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# EFFECT OF A NEW TEACHING MODEL USING COMPUTER SIMULATIONS ON PUPILS CHEMISTRY KNOWLEDGE AND SKILLS: A CASE STUDY

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**Abstract-** This paper aims to study the effect of including computer simulations in the problem-based learning method (PBL-SIM) on Moroccan pupils' learning of knowledge and skills in chemistry related to the electrochemical cell concepts. In a quasi-experimental design, pre- and post-tests were conducted before and after the teaching interventions, respectively. The pupils 'sample (160) of two high schools in Beni-Mellal city (Morocco) was divided into experimental and control groups, each with 80 pupils. The experimental group (EG) was taught the electrochemical cell's topics using PBL-SIM, whereas the control group (CG) was taught the same topics using the conventional lecture method. Descriptive and inferential statistics were used with the SPSS software to describe and compare the generated results. The analysis's findings indicate that the experimental group benefited significantly from the PBL-SIM method. Indeed, the EG pupils in the experimental group, taught by PBL-SIM, perform efficiently on all the questions of the posttest, for both knowledge types (CK and PK) or for total knowledge, there is a statistically significant distinction in the results between both groups in favor of the EG group with an average rank of (CK: 102. 25, PK: 102.64, total score: 102.58) versus the average rank of the CG group (CK: 58.75, PK: 58.36, total score: 58.43). This study showed that using the PBL-SIM method in learning conceptual and procedural knowledge related to electrochemical cell topics is efficient to improve the performance of high-school pupils in chemistry concepts.

**Keywords:** Computer Simulations, Teaching, Performance, High School, Electrochemical Cell, Knowledge.

## 1. INTRODUCTION

The theory and practice correlations generally lead to difficulties in understanding scientific and particularly chemical concepts at high school, where pupils start to develop observing, analyzing, and concluding skills. Various ways, approaches, models, and strategies were used in teaching and learning science, which required knowledge and complex skills to overcome cognitive constraints and learn the pupil's progressions [1]. So, it is usually beneficial to use and experiment novel techniques or methods to make the construction of chemical concepts easier for pupils. The chemistry learning in high school, where concepts are used to describe some expansive invisible worlds, affects the pupil's imagination and their own representations, which could be considered as alternative conceptions and inadequate scholarly knowledge and skills [2]. These conceptions reduce the learner's effectiveness in scientific reasoning and may even become insurmountable obstacles to his or her learning of chemistry.

Four distinct models were identified for teaching and learning redox reactions are:(1) the oxygen model based on oxygen transfer; (2) the hydrogen model, which takes into account the transfer of hydrogen; (3) the electron transfer model involving the exchange of electrons in reactions; and (4) the oxidation number model, which corresponds to a decrease or increase in the oxidation number during the reaction. Educational establishments employ the four redox reaction models to teach redox reaction topics [3]. The complex nature of pupils' conceptions in chemical fields cannot be restricted to simple suppositions and similarly applied arguments without taking into account the context. Misconceptions are conceptual difficulties that pupils may encounter in the explanation of chemical concepts as they are accepted by the scientific community [4].

Alternative concepts need to be considered in teaching as some teachers often use surface features (including color, shape, and dynamic aspects) of different representations to construct a learning of chemical phenomena. It is difficult to cross the boundaries of these representations and link them to understand the surface features on which the pupils reasoning is based [5]. Educational researchers have compared, for a long time, conventional learning methods to that using computer simulation in acquisition of scientific concepts, since simulations are more effective than conventional teaching methods [6].

Several researchers showed that computer-assisted instruction (CAI) is more effective than normal teacher-based methods in increasing academic achievement. Indeed, learners can acquire educational content faster with CAI than with traditional methods, and retention levels can be better with CAI. Investigation of CAI effects on the achievement and problem-solving competencies of science and technology showed that the implementation of interactive learning models helps learners to improve their achievement and develop their problem-solving skills. It has been shown that pupils are more effective and motivated to learn using computers, and then increased their self-confidence, which is not the case with some conventional methods [7].

In chemistry using CAI allowed pupils to reorganize their thinking on chemical phenomena and procedures and to construct useful mental models. It was claimed that CAI offers pupils the opportunity to enhance their conceptual thinking and form good-quality mind models. In the learner-centered learning approach, learners do not remain passive but actively engage in the teaching process (activities, knowledge acquisition, etc.) [8]. The main aim of CAI in learner–centered teaching is to supply learners with resources for improving the inability to understand. The use of molecule-level animations and video presentations improved pupils' ability to correlate the three representation types, according to various visualization strategies used to teach chemical ideas [9]: (1) macroscopic materials: provide observable chemical phenomena that are evident to the five senses (color, smell, density, etc.); (2) submicroscopic illustration: show the three-dimensional unseen particles (atoms, molecules, and ions) and their dynamic movements, reactions, and kinetics; (3) representation by symbols: include formulae, equations, physical properties, mathematical manipulation, and graphics.

This reflection process enables pupils to improve their conceptual understanding and ability to develop dynamic mental models [8]. Indeed, experiments on fluid dynamic equilibrium in a graphical design, a video display, and a molecular simulation were viewed by chemistry pupils to investigate whether the video displays or the particle simulations facilitated their conceptual understanding; the pupils showed a significant improvement in their responses between the first and second displays [8].

The present research aims to use and integrate computer simulations as a resource in teaching and learning chemistry, especially the Redox concepts and associated tram notions (electrochemical cells) in Moroccan high schools. The goal is to improve the teaching performance by using the learning simulation methods, and increasing the application of chemical knowledge at pupils by focusing more on the experimental chemical aspect than the theoretical one. As there are many issues that have not been thoroughly studied in the field of chemistry, this study also focused on differences in pupils' knowledge of chemistry concepts such as oxidation and reduction in cells to investigate the impact of the teaching method on Moroccan pupils' learning of these concepts and their conceptual framework. Our problem therefore consists of the following main questions:

- Are there any difficulties in the conceptual and procedural knowledge prerequisites of 2nd-year baccalaureate pupils in redox concepts?
- Are there significant effects on learning outcomes when using the PBL–SIM model in electrochemical cell topics of the 2nd year baccalaureate program?

This study allows us to identify the teaching strategies used by some Moroccan teachers to optimize pupils' learning and to adopt PBL-SIM in the chemistry field.

## 2. THEORETICAL FRAMEWORK

### 2.1. The Competency Approaches

The teaching methods of physics and chemistry are based on the competency approach, where teaching contents are translated into school activities in which the pupils are asked to realize tasks, following methodologies issued from constructivist and socio-constructivist theories [10]. In the socio-constructivist view, learning is seen as a process of social, cultural, and motivational knowledge construction in which experiential experiences, discussion, and communication with others are seen as crucial [11]. Learning is thus viewed as an individual knowledge construction process in which knowledge acquisition and emotional relationships are developed through social exchanges and language use. The constructivist and socio-constructivist frameworks of the competence approach consider that the learner constructs his knowledge by himself or in interaction with his peers and the teacher in the school environment. The learner crystallizes his learning by activating his knowledge with the learning subject that is proposed to him in the problem-solving situation.

The teaching of physics and chemistry contributes to the development of this desired formation, which requires a pedagogical approach based on education for choice and skills development. The problem-based approach meets these components, as it aims to develop transversal competences and problem-solving skills with realistic feasibility, either in everyday life or in the scientific or professional future of the learners, and at the same time to acquire qualitative learning. Within the problem-based approach, a distinction can be made between learning to solve problems and carrying out projects, as the official Moroccan pedagogical instructions recommend teaching physics and chemistry methods in the high school curriculum [12].

### 2.2. Problem-Based Teaching Method

Problem-solving occurs by the problem solver assembling known and acquired principles and laws to create new superior ones that allow the problem to be solved. After learning these rules and principles, the following "problems" require the application of new rules to find a solution [13]. According to PISA definition, the problem solving is the ability of a person to engage in an intellectual process to understand and solve problems for which the solution is not directly available and is a process that specifies how knowledge is organized and represented symbolically in long-term memory so that it can be activated effectively to solve the problem [14].

The pedagogical literature proposes several models, close to each other, for structuring problem-solving steps. The problem-solving approach is based on the assumption that repeated encounters with an appropriate set of problems will assist learners in acquiring a substantive knowledge base, developing a deeper understanding of important concepts, and developing problem-solving and interpersonal skills relevant to their future careers [15]. Problem–Based Learning (PBL) as a learning process was established on the principles of constructivism and a pupil-centered learning view. When using PBL, teachers assist pupils in focusing on solving problems in real-life contexts, which will enable them to think about problem situations as they try to solve them.

### 2.3. Knowledge and Skills Required in the Electrochemical Cell Topics

According to the Moroccan official curriculum of the Baccalaureate 2nd year, specialty Physics-Chemistry, the chemistry field defines the conceptual and procedural knowledge required to teach spontaneous transformation in the electrochemical cell [12]. Indeed, we have recently studied the difficulties in the acquisition of knowledge and skills in solving problems of redox reactions as used in electrolysis encountered by the second-year Moroccan baccalaureate pupils and the physics-chemistry trainee teachers [16].

### 2.4. Developing Content for new Teaching PBL-SIM Model

PBL-SIM is based on problem-based learning (PBL) that is organized around the investigation, explanation, and solving of constructive problems, where pupils learn what they need to know in small collaborative groups, and the teacher serves as a facilitator guiding pupils through the determined learning steps [17, 18]. On the other hand, PBL-SIM took into account the suggestions that simulations and virtual physics–chemistry laboratories on students' achievement should be presented at the proper time in the course using the right pedagogical technique with very particular educational objectives [19]. Successful educational technology integration in the teaching and learning of chemistry is necessary for solving problems issued from complex topic, being difficult to understand by pupils. To that purpose, simulations in PBL-SIM were integrated into the institutionalization and mobilization stages of the new concepts. In PBL-SIM, learning is acquired through the active participation of pupils in targeted and collaborative activities. It is pupil-centered, emphasizes pupil-initiated activities, and enables the acquisition of cross-curricular skills: teamwork, autonomy, responsibility, critical thinking, a logical and analytical approach to a problem, and communication.

In fact, the method (PBL-SIM) offers various ways to personalize the construction of learning (either through ICT, colleagues, or teachers). Also, it provides several means of action and expression (combining individual and group work, experimentation and the use of computer simulations). Therefore, the method consists of important stages, illustrated in Figure 1.

Problem situation stage (in class): the teacher presents the problem statement, and should be sure that everyone has understood what was asked, without any procedural guidance. The problem is followed by research questions relating to the new concepts and procedures that will be developed in the lesson.

Research stage (in class): the teacher divides the learners into groups, which examine and discuss how to solve the problem. This allows them to test their acquired knowledge, to perceive its limits and construct new ones, and to land them in a context that will give them meaning and facilitate their memorization. It is imperative that the teacher supervise the work and observe the production of each group (collaborative work) to plan the next step.

Sharing stage (in class): Each group communicates within the class its own production (on the blackboard) to be debated between the pupils with a confrontation of their proposals and argumentation to improve mathematical formulations. It should be graduated, starting with the least elaborated or not yet completed productions, and ending with the most master and completed solutions; then the teacher should enable pupils to put into words what they have learned. During this research stage, learners have to compare their results to the scientific question provided in phase 1.

Institutionalization stage (in class): The teacher gives status to the new chemical knowledge and procedures acquired during the research phase, and explains during the synthesis and sharing moments among the class community, which have to note in notebooks what can be consulted to solve other situations. This is done using a computer simulation resource.

Mobilization and exercising stage (in-class; out-of-class; in-class): In order to help learners to put their new knowledge and procedures into practice, the teacher suggests exercises and new equivalent situations. He considers more complex learning objectives that will require additional focus following the in-class and out-of-class exercises. This stage was divided into three parts (in-class, out-of-class, in-class), too included a blend of self-directed learning (out of class) and collaborative learning (in class).

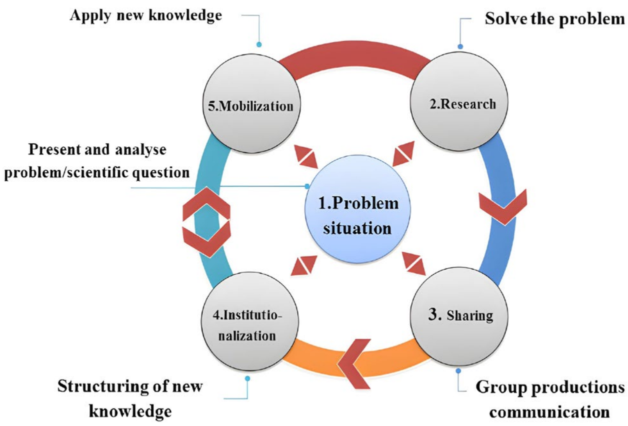


Figure 1. Stages of the PBL-SIM teaching-learning model

Through self and peer-assessment, the learning outcomes could be realized. When correcting proposed problems or exercises in class, the teacher gave the learners access to a computer simulation resource in order to provide a more in-depth explanation and help them retain their new knowledge.

## 3. MATERIALS AND METHODS

### 3.1. Research Design

In this work, a quasi-experimental design was applied to examine the effect of the PBL-SIM method on redox chemical concepts in Moroccan high schools (Figure 2). This study was carried out during the 2021-2022 school year, using a pretest and posttest for the two groups (EG and CG). This design allows evaluating the 2nd year of Baccalaureate pupils and understanding how computer simulations can improve teaching and learning of chemistry.

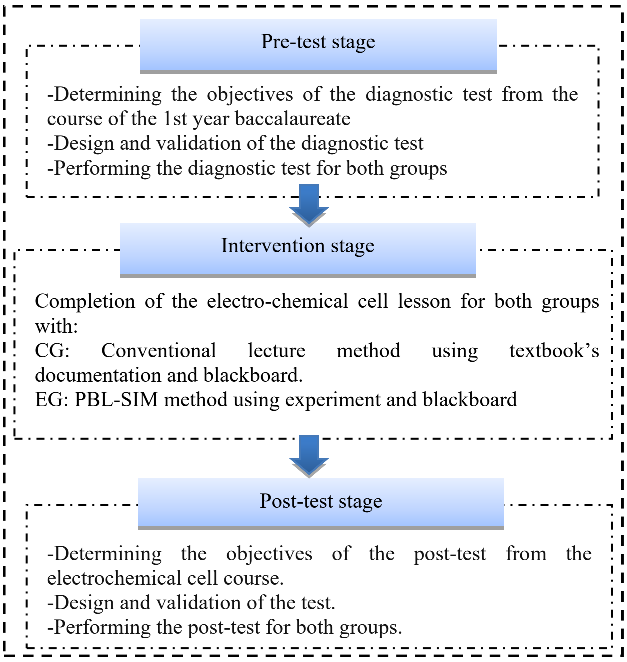


Figure 2. Research design consisting of three important stages

### 3.2. Target Population

The sample consists of 160 pupils in the second year of the Baccalaureate International French Option (BIFO) in the physics-chemistry section. The two groups are drawn from two high schools in the province of Beni-Mellal-Morocco: eighty (80) pupils for the control group and eighty (80) pupils for the experimental group. The choice of pupils was random. Both groups of learners were subjected to the same questions to ensure that variations in pupil responses were not due to differences in the wording of the questions.

### 3.3. Instrument

The survey consists of two questionnaires, submitted to the control and experiment pupil groups; the first questionnaire is used as a pretest, and the second as the posttest. The pretest questionnaire is composed of 17 closed questions involving conceptual knowledge (CK) and procedural knowledge (PK) concerning the Redox concept and associated trams, as taught at the 1$^{st}$ Baccalaureate level. The posttest questionnaire consists of 11 questions (10 closed and one open) for two exercises on the electrochemical cell's topics. The aim is to encourage pupils to understand the questions, predict answers, and avoid giving explanations. The two tests consist of thirty items, covering the Redox program content in accordance with the official pedagogical instructions adopted for Moroccan high schools. Each item consists of a question followed by at least three answers (correct and wrong); the pupils should choose the corrected answer. The suitable responses are based mainly on conceptual knowledge, such as providing Redox concept definitions, and procedural knowledge, such as the exploitation of Redox equilibria to obtain quantitative and qualitative data on electrochemical cell operating.

We distinguished between conceptual knowledge (CK): concepts and instructions, and procedural knowledge (PK): skills, and then identified these knowledge categories for the pretest and posttest questions.

### 3.4. Procedure

The approach used to teach and learn the spontaneous transformations in cells and energy recovery lessons was the conventional learning method based on documentation for the control group, and the problem-based learning method integrating computer simulations for the experimental group. The design research was followed in successive steps, as shown in Figure 1. The pretest was made for control and experimental groups under same educational conditions as a diagnostic test before starting the lesson. The aim is to determine the level and knowledge of both groups regarding the prerequisites of basic chemical concepts and reactions related to redox concepts. The test lasted one hour and was considered a review by the participating teachers to build on in the process of constructing the redox concepts.

The posttest was carried out for the same control and experimental groups after the electrochemical cells lesson, taught in different conditions, because the goal was to determine the difference between the performance of the pupils in the redox concepts when using simulation to support an experiment in the problem-based learning method. For the control group (CG), the teacher conducted the electrochemical cell's lesson in a conventional lecture way without using any experimental material to carry out the cell experiment. He used only the textbook's documentary activities without any computer simulation tools. For the experimental group (EG), the teacher adopts the PBL-SIM in the electrochemical cell lesson. An overview of the lesson process is given below.

At the beginning, the teacher presents the following proposed problem situation: "In our daily lives, when a driver turns the ignition key of his car, the starter motor is supplied with current from a lead-acid battery". After a debate facilitated by the teacher, the class group decided that electrochemical reactions are involved in all these processes, which use chemical components to produce spontaneous electrical energy. To understand this phenomenon, the teacher will decontextualize and model it in their laboratory with Daniel's electrochemical cell experiment. Following the description, presentation, and preparation of the various components of the experiment, which consists of two semi-cells (one is a zinc strip immersed in a solution of zinc sulfate; the other is a copper strip immersed in a solution of copper sulfate), a KCl salt bridge between the two semi-cells, and a conducting wire connecting the two strips of metal externally through a galvanometer, the teacher sets up Daniel's cell and asks the pupils to note the observed phenomena (macroscopic views). The proposed observations are then discussed commonly by learners (pointer of the galvanometer, color change of the sulfate solution, decrease of the zinc strip, deposit on the copper strip, etc.). Finally, the teacher asks the learners a scientific question: "How do you explain the operation of an electrochemical cell?". To answer this question (the research stage), the teacher divides the class into working groups and facilitates the activity's progress, answering group members' questions, etc. Then, each group assigns an element to share the research findings on the class blackboard (the sharing stage).

At the institutionalization stage and for depth explanation by modeling reactions at each electrode of Daniel's cell (submicroscopic), the teacher uses a computer-simulated video at the PCCL website [20] as an illustration of Daniel's cell experiment, where it shows how the cell works and the transformations occurring at each electrode (a screenshot of the simulation used is shown in Figure 3). The computer simulation video allowed learners to follow the chemical system evolution produced in Daniel's cell in terms of microscopic redox chemical transformation events ($Zn^{2+}$ is formed by the loss of electrons from the Zn atom, $Cu^{2+}$ is reduced to the copper atom Cu after gaining electrons; KCl is dissolved into chloride ions $Cl^{-}$ and potassium ions $K^{+}$) and subsequent symbolic representations (oxidation equation, reduction equation, overall cell chemical reaction, dissociation in the salt bridge, units, direction of current).

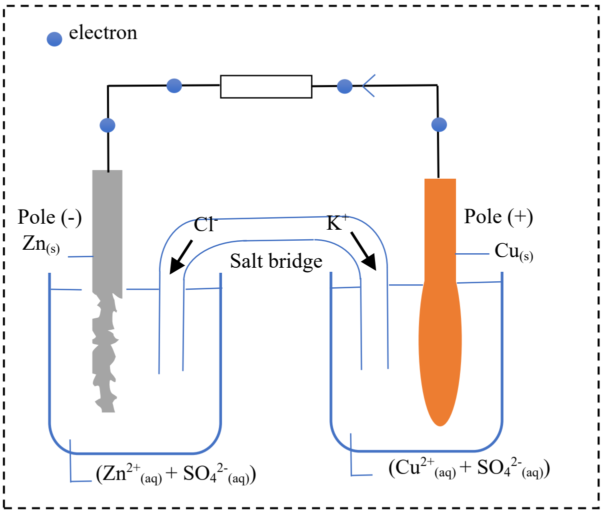


Figure 3. Screenshot of a computer simulation [20]

The teacher recommends a new electrochemical cell situation where the zinc rod in Daniel's cell is swapped out for an aluminum rod dipped in an aluminum chloride solution in order to apply the new knowledge. Following some consideration, the teachers offer a link to a computer simulation (on the PCCL website) that explains how the cell functions and how to resolve the problem. The lesson lasted two hours, and the posttest was administered to both groups during the exercise session two weeks later, as it was a problem-solving exercise for the practical work of two experiments, and the duration of the test was set at one.

### 3.5. Data Collection and Analysis

As a primary study, we administered a pretest to pupils in the two groups. The EG group was taught using simulation activities, and the CG group used the usual teaching method to learn the same subject as the experimental group. The experiments were presented on the video projector, due toa lack of computers. After closing the intervention process, we administered the posttest questionnaire to both groups. The collected data was processed using IBM SPSS version 23 software. Descriptive statistics (minimum, maximum, mean value, medians, standard deviations, and percentage) and inferential statistics (Mann-Whitney U test non-parametric) were used to analyze the data according to the gender variable and the method used. All results were interpreted as $p<0.05$. The Cronbach's alpha value was calculated for the pretest (at 0.950) and posttest (at 0.982), which means good reliability [21], and enabled us to carry out the test items for both groups before and after the implementation session. The total score of the pretest is 17 (CK/11, PK/6) and total score of the posttest is 12 (CK/5, PK/7) (1 for correct and complete answers and 0 for incorrect or incomplete answers).

## 4. RESULTS

### 4.1. Statistical Results Description the Pretest and Posttest in Terms of Effective

Table 1 presents the percentages and means scores of the corrected answers provided by the pupils in the pretest made on the redox concepts for the control and experimental groups.

Table 1 shows that the two groups of pupils completed the problem items at different means. Question 3 (the redox reaction meaning) is realized with higher mean scores as well as for the control CG (0.98) and experimental EG (0.95) groups, with a standard deviation of 0.157 and 0.219, respectively. Question 9 (What does the redox reaction involve?) is successful with the second-highest score, as CG (0.91) and EG (0.89) groups have a standard deviation of 0.284 and 0.219, respectively. Question 2 (What is an oxidant?) is also well supported for the two groups with the same mean score (0.81) and standard deviation (0.393). Question 14 about the half-equation entries is answered correctly with a mean score of 0.7 (CG) and 0.68 (EG) with standard deviations of 0.461 and 0.471, respectively. Question 5 (The agent that loses electrons) is provided with mean true responses and standard deviations of (0.65; 0.48) for the CG group and (0.63; 0.487) for the EG group. The question 10 (the redox reaction between the same reactant type) is correctly answered by the two groups, with a mean and standard deviation (CG: 0.64, 0.484) and (EG: 0.66, 0.476), while the question 6 (stoichiometric numbers of oxidation and reduction half-equations) is realized (CG: 0.60, EG: 0.59) as means and (CG: 0.493, EG: 0.495) as standard deviations.

Table 1. Statistical description of the pretest results by total effectiveness for the CG and Eggroups

| Items | Correct Pretest Answers | | | | | |
|---|---|---|---|---|---|---|
| | CG | | | EG | | |
| | *N* (%) | Mean | *SD* | *N* (%) | Mean | *SD* |
| Q1 | 83.75 | 0.84 | 0.371 | 81.25 | 0.81 | 0.393 |
| Q2 | 81.25 | 0.81 | 0.393 | 81.25 | 0.81 | 0.393 |
| Q3 | 97.5 | 0.98 | 0.157 | 95 | 0.95 | 0.219 |
| Q4 | 53.75 | 0.54 | 0.502 | 56.25 | 0.56 | 0.499 |
| Q5 | 65 | 0.65 | 0.480 | 62.5 | 0.63 | 0.487 |
| Q6 | 60 | 0.60 | 0.493 | 58.75 | 0.59 | 0.495 |
| Q7 | 45 | 0.45 | 0.501 | 41.25 | 0.41 | 0.495 |
| Q8 | 35 | 0.35 | 0.480 | 32.5 | 0.33 | 0.471 |
| Q9 | 91.25 | 0.91 | 0.284 | 88.75 | 0.89 | 0.318 |
| Q10 | 63.75 | 0.64 | 0.484 | 66.25 | 0.66 | 0.476 |
| Q11 | 47.5 | 0.48 | 0.503 | 42.5 | 0.43 | 0.497 |
| Q12 | 23.75 | 0.24 | 0.428 | 27.5 | 0.28 | 0.449 |
| Q13 | 22.5 | 0.23 | 0.420 | 23.75 | 0.24 | 0.428 |
| Q14 | 71.25 | 0.70 | 0.461 | 67.5 | 0.68 | 0.471 |
| Q15 | 57.5 | 0.58 | 0.497 | 50 | 0.50 | 0.503 |
| Q16 | 15 | 0.15 | 0.359 | 16.25 | 0.16 | 0.371 |
| Q17 | 11.25 | 0.11 | 0.318 | 13.75 | 0.14 | 0.347 |
| Total | 54.41 | 9.24 | 5.396 | 53.24 | 9.05 | 5.609 |

The questions Q15 (What do you need to use the redox reaction for calibration?), Q4 (What is the correct writing of the half-equation of a redox reaction?) and Q11 (What do you need to define as an oxidized and reduced reagent?) are realized at medium mean scores varying from 0.58 to 0.48 for the control group and from 0.56 to 0.43 for the experimental group. The responses to these questions require the pupils to acquire conceptual knowledge (selection, writing, and distinction).

The remaining questions are: Q7 (What is the oxidant in the redox reaction pair?), Q8 (A redox reaction equation reflects the conservation of...), Q12 (Metals in the left or middle part of the periodic table tend to give up one or more electrons...), Q13 (Non-metals in the right-hand part of the periodic table would get one or more electrons...), Q16 (What happened at the beginning of the titration?), and Q17 (What happened at the equivalence step of the titration? are generally achieved at low average scores ranging from 0.45 to 0.11 for CG and from 0.41 to 0.14 for EG. To perform well on questions Q8, Q12, and Q13, pupils need to possess conceptual knowledge CK (definition, naming); while questions Q7, Q16, and Q17 require pupils to acquire procedural knowledge PK (determine, recalculate, specify).

The pretest results (Table 1) showed that the total arithmetic mean of the control group is 9.24, with a standard deviation of 5.396, which is slightly higher than that of the experimental group, estimated at 9.05, with a standard deviation of 5.609. Table 2 presents the percentages and means scores of the true responses obtained from the control and experimental group pupils in the posttest (problems 1 and 2).

Table 2. Statistical description of the posttest results

| Items | | CG | | | EG | | |
|---|---|---|---|---|---|---|---|
| | | *N* (%) | Mean | *SD* | *N* (%) | Mean | *SD* |
| Problem 1 | Q1 | 51.25 | 0.51 | 0.503 | 95 | 0.95 | 0.219 |
| | Q2 | 46.25 | 0.46 | 0.502 | 95 | 0.95 | 0.219 |
| | Q3 | 38.75 | 0.39 | 0.490 | 92.5 | 0.93 | 0.265 |
| | Q4 | 47.5 | 0.48 | 0.503 | 97.5 | 0.98 | 0.157 |
| | Q5 | 45 | 0.45 | 0.501 | 96.25 | 0.96 | 0.191 |
| | Q6 | 43.75 | 0.44 | 0.499 | 96.25 | 0.96 | 0.191 |
| Problem 2 | Q1 | 65 | 0.65 | 0.480 | 97.5 | 0.98 | 0.157 |
| | Q2 | 56.25 | 0.56 | 0.499 | 93.75 | 0.94 | 0.244 |
| | Q3 | 46.25 | 0.46 | 0.502 | 92.5 | 0.93 | 0.265 |
| | Q4 | 40 | 0.40 | 0.493 | 86.25 | 0.86 | 0.347 |
| | Q5 | 37.5 | 0.38 | 0.487 | 85 | 0.85 | 0.359 |
| Total | | 47.05 | 5.18 | 4.980 | 93.41 | 10.28 | 2.222 |

Table 2 shows that the total percentage realized by the experimental group (93.41%) is close to twice the total percentage of the control group (47.05%). This showed the positive effect of the cell lesson teaching method, in appropriate conditions, on the performance of the experimental group pupils, who became more masterful of the conceptual and procedural knowledge relating to cell and redox topics concepts after achieving the lesson.

Concerning the problem 1, question 1 (identify the charge carriers responsible for the current flow out of the column) is realized by the control group at 0.51 as the highest mean with a standard deviation of 0.503. This question is well answered in the experimental group with a mean of 0.95 and a standard deviation of 0.219. Question 4 (write the half redox equation for the anode) is carried out with a mean (0.48) and standard deviation (0.503) in the CG group, whereas it is achieved in the EG group with a higher mean (0.98) and standard deviation (0.157). Question 2 (identify the charge carriers responsible for the current flow into the column) had a mean (0.46) and a standard deviation (0.502) in the control group, which is well realized in the experimental group with 0.96 as the mean and 0.219 as the standard deviation. The questions Q5 (write the half redox equation at the cathode) with a mean (0.45), Q6 (write the redox equilibrium equation in the accumulator) with a mean of 0.44, and Q3 (complete the diagram) were realized generally at medium mean scores (0.45) by the control group; however, they were well achieved by the experimental group with important mean scores (0.96).

For the problem 2, the question 2 (determine the chemical system evolution sense in the cell) is achieved by the two groups at (CG: 0.65, EG: 0.98) as mean scores and standard deviations (CG: 0.480, EG: 0.157). Question 2 (deduce the conventional representation of the studied cell) is realized with relatively medium mean scores (CG: 0.56, EG: 0.94) and standard deviations (CG: 0.499, EG: 0.244). As indicated in Table 1, the remaining questions Q3 (Expression of the concentration $[Cu^{2+}]$ at $t$ versus $t$, $C_0$, $I$, $V$, and $F$.), Q4 (Deduce the electric current value $I$ passing in the circuit.), and Q5 (Determine versus $t_c$, $F$, $I$, and $M$, the mass variation $\Delta m$ of the aluminum blade when the cell is completely worn out; calculate $\Delta m$) were realized at low means scores (0.46, 0.4, 0.38) by the control group, but with important mean scores (0.93, 0.86, 0.85) by the experimental group.

As seen in Table 2, highlighting the posttest results, the total arithmetic mean score of the experimental group (10.28), realized with a standard deviation of 2.222, is greater than the total arithmetic mean score of the control group (5.18), achieved with a standard deviation of 4.979.

### 4.2. Pre and Posttest Descriptive Results According to Knowledge Types

Table 3 presents the means and standard deviations of the overall results according to the two studied knowledge types.

Table 3. Descriptive results of the tests according to the type of knowledge types

| | | | Pretest | Posttest |
|---|---|---|---|---|
| Control group (CG) | CK | Mean | 6.59 | 2.20 |
| | | SD | 3.423 | 2.001 |
| | PK | Mean | 2.65 | 2.98 |
| | | SD | 2.044 | 2.997 |
| Experimental group (EG) | CK | Mean | 6.41 | 4.23 |
| | | SD | 3.567 | 0.907 |
| | PK | Mean | 2.64 | 6.05 |
| | | SD | 2.136 | 1.330 |

The mean results indicate that there is not a great difference in mastering conceptual and procedural knowledge between the control group and the experimental group in the pretest items. For the CG group, the average for conceptual knowledge is 6.59 for the control group and 6.41 for the EG group. Concerning procedural knowledge, the averages of the two groups are very close (2.65 and 2.64), so we can see from these results that conceptual knowledge is better mastered than procedural knowledge by both groups, which seem to have generally similar levels. Thus, the observed means of completing the different posttest questions indicate that the pupils mastered conceptual knowledge (CG: 2.20, EG: 4.23) and procedural knowledge (CG: 2.98, EG: 6.05). In conclusion, the experimental group that integrated the simulation of a cell's experiment into the teaching-learning sequence was more successful in solving problems with conceptual and procedural knowledge compared to the control group that learned the same subject through the traditional method.

This is evident, as the experimental group excelled in most of the test items of the two posttest problems requiring conceptual and procedural knowledge to provide correct answers compared to the control group, which encountered difficulties in solving the problems as indicated by the percentages obtained for the total answers (Table 3).

### 4.3. Pupils' Performances Distribution in Pre and Post Tests According to the Used Method and Knowledge Types

The main purpose is to examine the effect of integrating simulation on the learning of chemistry by pupils in the 2nd year of the baccalaureate. Indeed, we first examined and compared the findings of the diagnostic pretest and the posttest according to the method adopted in solving chemistry problems involving redox concepts. All analyses were performed using SPSS Statistics 23 to calculate the percentage and the test *U*, the Mann-Whitney.

The results of the normal distribution for the control and experimental groups are presented in Table 4. The method used for the distribution of the obtained data is the Kolmogorov-Smirnov test, as the number of samples is > 50. The data are said to have a normal distribution if the Kolmogorov-Smirnov value is greater than the significant value of 0.05. As shown in Table 4, the findings of the pretest and posttest normality, with Kolmogorov-Smirnov p-values (for the pretest) of (0.001, 0.000), as well as in the control and experimental groups, respectively, do not have a normal distribution.

Table 4. Normality of the pretest and posttest according to the groups

| | Pretest | | | Posttest | | |
|---|---|---|---|---|---|---|
| | Statistic | *df* | Sig | Statistic | *df* | Sig |
| CG | 0.134 | 80 | 0.001 | 0.237 | 80 | 0.000 |
| EG | 0.141 | 80 | 0.000 | 0.465 | 80 | 0.000 |

*This is a lower bound of the true significance

The groups did not have a normal distribution, and the posttest normality results show that the Kolmogorov-Smirnov p-value of the method used successively for the control and experimental groups is (0.000).

Table 5. Mann-Whitney U-test results for the pretest and posttest according to the teaching methods used

| | Knowledge Types | Group | *N* | Mean Rank | Sum of Rank | U Mann-Whitney | Wilcoxon W | *Z* | Asy. Sig |
|---|---|---|---|---|---|---|---|---|---|
| Pretest | CK | CG | 80 | 81.56 | 6525.0 | 3115.0 | 6355.0 | -0.293 | 0.770 |
| | | EG | 80 | 79.44 | 6355.0 | | | | |
| | PK | CG | 80 | 81.38 | 6510.5 | 3129.5 | 6369.5 | -0.247 | 0.805 |
| | | EG | 80 | 79.62 | 6369.5 | | | | |
| | Total score | CG | 80 | 81.54 | 6523.5 | 3116.5 | 6356.5 | -0.286 | 0.775 |
| | | EG | 80 | 79.46 | 6356.5 | | | | |
| Posttest | CK | CG | 80 | 58.75 | 4700.0 | 1460.0 | 4700.0 | -6.768 | 0.000* |
| | | EG | 80 | 102.25 | 8180.0 | | | | |
| | PK | CG | 80 | 58.36 | 4669.0 | 1429.0 | 4669.0 | -6.851 | 0.000* |
| | | EG | 80 | 102.64 | 8211.0 | | | | |
| | Total score | CG | 80 | 58.43 | 4674.0 | 1434.0 | 4674.0 | -6.807 | 0.000* |
| | | EG | 80 | 102.58 | 8206.0 | | | | |

In this case, the distribution of the data does not have a normal distribution because the p value of Kolmogorov-Smirnov is lower than the alpha level (0.05). Concerning the homogeneity of the variance between the two types of knowledge for the pretest, we accept the null hypothesis of homogeneity because of the significance of Levene's $0.688 > p$ value, and the posttest is non-homogeneous with a significance equal to $0.000 < 0.05$, which implies that the null hypothesis is rejected. Thus, the Mann-Whitney U-test will be used to compare the results according to posttest results and the types of knowledge (CK and PK).

## 5. DISCUSSIONS

The obtained results from Table 1 show that the pupils understanding level of the redox concepts as used in the beginning and equivalence of titrations (Q17, Q16) were very low in the pretest, as well as for the CG and EG groups, as given in terms of means for Q17 (CG: 0.11, EG: 0.14) and Q16 (CG: 0.15, EG: 0.16).

In terms of total percentages obtained as an average of all questions, one can see that there is no significant distinction in the performance of the CG (54.41%) and the EG groups (53.4%), since pupils of both groups have adopted the conventional lecture method in the precedent 1st baccalaureate level. To note that in the Moroccan context, the pedagogical engineering of education in the high school consists of 3 years: the 1st year (Common Tronc) and the 2nd year (the Baccalaureate classes consist of two years' levels: the first year and the second year of Baccalaureate). The use of the official school management system "MASSAR" (https:/massarservice.men.gov.ma/moutamadris/Account) during the constitution of classes at the start of the school year explains the equivalence of the two groups' pretest results, as demonstrated by Levene's significant value ($0.688 > p$ value), and ensures the equality of the distribution between the groups at the time of class constitution.

It is noted that similar findings from other studies have been obtained, indicating the difficulty of teaching and learning complex chemistry concepts. Indeed, [22] confirms that pupils have difficulties in defining and clarifying the meaning of electron transfer. Chemistry teachers help pupils to accept the electron model as a concept to both explain and represent redox reactions [23]. Additionally, difficulties in learning chemical concepts are due to pupils' difficulties in writing correct and balanced chemical equations [24], and to the fact that explaining chemistry requires pupils to apply many ways that chemists use to form their reasoning in relation to chemical processes [25]. In the Moroccan context, the baccalaureate pupils and the physics-chemistry trainee teachers have encountered difficulties in using the basic skills used in electrolysis to solve problems involving chemical concepts such as equation of reaction, quantity of matter, concentration, and the RICE table [26].

The pretest findings are explained by the fact that the two groups were not able to successfully acquire the knowledge required by traditional teaching methods, as evidenced by their difficulties with learning redox concepts or their relatively low retention of what they had learned in the preceding year. The identification of difficulties with the redox and related concepts (CK and PK) in CG and EG groups in the pretest highlighted the design of a new PBL-SIM, and measured its effect on the posttest results, and provided an effective way of teaching this type of concept, which seems complex and abstract for pupils. In this method, the learners work in an active environment that promotes a learner-centered approach for enhancing meaningful learning (linking new and previous knowledge). While scientific computer simulations support the institutionalization and exercises, the teacher's role is limited to presenting the problem situation, scientific question, experiment, institutionalization, and exercises. The percentage of correct responses that the pupils achieved in items such as determining the charge carrier's names responsible for the current passing in and out of the cell, cell polarity, writing the redox half-equations associated with the anode and cathode, balancing the equation, the evolution sense of the chemical system in the cell, and expression and calculation (concentration, intensity, and mass variation) reveals the positive effect of this method on learning.

Indeed, for the problem-solving skills of EG group pupils exposed to the PBL-SIM method, it is evident from the high total percentage (93.41%) obtained correct answers in the posttest compared to the control group exposed to conventional lecture, where the percentage obtained correct responses is low (47.05%). On the other hand, whether by knowledge types (CK or PK) or total knowledge, there is a statistically significant distinction in performance between the two groups in favor of the problem-based learning method integrating simulation with a mean rank (CK: 102.25, PK: 102.64, total score: 102.58) compared to the conventional lecture method with a mean rank (CK: 58.75, PK: 58.36, total score: 58.43) (Table 5). In this study, we noted that in the research stage, the pupils are unable to describe how the current is generated and flowed, because the cell's circuit is not closed (by wire), but by using simulation, pupils were able to correct their erroneous representations of redox reactions and how electrochemical cells work in the submicroscopic view [16]. Generally, the PBL-SIM shows the efficacy and positive effect of using simulation in teaching the cell's concepts in a problem-based learning approach. Indeed, the use of computer simulations in practical work rooms as a tool for scientific structuring and mobilization and for exercising stage has made the 2nd year baccalaureate pupils perform more effectively and efficiently when completing chemistry questions incorporating the concepts of cells and redox.

The pupils react favorably to the integration of the computer simulations in teaching, which facilitates their progress and their involvement in the learning of oxidation-reduction concepts. The scientific simulations seem to place the learners in a situation where they must model abstract concepts into observable and temporal evolution of concepts using three-dimensional animated illustrations (e.g., graphic design, atoms, molecules, ions, interactions and dynamic movements of species, etc.) [11], which allowed them to correct the erroneous representations, acquire and construct their experimental activities. However, it is absolutely essential that learners understand the differences between the computer simulations (and the model's limitations) and reality; otherwise, they will form misconceptions [27].

It can be concluded that teaching scientific concepts to pupils using multimedia that simulates the real phenomenon may help them to well understand chemical notions and difficult abstract concepts, and it makes the learning of chemistry processes relatively easy. Besides, the learning based on simulations allows pupils to change the chemical elements of the experiment and gets the desired result easily and without hesitation; it also allows us to take into account the individual differences in the pupil's ability to use the experimental approach, which is based on hypothesis building, observation, interpretation, and conclusion.

Many studies showed the difficulties encountered by pupils in understanding cells and in the simulations role in teaching and learning the redox topics. According to [26], the most common misconception is that electrons surround the entire electrochemical cell. Over 50% of the sample thought that electrons flowed from the anode and back through the wires, the cathode and its solution, the salt bridge, and finally through the anode solution. Other authors have reported a similar misconception [28]. Pupils referred to the cathode of an electrochemical cell as a positive electrode and the anode as a negative electrode, which is considered an erroneous conception [29]. Previous work has shown that using modeling and summarization in teaching general chemistry subjects, particularly cells, helps to explain the events occurring at the micro-level in electrochemical cells, and this is effective in removing misconceptions [30].

## 6. CONCLUSIONS

The effect of computer simulations on Moroccan pupil's performance in solving chemistry problems involving conceptual knowledge (CK) and procedural knowledge (PK) on cells concepts is studied considering the teaching method. This study is carried out on a control group (80) and an experimental group (80). The two groups were evaluated by a pretest and a posttest in two different situations, as indicated in the procedure part. The obtained results for the control and experimental groups in the two situations were compared and analyzed using the Mann-Whitney U-test. The study showed that there is a significant distinction between the levels of mastery of conceptual and procedural knowledge in the issue of electrochemical cells' solving problems.

Regarding the effect of scientific computer simulation, the EG group performed better and more efficiently than the CG group, which showed the positive effect of using the scientific simulations software in the problem-based learning method for the construction of conceptual and procedural knowledge related to redox topics. Computerized data acquisition allowed experiments to be carried out at a suitable time, thus widening the empirical scope of knowledge application. While data processing and manipulation of mathematical models allowed the learner to better interpret experimental results related to the redox concept and its associated tram notions, the use of scientific simulation seems to be efficient in improving the performance of high school pupils and generally reducing the problem-solving difficulties encountered by pupils in the acquisition of chemistry concepts.

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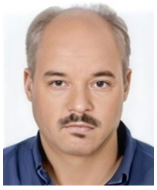

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