to deal with this kind of situation:

> «*The tasks we are used to: I have to balance the redox half-equations knowing that the couples are provided in the textbook or given in the exams. Then I have to calculate the amounts of material formed or consumed*».

The learns reveals that they are not used to doing these types of exercises either during the formative evaluation or during the exams. Therefore, we proposed to these respondents an exercise from a baccalaureate exam. Here is an excerpt from this exam:

> *"Zinc is prepared by electrolysis of a solution of zinc sulphate acidified with sulfuric acid. The sulphate ions do not participate in the reaction. A metallic deposit is observed at one electrode and a gaseous release at the other. What reactions are likely to occur at the anode and cathode? The redox couples to consider are: Zn2+(aq)/Zn(s) and O2(g)/ H2O(l) ».*

We have noticed that in all the baccalaureate exams, the redox couples are provided, the task is to write the redox half-equations and then the balance equation that describes a chemical transformation. It is obvious that this type of exercise solicits only lower order cognitive abilities. These tasks rely on the memorization of facts and calculation techniques.

To this exercise, all the respondents answered as follows:

At the cathode: $Zn^{2+} + 2e^- \leftrightarrows Zn$ (s), at the anode: $2H_2O \leftrightarrows O_2 + 4H^+ + 4e^-$

We took the opportunity to ask these respondents to model these transformations using an electrical diagram. Only one learner was able to answer this task correctly.

These types of exams clearly indicate the emphasis on rote learning of procedures. These typical assessments mask the difficulties that students may encounter in relation to basic concepts. In this electrolysis problem, the learners were unable to assess the reactants that can react at the anode or cathode, to predict the possible transformations, to model microscopically the movement of the electrons given up or captured. Yet, these are the tasks that embody the scientific practices of an expert. The latter has the capacity to mobilize a range of knowledge and know-how in an integrated way.

In Question Q7: Is dissolved oxygen a stronger oxidizing agent than water? Justify your answer.

72 learners claim that water is more of an acid-base amphoteric, but O_2 is an oxidant, so we cannot say that O_2 is the most oxidant. 48 used the following reasoning: the most oxidizing is O_2 because it contains a lot of oxygen; during an oxidation it will provide a lot of oxygen to the reaction mixture.

It is surprising that all respondents were completely unaware of the properties of water and the chemical role of O_2. The structure of the program, the type of assessment and probably the teaching practices did not allow the learners to grasp the chemical roles of water and O_2. They need to understand that this is a fundamental idea in chemistry.

To sum up and answer question 2 of our research, the learners were unable to mobilize their knowledge in complex situations because teaching-learning appears to be limited to the development of declarative and procedural knowledge. Consequently, the proposed assessments only require the mobilization of lower order cognitive operations. In fact, the assessments are only based on fragments of the content to be taught, and not on integrated scientific practice. Learners are used to tasks that focus on memorization while solving textbook exercises or exams and that require only low-level thinking. These assessments are typical and classic and do not really reveal the difficulties that students have with the fundamental notions of chemistry. In this context, Cooper et al (2013) advocate avoiding typical assessments as they may mask students' difficulties with basic concepts.

Presumably, teaching practices do not seem to be based on the construction of learning and problem solving to correct misconceptions. These respondents were content to mobilize only fragmented procedural knowledge related to the macroscopic registers describing chemical transformations despite the microscopic register.

The misconceptions are mainly related to the concepts of electronegativity, polarity of a bond and the Lewis diagram, hence the need to design a more effective teaching allowing the acquisition of these main concepts by the learners. Through this teaching, the learner should understand the purpose and usefulness of these concepts. This instruction should incorporate formative or summative assessment aimed at mobilizing all disciplinary knowledge in an integrated and coherent manner. Learners will be required to solve contextualized problems based on the modeling activity. The models constructed allow the mobilization of higher order cognitive abilities.

5.2 *Results of the theme related to the mobilization of the concept of redox in everyday life*

The purpose of this second study was to investigate how familiar the respondents were with complex problem solving. All the tasks are constructed by referring to the examples of everyday life which are recommended in the program.

The analysis of the questionnaire reveals that the majority of the respondents do not have the capacity to analyze or interpret redox phenomena as recommended in the program. They were restricted to mobilize fragmented knowledge that relied solely on lower order cognitive abilities.

In question Q8, give the active constituents of two oxidizing antiseptic solutions, specifying their Ox / Red pairs. Learners should know the solutions of bleach and hydrogen peroxide as antiseptic solutions. These two examples are recommended in the program. However, the program designers did not specify either their redox couples or the chemical manner in which they react.

Only 6 learners proposed correct answers: a solution of bleach ClO^- and a solution of hydrogen peroxideH_2O_2; the redox couples are ClO^-/Cl^- and H_2O_2/H_2O 114 learners proposed an incorrect answer: $Fe^{3+}/Fe^{2+}$and MnO_4^-/Mn^{2+}

The discussion with the (TL) revealed that $Fe^{3+}/Fe^{2+}$and MnO_4^-/Mn^{2+}, among others, the most used redox couples in high school teaching, especially in a colorimetric dosage. And with practice and repetition, these couples became anchored in their memories. It is therefore obvious that if knowledge is not built up in a coherent way, then learning becomes meaningless and rote learning becomes predominant.

Question Q9: Consider the following chemical equation: $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

This transformation is used in the fuel cell recommended in the high school and university programs. The constituents of this cell are different from those of the Daniell cell, which is based on metal plates and their metal ions. We wanted the interviewees to provide as much relevant information as possible on this transformation and on the didactic approaches adopted in teaching the fuel cell.

First question: Is this transformation a redox transformation?

Second question: Can this transformation be used to produce electricity?

Third question: Is it a forced or spontaneous transformation?

The program recommends studying a few cells used in everyday life (such as fuel cells, Leclanché cells, etc.). However, there is no indication of the content to be taught, the learning activities, or the cognitive skills to be developed.

85 learners answered as follows: It cannot be a redox transformation because the two gases do not contain free electrons to be exchanged, rather it is a combustion reaction. 25 learners answered: It cannot be a redox transformation because it is an addition reaction without electron exchange. 10 learners answered: It is a redox transformation, the equations involved are: $H_2(g) \leftrightarrows 2H^+(aq) + 2e^-$; $1/2\ O_2(g) + 2H^+(aq) + 2e^- \leftrightarrows H_2O(l)$, the balance equation is : $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

The answers to the second question regarding the possibility of using this transformation to produce electricity are as follows:

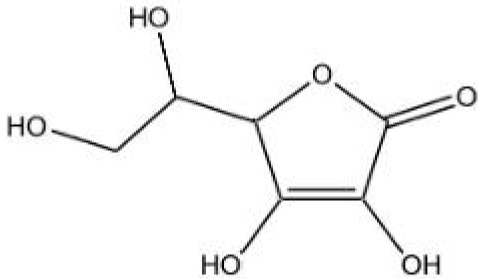
103 learners answered: This transformation cannot be used to produce electricity because the two reactants are gases and are not metals.
17 learners offered the following response: The transformation is redox so we can use it to produce electric current but the medium is not conductive because there are no ions.

As for the question: is it a forced or spontaneous transformation, the answers are as follows:

55 learners pointed out that it is a forced transformation by a flame, it requires a very high thermal energy, 42 proposed as an answer: This transformation can be neither spontaneous nor forced because it is not a redox transformation
23 learners answered: The two gases are in air, so there is no reaction between them and therefore this transformation is forced.

The majority of those interviewed seemed unaware that combustion is also a redox transformation.

From the discussion with (TL), we deduced that during learning and formative or summative assessment, learners are only expected to balance the redox half-equations without discussing the possibility of the evolution of the chemical transformation that describes the operation of the fuel cell. Learners do not solve problems aimed at challenging their conceptions. They have not constructed problems in class with their teachers whose solution requires the integrated mobilization of a range of knowledge linked to the macroscopic and microscopic registers.



In question Q10: In the food industry, ascorbic acid is used as an antioxidant, explain why: use the semi-developed formulae and then write the half-equation which models the oxidation of the organic function carried by carbons 2 and 3 (C2 ene-diol function), learners should consider that ascorbic acid with the empirical formula $C_6H_8O_6$ is a reducing agent that reacts readily with a variety of oxidants, including oxygen in air or in solution. This acid can act as a reducing agent and oxidize instead of food (such as fruit), resulting in a slowing of their oxidation by dioxygen. They should predict that the ene-diol function can oxidize in the presence of O_2 to become a ketone. This transformation is used to preserve food.

Not all respondents were able to provide an explanation for the fact that ascorbic acid is an antioxidant.

Most learners reasoned as follows: since ascorbic acid is an acid so its transformation is:$C_6H_8O_6 \leftrightarrows C_6H_7O^-_6 + H^+$
When we proposed the couple $C_6H_6O_6/C_6H_8O_6$ to them, they were all able to write the following half equation: $C_6H_8O_6 \leftrightarrows C_6H_6O_6 + 2H^+ + 2e^-$.

This last chemical equation requires only the mobilization of procedural knowledge. Moreover, this type of task is preponderant in their learning, including in formative and summative evaluation activities.

The (TL) stated that ascorbic acid cannot be a reductant; rather it is an acid, because most exercises and exams are based on the acid-base determination of this substance with sodium hydroxide solutions.

all the respondents reasoned in the same way, estimating that ascorbic acid is an acid so it releases an H^+ proton.

The high school program only requires knowledge of ascorbic acid as a reductant, but without any indication of its redox couples or how it can act.

Also, we found that the chemical properties of this acid are not reinvestigated in the organic chemistry program. Consequently, the knowledge remains superficial due to its linear and non-spiral construction.

In question Q11: Bleach labels read: « When in contact with an acid, a toxic gas is released. This gas is very dangerous to health. This solution must be kept in opaque containers». Explain chemically in a detailed way these two indications.

The reasoning should be based on:

Bleach is a very basic solution. The properties of this solution are due to the oxidizing nature of the hypochlorite ions ClO^-. These ions can give rise to various reactions;

- In a basic medium, the hypochlorite ion reacts slowly with water;
- In an acidic environment, the hypochlorite ion dismutes and gives the gas Cl_2 and the ions Cl^-.

Not all learners were able to answer this question. They suggested giving them the redox or acid-base pairs to answer. Regarding the second question, 100 learns answered as follows:

The opaque container prevents the reaction of bleach with UV light, but they did not specify the origin of this transformation.

As pointed out above, the high school program only requires knowledge of bleach as an oxidizing substance, but without any indication of how it can act. Similarly, in chemical kinetics, the program has not taken into account the reaction of bleach with water. Instead of this transformation, the program recommends studying the kinetics of the oxidation of iodide ions by peroxodisulphate ions $S_2O_8^{2-}$. Thus, we deplore a teaching devoid of meaning and not built according to a spiral approach. The learners do not grasp the applications of the transformations in everyday life.

To sum up and to answer question 3 of our research, the learners were unable to mobilize their knowledge in situations that give meaning to learning. In fact, the majority of respondents did not understand chemical phenomena related to everyday life and which are interpreted by the concept of redox. The learners were not able to articulate the basic concepts to be able to explain the principle of operation of a fuel cell. The actions of bleach, ascorbic acid and oxygen are not known by the majority of learners. Indeed, the learners can only mobilize certain fragmented knowledge which is insufficient to describe and explain the chemical phenomena contained in the program. They are used to typical assessments that do not rely on modelling activity and on the articulation between the experimental and theoretical aspects. It seems that teaching practices are not based on activities that allow the learner to construct knowledge, to articulate it and to be able to mobilize it in new situations related to the applications of chemistry in everyday life.

6. Cross-Analysis of the Different Results

The designers of the chemistry program proposed the content to be taught, the pedagogical activities and the abilities to be developed. However, they did not indicate the skills to be developed by the learners in relation to those prescribed in the curriculum. Although, the curriculum recommends that the pedagogical renovation is to be based on the competency-based approach, the prescribed abilities as presented in the section "Competencies required" seem to support a behaviorist teaching-learning approach, as these abilities are spelled out in the form of fragmented behaviorist operational objectives.

A total of 32 teaching objectives are recommended for the topic of redox. These objectives are neither organized nor grouped around specific skills to be developed.

We can therefore deduce that the redox program is developed according to an approach that does not allow the sustainability of learning; it is an approach that is not appropriate for the construction of skills. Thus, the structuring and articulation of knowledge are not relevant. This analysis of the program confirms our first research hypothesis, which states that the structuring and articulation of disciplinary knowledge related to the concept of redox in the program are neither relevant nor in harmony with the spiral progression.

On the other hand, the majority of the respondents do not master the fundamental knowledge that allows them to interpret the different chemical transformations and, on the other hand, they are unaware of the applications of these transformations in everyday life. This fact confirms our second hypothesis that the knowledge and teaching activities selected by the designers of the program have no effectiveness on the scientific training of learners.

The discussion with some of the respondents allowed us to deduce that the learners during their lessons are only supposed to write down the balanced reactions and then to make a balance of the material formed or consumed. From these facts, the erroneous reasoning used by the respondents are the consequences of the didactic transposition operated by the designers of the program, of the teaching practices and of the type of formative or summative evaluation.

7. Conclusion and Implications

This research aimed to investigate the conceptual framework mobilized by learners to solve theoretical and everyday life situations modeled by chemical transformations. The results of this questionnaire reveal that these respondents experience major epistemological difficulties related to the knowledge of the topic to be taught. The notional resources poorly mobilized by the respondents are mainly those related to the microscopic and theoretical registers that allow the prediction of the possibility of a transformation. The actors interviewed are unaware of almost all the application of the concept of redox in everyday life.

On the other hand, the analyses of the program show that the cognitive abilities mobilized by the learner to carry out the tasks proposed to him/her belong only to the lower taxonomic level of the kind: to write the redox half-equations, to deduce the balance equation, to identify the oxidizer or the reducer of a redox couple, to recognize the anode, the cathode, to carry out a table of progress to calculate the quantities formed or transformed. We note the absence of higher order abilities such as: analyzing, interpreting, arguing, making a synthesis, or proposing an experimental protocol to verify a hypothesis.

Knowledge is not introduced in a logical progression, with the aim of achieving a spiral integration of the different chemical concepts. This favors fragmented learning and a linear construction of learning. We can then say that the didactic transposition operated in the program for the conceptualization of the concept of oxidation-reduction favors only the memorization of declarative and procedural knowledge, and consequently the learning remains superficial.

We argue that the structure of the syllabus and the type of assessment adopted in the baccalaureate examinations are at the root of the problematic results found among the respondents. The majority of these respondents were unable to relate the chemical properties of several substances to concepts related to their microscopic structures. This link is a fundamental idea for interpreting chemical transformations.

On the basis of the results obtained, we recommend that the program designers carefully reform the study contents, especially in their progression, to improve the learners' understanding of the fundamental concepts of chemistry. At each school level, aspects related to the microscopic register should be developed and integrated progressively in order to promote learners' achievements. Learners should understand the relationship between the microscopic structure and the macroscopic properties of a substance. Particular emphasis should be placed on water, which undergoes the majority of chemical transformations. The learner should know that microscopically water has the properties of a polar, redox amphoteric and acid-base amphoteric solvent. The mastery of these fundamental concepts must be achieved by adopting pedagogical methods that mobilize problem solving based on modelling activity. Through these methods, learners mobilize high-level cognitive skills. And to make sense of these concepts, emphasis should be placed on contextual and authentic problem solving during the process of learning development, during formative and certificate assessment.

The remainder of our research aims to present an exploratory analysis of the topic of redox in textbooks in order to investigate the adequacy of teaching and learning activities with the requirements of a competence-based approach. We will present teaching-learning activities that we consider to be more efficient. These situations were developed by trainee teachers under our supervision. We will discuss the results of their classroom experiments in collaboration with teachers responsible for the internships.

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Appendix 1: Table I shows the content to be taught on redox in the three years (the content to be taught is the result of an external transposition made by the program designer's)

The content to be taught in 3rd Middle school	The content to be taught in 2rd high school	The content to be taught in 3rd high school
1) Conditions for rust formation. 2) Role of oxygen in iron corrosion 3) Oxidation of aluminum 4) Formulations of metal oxides 5) Combustion of organic materials in air. 6)Action of hydrochloric acid and soda on iron, zinc, aluminum and copper.	1) Examples of redox reactions by electron transfer (transfer of electrons between a metal and a metal cation. 2) Definitions of oxidant and reductant 3) Concept of the OX/Red couple. 4) Write the equation for the reaction between an oxidant and a reductant, the oxidant-reductant pairs being given. 5) Know examples of reducers and oxidants from the table of chemical elements. 6) Know some Common Ox/Red pairs. 7) Know some applications of redox reactions in everyday life. 8) Know some examples of reducing and oxidizing agents in everyday life (ascorbic acid, bleach, hydrogen peroxide...) 9) Redox determination Manganimetry 10) Combustion of hydrocarbons and alcohols. 11) Controlled oxidation of a primary and secondary alcohol. 12) Controlled oxidation of an aldehyde	1) The kinetic factors of a slow redox transformation transformation. Microscopic interpretation. 2) The spontaneous exchange of electrons between a metal cation and a metal (the two reactants are either in contact or separated) 3)The experimental realization of the Daniel cell 4) The role of the salt bridge. 5) The conventional diagram of a battery. 6) The notions of anode and cathode 7) Batteries, devices involving spontaneous transformations allowing energy to be recover energy. 8) The use of the spontaneous evolution criterion to determine the direction of movement of charge carriers in a cell or to determine the direction of movement 8) The use of the criterion of spontaneous evolution to determine the direction of movement of charge carriers in a cell or to predict the poles of a battery. 9) The relationship between the quantities of matter of the species formed or consumed, the intensity of the current and the duration of the transformation, in a battery, the concept of Faraday's constant. 10) Study of some common cells (the salt cell and the alkaline cell, the hydrogen cell, etc.). 11) Experimental realization of a forced transformation. 12) Study of some reactions at the anode and cathode during electrolysis. - 13) Study of some applications of electrolysis (Study of the lead-acid battery, electro-zinc plating, chromium plating...) - 14) Study of respiration and photosynthesis