Research Article

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Epistemological and Didactic Difficulties of Teaching Chemistry in Moroccan High Schools

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Abstract

This article focuses on the difficulties faced by actors in the process of teaching and learning chemistry, in particular the concepts of redox and acid-base. As to methodology, two tests were developed to conduct two empirical studies. The first test to identify the conceptual difficulties encountered by these actors when teaching the concepts above. The second test examines the skills mobilized by in-service and preservice teachers at the training center to solve daily life situations involving knowledge covered in the high school program such as electronegativity, polarity of a chemical bond, oxidation state of a chemical element, Lewis structure, rules or laws allowing the prediction of a spontaneous transformation, microscopic modeling of a chemical transformation and the classification of the different ox/red pairs, based on standard potentials. The results of these two studies reveal that preservice and in-service teachers have epistemological deficiency related to the knowledge to be taught and are unable to mobilize the appropriate knowledge to solve practical chemistry problems. Consequently, they cannot mentor learners to acquire the skills assigned in the chemistry curriculum: in particular, solving the problems providing from real and daily life. Individual interviews allowed us to better explain the dysfunctions causing these difficulties.

Keywords: *Teaching, chemistry, epistemological difficulties, teachers, skills, chemistry curriculum, problems solving*

1. Introduction and Research Questions

In Morocco educational centers, the secondary cycle combines both middle and high school cycles. Each of these cycles has three levels. If students pass the exams in the last year of high school, they get a diploma qualified as the gateway to higher education.

This research focuses on analyzing the epistemological and didactical difficulties related to chemistry teaching at high school, in particular the concepts of oxidation-reduction and acid-base.

In fact, the success of the teaching-learning process is not only about teachers mastering some declarative and procedural knowledge, but also mobilizing it in contextualized situations which will make it meaningful.

According to the Moroccan chemistry curriculum in high school (The Moroccan High school chemistry curriculum), teachers should provide students with a scientific culture associated to environmental education, health and scientific actualities. Moreover, they have to guide them, during the teaching-learning process to acquire modelling methods and solving problem situations strategies, notably those from daily life, while mobilizing a corpus of knowledge for this effect.

In order to find out what the situation is in practice, we asked the teachers, responsible for supervising the traineeships of future teachers, about the difficulties of teaching chemistry in conformity with the official guidelines at the high school, especially in the final year. These teachers report difficulties in chemistry teaching/learning in general and the topic of redox particularly. These difficulties are principally epistemological and didactic.

These results have led us, as researchers and trainers, to investigate these various difficulties. This choice is motivated by the fact that successful teaching of chemistry requires teachers to master the content to be taught, as well as different teaching approaches and methods. These approaches allow students to be implicated in the construction of their learning through contextualized activities giving meaning to the concepts studied. The approach adopted should be based on questioning students through triggering situations, problem-solving and activities connected with their interests and providing of their daily life.

With this perspective, we have attempted to answer the following research questions which concern both in-service and trainee teachers.

1. What are the major difficulties associated with the main concepts of chemistry at high school?
2. What are the major difficulties related to the mobilization of these concepts in the resolution of everyday situations?

2. Theoretical Framework

In Morocco, the physics-chemistry curriculum officially recommends the competency-based approach which requires solving problems that can be defined as didactic situations built around an obstacle. This obstacle should cause a cognitive conflict to the students, and the knowledge to be learned is the relevant tool to solve these problems (Douady, 1984).

In chemistry, problem solving is based on experimental and theoretical activities and on the modelling approach (Boilevin, 2013). The theories and models used to describe chemical transformations and their consequences are based on macroscopic and microscopic descriptions of entities (Johnstone, 1993). We consider that the diversity of models and their different functions (explanation, prediction, representation, description, determination of a quantity) may provide a bridge between the empirical registers of macroscopic or microscopic domain and the theoretical registers of the chemical transformation's thermodynamic, their kinetic theory.

The construction of knowledge in chemistry mobilizes conceptual tools allowing the development of the abstraction capacities necessary to relate the elements of the material world (observable objects and events) and elements of the theoretical world (Kermen & Méheut, 2009).

In the case of the chemical reaction, Taber (2013) considers chemical language as a relay for reasoning both on the macroscopic (chemical substances, solutions) and on microscopic entities based on the same symbols. However, using the same register of representations for several interpretations can make a learning difficulty for students. Chemistry teachers should therefore take into account the semantic charge conveyed by the signs of chemical symbolism (Dehon & Snauwaert, 2018).

The study of teachers' professional knowledge often refers to Pedagogical Content Knowledge (PCK) and concerns knowledge specific to teach (Shulman, 1987). This PCK includes four areas of teacher's knowledge (Grossman, 1990): General pedagogical knowledge, disciplinary knowledge, contextual knowledge and didactic knowledge related to disciplinary content. In this last area, the teacher must carry out a didactic transposition of the different chemical concepts, making them educationally accessible by considering the cognitive development and prerequisites of the learners (Chevallard, 1985). Therefore, it is important to consider the teacher's knowledge as indissociable from the issues of knowing, and cannot be studied or understood without taking into account the specificities of the disciplinary contents (Amade-Escot, 2000).

The process of didactic transposition consists of three phases as stated by Perrenoud (1998): The external transposition carried out by the conceptors of curriculum and the content to be taught, the internal transposition by textbook makers and teachers, who translate the teaching contents into teaching activities, may permit the building and developing skills in conformity with officials' orientations. We note that in the scientific education, a distinction must be made between the chemistry of scientists, the chemistry to be taught, the chemistry taught, the chemistry acquired by students at school and the chemistry assessed by the education system officials (Boilevin, 2013).

The knowledge to be taught and the knowledge indeed taught undergo, at the different stages of their selection and teaching, a complex process of transformation, which involving knowledge fundamentally divergent from academic knowledge (Petiot & al, 2016).

This leads to consider the functioning of the didactic system modeled by the didactic triangle centered on the ternary and irreducible relationship between the teacher, the learners and the knowledge taught. The Teacher-Knowledge axis characterized by the teaching process indicates the importance for the teacher to master the area of the knowledge to taught and how to illustrate it. The teacher has to transpose the knowledge to be taught to the knowledge taught. The Student-Knowledge axis concerns the learning process and considers how students learn and assimilate content, but also their representations and pre-understandings as well. The last axis Teacher-Student concerns the forming process and deals with the knowledge of classroom interactions and group dynamics as well as the ability to manage them in other words, the leadership and teaching style. As Serghini (2022) point out that, the epistemic, pedagogical, didactic, psychological and social dimensions that constitute practice, interact with each other to enable the teacher to adapt to the professional situation and to manage the students' learning at the same time.

These elements related to the functioning of the pedagogical and didactic system underline the importance of the teacher's skills in terms of the content to be taught, didactics, pedagogy and the notion of social reference practices. We assume that the notions of social reference practice and didactic transposition are complementary and constitute the central pillars of teaching. Indeed, the social practices of reference are sources that feed the teaching activities via external and internal transpositions in order to give meaning to learning (Lebeaume, 2001).

In this regard the official Moroccan guidelines specify that teaching must establish an integrated scientific culture among the students in connection with environmental education, the other disciplines, the history of science and current scientific events. In this context, Martinand (1989) has elaborated the concept of social reference practice. He investigates the links between the aims and teaching contents with daily situations taking place outside the school. In physics teaching, the use of natural and technical phenomena as social practices has become essential to make more sense to the learning. Therefore, it is important to develop an appropriate problem-situation from the student's environment and guide him/her to overcome the epistemological obstacles necessary to construct new knowledge (Bachelard, 1947). However, problem situations are complex to develop, plan and practice by teachers (Venturini &Tiberghien, 2012). For those considerations, the temporal organization and progression of learning should also integrate a reflection on the issue of epistemological obstacles during external and internal didactic transposition (PASTRE, 2008).

Given the crucial role of the teacher and in order to ensure the didactic transposition which falls to him/her in a teaching context based on the competence approach and socio-constructivism, in addition to master the knowledge, he/she must grasp the meaning of the concepts taught. He/she must also be able to mobilize them in situations of the pupil's daily life in order to make the established learning more meaningful.

3. Research Methodology

This research focuses on the study of didactic and epistemological difficulties in the teaching and learning of chemistry in general and the concept of redox in particular. Thus, we carried out an experiment, using a questionnaire to identify the conceptions that preservice and in-service teachers at high school have when mobilizing the concepts of chemistry in daily situations and problem solving.

The objective of this paper is to identify the conceptual network mobilized by the interviewees to model chemical transformations and explain daily life situations.

This experiment involved 180 preservice teachers and 150 in-service teachers working in different Moroccan high schools.

The questionnaire administered for this purpose contains 22 items in the form of open questions (Index). The first thirteen questions cover the epistemological aspects of chemistry. The other questions are about the concept of redox, in particular its daily applications as recommended in high school cycle. These items were based on the interviews results with tutors of trainee teachers in schools. The interviews focused on the main aspects of chemistry qualified as problematic in the teaching and learning of chemistry especially redox.

Through the open questions of this survey, candidates should mobilize the following resources, which constitute almost all the basic concepts of the content to be thaught in the high school cycle namely the concept of electronegativity and its evolution in the periodic table of chemical elements, the polarity of a chemical bond, the oxidation state of a chemical element, Lewis diagrams, rules or laws allowing the prediction of a spontaneous transformation, microscopic modelling of a chemical transformation and the classification of the different ox/red pairs, based on standard potentials.

Answering the questions requires using the notional content recommended in chemistry curriculum, except for question 7 and 9 which aim to classify ox/red couples according to their standard potential. This choice is motivated by the role of standard potentials in the classification of redox couples to be mobilized by the teacher in the selection of appropriate reagents leading to chemically possible transformations.

For a better exploitation of the questionnaire results, we developed an evaluation grid based on the degree of mastery of each notional resource by considering the following scale: mediocre, fair and good. The mention “mediocre” corresponds to false or insignificant propositions or entirely absent; whereas "fair" concerns correct propositions but with incomplete or unsatisfactory justifications. As for «Good", it refers to correct proposals and justifications.

4. Results And Discussion

The analysis of the survey revealed that the majority of the research subjects had little or no mastery of the aspects related to the conceptualization of the various concepts of chemistry for the high school cycle. Indeed, as illustrated in the diagram below, a large majority answered incorrectly to the items related to the epistemological aspects.

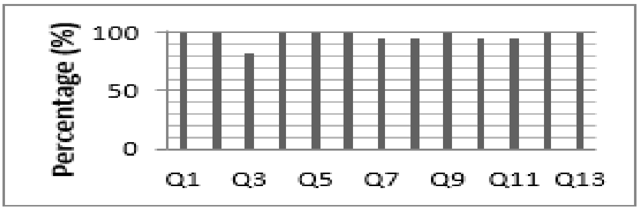

Figure 1. Percentage of respondents with a mediocre level of mastery, concerning the conceptualization of concepts of chemistry.

If we consider, for an example, in the first question, candidates were asked to give with justification, the Acid/Base pair, to which CH_3COOH and CH_4 belong.

10 teachers explained that the molecule CH_4 cannot be an acid since methane is a gas. However, in high school's syllabus, HCl is studied as a strong acid in water, and yet it is a gas.

140 teachers and all the trainees used the following reasoning:

$$CH_3COOH \rightleftharpoons CH_3COO^- + H^+$$

the couple is CH_3COOH / CH_3COO^-

$$CH_4 \rightleftharpoons CH_3^- + H^+$$

the couple is CH_4 / CH_3^-

The participants did not use the concept of electronegativity or the notion of the least bonded hydrogen in a polar bond. Therefore, for them, each molecule that contains hydrogen constitutes an acid. However, the CH_4 molecule cannot be an acid. We have also observed the total absence of modelling of transformations at the microscopic level.

In question Q3, participants were asked to give the redox couples of water and to justify their answer.

Only 28 in-service teachers and 10 preservice teachers gave the redox couples of water in a correct way but without explanation.

The others proposed the following pairs H_3O^+/H_2O and H_2O / HO^- which are the acid-base pairs of water and not its redox pairs.

Teachers should use Lewis diagrams, the oxidation state of oxygen and hydrogen in order to answer this question.

In Q4, candidates were asked to justify the possibility, or not, to balance the element oxygen, in a redox half-equation, with O_2 instead of H_2O.

No answers were given by the trainee teachers however 40 in-service teachers proposed the following: " To balance the element oxygen, you have to add H_2O, it is like a law". Some added that balancing with O_2 will complicate the explanation for students. Ten other teachers replied that oxygen is a non-polar gas, so it cannot exist in aqueous solutions.

Teachers should mobilize, among other things, the concept of the oxidation state of a chemical element in order to answer this question.

In the next question, participants had to write the balance equation for the reaction between Cl^- and Br_2.

Five in-service teachers answered that all halogens have the same chemical properties, therefore no reaction is possible between Cl^- and Br_2. The other participants gave the balance equation for the following reaction:

$$Br_2 + 2Cl^- \rightarrow 2Br^- + Cl_2$$

However, chemically, no spontaneous transformation is possible, since Cl_2 is more oxidising than Br_2. Not all participants were able to use a rule or law to predict the possibility of a spontaneous transformation. For example, the oxidising power increases from bottom to top in the halogen column.

In question Q8 they were asked to model microscopically the reaction between zinc and copper (II) ions. Not all respondents were able to model this reaction microscopically, but all gave its macroscopic model.

In question Q9, they were asked to give three noble metals with the chemical meaning of their appellation.

30 in-service teachers attested the existence of noble gases but not nobel metals. Others suggested, without justification, gold as the only noble metal.

A noble metal is a metal that is resistant to oxidation and corrosion. It is not a synonym to precious metal. Chemically its outer shell is complete, besides this, that this metal is less reductive than H2 gas. This is the case for copper, silver and gold.

Question Q10: In the Daniell cell, the copper plate is the cathode (the + terminal), and the zinc plate is the anode (the - terminal). What is the significance of the (+) and (-) terminals of an electrochemical cell?

Only 12 candidates answered, and consider that experimentally the current flows out of the copper plate and passes to the zinc plate, therefore the copper plate is the (+) terminal.

The majority were unable to use the concept of the potential of an electrode and to refer to the equivalence between that electric current and a hydraulic current which can be caused by a difference in height, whereas in a battery the current is caused by a difference in potential. The potential of the zinc electrode is the smallest. Therefore, this electrode is the (-) terminal.

The figure 2 illustrates the answers given regarding the daily applications of the redox concept.

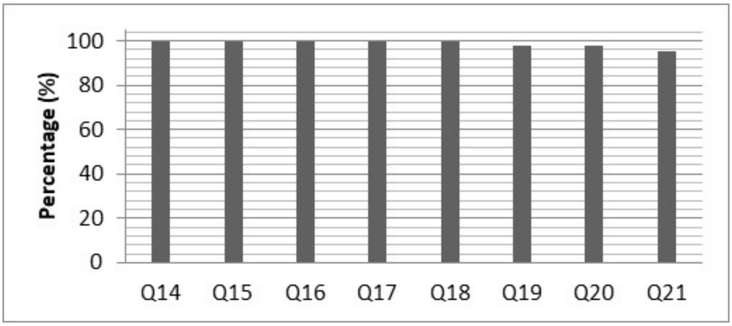

Figure 2. Percentage of interviewees with poor mastery of the application of the concept of oxy-reduction in daily life

In question 15, students were asked to justify whether bleach can or cannot be mixed with acid solutions. 10 teachers answered that bleach is a strong acid and can be mixed with acidic solutions because no transformation is possible, however bleach can react with basic solutions. All the interviewees were unaware that bleach is a basic solution, essentially made up of the hypochlorite ion, which is classified as a powerful oxidant that undergoes a disproportionation reaction in an acidic medium, releasing chlorine, which is a toxic gas.

As to the question “What is the scientific contribution to the students of the study of alcohols combustion recommended in the 1st Bac (2nd year of high school program)?”, all the candidates answered that students should write the equation of the reaction and to carry out a material balance aiming to calculating the formed or transformed quantities. None of them mentioned the usefulness of the energy aspect of this transformation, nor the polluting aspect caused by the emission of gases responsible for the greenhouse effect.

These results show that teachers and trainee teachers have difficulties in explaining the phenomenon of iron corrosion, and they almost unaware of the majority of applications of redox in daily life. However, the mobilization of knowledge in everyday life is an the major objective of for teaching-learning process, besides it gives meaning to learning.

The data we collected by doing individual interviews with in-service teachers and group discussions with trainees allow us to identify several causes of this dysfunction. We can summarize their statements as follows:

- The exercises suggested in high school courses target only the mobilization of declarative and procedural knowledge. Through these subjects, students are supposed to just write the redox half-equations, the equation of the reaction and to carry out a material balance aiming to calculating the formed or transformed quantities, and all the studied transformations are modeled in a macroscopic way. Logically, teachers align their practices with the baccalaureate subjects including assessment practices.

- These actors are unable to develop problem situations based on activities related to daily life. These activities are not spelled out either in the program or in the textbooks.
- During their studies at the university, the training was based on a very theoretical program.
- The training was disconnected from any epistemological contribution, without a link to the applications of chemistry in everyday life. It does not allow the development of a scientific culture also the interpretation of the studied transformations is based only on the macroscopic registers.
- The training of these interviewees during their academic cursus has been based on a transmissive teaching, which aims only at the mastery of declarative and procedural knowledge.

However, the success of this teaching requires a teacher who correctly masters the knowledge to be taught and the different pedagogical approaches allowing to guide the student in teaching-learning situations through activities associated with the social practices of reference. Indeed, at the institutional level, the challenge of teaching chemistry in middle and high schools is the acquisition by the students of a body of knowledge and knowing-how, but also the development of disciplinary and transversal skills. These skills require the effective mobilization of a set of resources in problem solving. Their development is an evolutionary process that continues throughout the training. These targeted skills are listed in the table below:

Table 1: The competences recommended in the high school cycle.

Disciplinary competences	Transversal skills
1) Mobilizing in an integrated way, disciplinary knowledge to solve problems; 2) Implement steps of an approach to solve a problem. 3) Use models and laws to describe chemical transformations; 4) Implement an experimental protocol in accordance with safety rules.	1) Understanding the scientific method in its various dimensions; 2) Acquire a scientific vocabulary to perform common procedures (mathematical treatment; data collection, argumentation, ...); 3) Acquire research and self-study methodology using TICE and working in groups; 4) Develop an integrated scientific culture that is linked to the environment and health.

The development of these skills among students requires the teacher's mastery of knowledge as well as approaches based on socio-constructivism. Moreover, the curriculum of physics and chemistry stipulates what the student should be at the heart of the learning process and an effective actor in the construction of his knowledge. Thus, the teacher must suggest intriguing activities related to the interests and the daily life of the student. The approach must be based on interrogating the student through triggering situations and problem solving. These activities will induce a break with the learner's prerequisites and mental representations. This pedagogical approach allows the student to develop higher order cognitive abilities (analyzing, arguing, formulating a synthesis).

5. Conclusion and Perspectives

In this paper, we aimed to identify the conceptual network mobilized by in-service and preservice teachers to solve daily situations modeled by redox and acid-base transformations. Our objective, through a survey intended for these actors, was to apprehend the conceptual difficulties encountered by these actors during the chemistry teaching. The results reveal that the participants experience major epistemological difficulties relating to the knowledge of the content to be taught. The notional resources poorly used by the participants are mainly those linked to the microscopic and theoretical registers that allow the prediction of the possibility of a transformation. Findings show that the participants are unaware of the application of the concept of redox in an authentic context which they are supposed solve. Therefore, they cannot guide the students to acquire the skills assigned in the chemistry curriculum and to solve a real-life problem.

Based on these results, we plan to identify and analyze the students' representations of the topics in the survey, the more detailed analysis of the chemistry curriculum, and the teaching practices.

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Annex

Q1: Give (with justification) the Acid/Base pair, to which belong the following compounds: CH_3COOH and CH_4.

Q2: Explain why H_2O is an ampholyte redox?

Q3: Give the redox pairs of water justifying your answer.

Q4: Is it possible to balance the oxygen element, in a half-equation redox with O_2 instead of H_2O?

Q5: Write the balance equation of the reaction between Cl^{-} and Br_2.

Q6: Give an example of reducing anion acid and an example of oxidizing anion acid.

Q7: Give the classification of the following elements according to their reducing power: Al, Cu, Zn, Li, Au, Fe, and H_2.

Q8: model, in a microscopic way, the oxidation-reduction transformation between zinc and copper ions (II).

Q9: Give three noble metals. In what chemical sense are they called noble metals?

Q10: In Daniell cell Zinc serves as the anode (Terminal (-) and Copper serves as the cathode (Terminal +). What is the meaning of the (+) and (-) terminals of an electrochemical battery?

Q11: Bleach contains a very useful oxidizing agent. What is the name of this oxidizing agent and what is its redox couple?

Q12: bleach should be kept in opaque containers. Why?

Q13: Write the reaction equations of photosynthesis and of the reaction of cellular respiration. Do the two previous transformations constitute spontaneous or forced transformations?

Q14: Can an iron pieces be cleaned with bleach? Justify.

Q15: Can bleach be mixed with acid solutions? Justify.

Q16: Can you cook a tomato sauce in an iron pan? Justify.

Q17: Can you cook a tomato sauce in an aluminum pan? Justify.

Q18: In the food industry, ascorbic acid is used as an antioxidant. Explain why?

Q19: Give the principle of a breathalyzer?

Q20: Iron corrosion is an electrochemical transformation with the humid or aqueous atmospheric environment. Write the half-equations redox, and then explain this electrochemical phenomenon.

Q21: The electrolysis of a Sulfuric acid solution is carried out using graphite carbon electrodes. Draw the electrical assembly, specifying the anode and the cathode, then write the possible half-redox equations at each electrode.

Q22: What is the scientific intake to learners following the study of alcohol combustion recommended in the high school program?