Chemistry: Bulgarian Journal of Science Education | Volume 28 Number 3, 2019 | Природните науки в образованието

Problems
Задачи

STUDY OF MOROCCAN PUPILS' SKILLS IN SOLVING CHEMISTRY PROBLEMS AT FIRST YEAR OF HIGH-SCHOOL

Ali Ouasri
Centre Régional des Métiers de l'Education et de la Formation (Morocco)

Abstract. This study purpose to analyze the macro-skills (assimilate, analyze, and achieve) that Moroccan pupils (16 – 17 years) of high-school (first-year classes) master to solve chemistry problems involving chemical concepts such as equation of reaction, complete reaction, molar mass, amount, volume, concentration, RICE table, and dilution. The pupils were asked to provide answers on problems' questions including implicit tasks, which are arranged from the simple to the complexe at the problems' end. The pupils' answers are analyzed in terms of macro-skills with regard to the (1st, 2nd, 3rd degree) skills, which pupils would master to succeed the different tasks relevant for the problems, and discussed in terms of novice/expert problems solvers taking considering conceptual understanding and algorithms that pupils could master to solve correctly the problems' tasks. The findings show that pupils succeed tasks, which require mastering of assimilate skills (1st degree skills) more easily than those requiring others skills, especially achieve skills (3rd degree skills), needed to solve the complexe tasks.
Keywords: problem-solving; tasks; knowledge; skills; assimilate; analyse; achieve; performance; capacity

Introduction

Problem-solving, as an important part of most science courses, is very effective in improving pupils' achievement in education (Aka et al., 2010; Gock, 2010) because when pupils managed to solve problems, their motivation will increase, and eventually they will be eager to learn (Hamza & Griffth, 2006). Problem-solving is a tool of pupils' centred, active learning and knowledge development (Aka et al., 2010), and it was used as the primary domain of large-scale assessment systems around the word such as the OECD Programme for International Student Assessment (PISA) (Greiff et al., 2013).

In education, providing pupils with problem-solving skills help them to improve scientific thinking (Aka et al., 2010). But, the failure to solve problems occurring in learning would reduce motivation, and pupils will be less interested in pursuing education as a result of the lack of "problem-solving" skills (Teichert & Stacy, 2002; Bodner, 2003). Several factors influence the abilities in solving problems: the problem's nature, the learner's development level and their knowledge base, the motivation and "problem-solving" skills, and many individual and psychological factors (Reid & Yang, 2002).

According to Johnstone (1993), the problems are classified based on three variables: the provided data, the used method, and the goal to be reached. Based on each variable' information, Johnstone (1993) has identified eight problems' types: Type 1 an algorithmic problem that can be considered as an exercise. Type 1 and 2 normal problems, usually found in textbooks and examination papers. Type 3 and 4 are more complex problems involving seeking data and reasoning. Types 5 to 8 are even more open problems, encountered in real life. Where data, method or goals are not known, then the problem is regarded as an open problem.

When all informations including the solving path are known, a problem is considered as algorithmic exercise. Algorithm problems involving "lower level thinking" skills to solve problems are more than the form of an exercise that requires subjects to do simple applications and easy identifications of precedings and used data (Zoller & Pushkin, 2007). Conceptual problems usually involve non routine chemical phenomenon among pupils that should use previous learned concepts to solve these problems (Surif et al., 2014). While, open-ended problems require creativity and application of "higher-level thinking" skills, not only knowledge consumption (Overton et al., 2013); the useful elements are not obvious for solving, and subjects must transform or reorganize the given data to find original answers to problems.

Different researchers' currents are interested in problem-solving, from the expert/novice paradigm (Chi et al., 1981) to those worked on capacities' development in solving problems to increase students' performance (Reof, 1983; Caillot, 1988; Dumas-Carré & Goffard, 1997; Heyworth, 1999; Aka et al., 2010; Mazouze, 2016). The currents' preoccupation focus on pupils-centred learning environement, in which pupils are actively involved in learning process, but should also be given counseling if they have difficulties in solving problems. Competency-based learning aims to enhance "novice" pupils to mobilize their knowledge and skills to solve problems' situations (Perrenoud, 1997; Jonnaret, 2002; De Ketele & Gerard, 2005; Tardif, 2006).

The present paper aiming to study the mastery of macro-skills at pupils in problem solving contains five parts: the problem illustrating some pupils' difficulties in solving chemistry problems in Moroccan high-school context, and the research questions. It is to note that the high-school in Moroccan education system contains three years: common curriculum year, first and second baccalaureate years. The conceptual framework discusses the macro-skills and associated capacities that would be mastered to solve problems' tasks, as well as declarative, conceptual and procedural knowledge; this part discus either the impact of tasks' organization on knowledge and skills development. The third part concerns the methodology, the target population, investigation methods and data collection instruments. In the fourth part, are presented the obtained results, which are analyzed and discussed in the fifth part. This may highlight performances and difficulties that pupils at this grade encountered in solving chemistry problems including complete chemical reaction, mass, amount, volume, concentration, and RICE (Reaction, Initial concentration, Change in concentration, Equilibrium concentration) table also known as ICE table.

Context and problem

The performance of Moroccan pupils in solving chemistry problems during the exams is not satisfactory. In order to improve problem solving skills, it is needed to know the difficulties encountered by pupils and found a way out to overcome these difficulties. In different contexts, the learners encounter difficulties to master scientific concepts in problem-solving activities (Caillot, 1988; Crahay & Lafontaine, 1986; Goffard, 1994; Giordan, 1998; Reid & Yang, 2002; Orange, 2005; Drummond and Selvaratnam, 2008; Overton et al., 2013; Ouasri, 2016; 2017a; 2017b; 2017c; 2017d; 2017e). Accordingly, the pupils' difficulties in problem-solving could be due to: (a) non-understanding of words and concepts given in problems; (b) lack of attention, of rigor, of investment, and weariness in "problems- solving" situations; (c) lack of mental representations that enhanced pupils to elaborate schemata, which help to construct, analyze, select, structure, and interpret new information (Sweller, 2003); (d) lack of prerequisites, of interlinked intelectual skills and strategies, and of logical reflexes.

In chemistry, Drummond & Selvaratnam (2008) have identified four intellectual strategies to solve problems: clear presentation of problems, identification of strategy to reach a required goal, identification of principles needed in solving, and proceeding step by step. The authors found that the majority of subjected students in South Africa were unable to use the required strategies, and many students with skills were able to use strategies, but did not recognize the necessity for doing so. The pupils' failure in problem-solving is not always due to their inability to reason, but rather on lack of experience and strategy (novice) to approach problems. The pupils without complex reference situations did not know how to treat problems, and can only reproduce solutions from similar problems that have previously been seen.

Chemistry problem-solving is more difficult for pupils, since the matter's representations are characterized by different levels (Johnston, 1982; Williamson & Abraham, 1995; Treagust et al., 2003; Gilbert & Treagust, 2009; Talanquer, 2006, Gkitzia et al., 2011). According to Johnston (1982), and Treagust et al. (2003), there are three levels that are described as: (a) a real macroscopic level (observable phenomena: color, phase) corresponds to tangible and visible chemicals that may be part of everyday students' experiences; (b) a sub-microscopic level also real comprises a particulate level that can be used to describe and conceptualise electrons, molecules or atoms' movement; (c) a symbolic level (chemical equations and formulas) involving a wide variety of pictorial images, and algebraic formulas and computational forms of the sub-microscopic representation.

The informations' representation is made at three distinct levels (motor, pictorial, abstract-symbolic) in human brain (Ambrus, 2014). The changes in levels of the brain's spontaneous activity occurred in different areas, depending on nature of the task performed by the subject (Kaufman et al., 1990; 1992; Wang et al., 1990). The level of intrinsic activity of the brain changes as a subject performs different mental tasks. Further, the task-relevant changes arise from circumscribe brain's regions, and the involved regions vary depending up the task' nature. Accordingly, the visual areas of the brain are engaged in mental imagery, and the non-visual areas are involved in such tasks. Performing the imaging task involves then regions of the cortex that are not normally engaged in visual sensory-perception; so, the pictures and algebraic are two separate types of problem-solving, which use two different parts of human brain.

The macroscopic, sub-microscopic and symbolic levels are linked, and contribute all to the learners' construction of meaning and understanding, which are reflected in their personal mental model of the phenomena. The representations link reality and theory, and in this way are vital to explanations. The ability to transfer from reality to the representation is not always instinctive, and must be practised; similarly, the ability to transfer from one type of representation to another is an inherent skill in understanding chemistry.

Establishing conceptual relationships among macroscopic, symbolic, and microscopic levels is important for pupils to meaningfully understand chemistry. But, several studies revealed that pupils could not correctly explain chemical concepts using these three levels (Hinton & Nakhleh, 1999; Del Pozo, 2001). Especially, pupils have difficulties to understand chemistry topics at the symbolic and microscopic levels (Wu, 2003). Some reasons of these difficulties might be their poor understanding of particles' nature (Williamson & Abraham, 1995); the lack of understanding of chemistry concepts may be linked to the students' inability to build complete mental models that visualize particulate behavior. Working on the particulate nature of matter, Williamson claimed how students interpret particle behavior and the mathematics that accompanied it are processed in different parts of the brain leading to four representations of matter: macroscopic, sub-macroscopic, and then symbolic and mathematical as two separate levels. Nakhleh & Krajcik (1994) have described four levels representing matter: macroscopic system, microscopic system, symbolic system, and algebraic system; the two latest levels are here separate as has been claimed by Williamson.

In British Columbia, high school students were directed to use critical thinking techniques in calculating the base concentration after a titration experiment (Anamuah-Mensah, 1986). The finding showed that 80% of students used the formula, and 20% of them used the concept of (proportional reasoning) to solve the problem. The students that used the formula could not understand the relationship with the constants contained in the formula they used. Although those who used the concept of "proportional reasoning" showed were able to examine this relationship. This reveals that when students examined the macroscopic behaviour, then weak links could be made between conceptual understanding and problem solving in chemistry. The discussions indicate that students have various weaknesses in controlling conceptual and procedural knowledge to solve problems in chemistry.

In the Moroccan context, chemistry problems at the first year of high-school focus on complete chemical reactions (Ouasri, 2016). Without mastering the different levels of matter's representation and their interrelation, a learner can't use correctly chemistry models to predict chemical reactions. It is difficult for pupils to understand reactions involving matters, their names, their chemical formulas, their usual conditions, and their physical and chemical properties. The chemistry problems imply implicit knowledge and skills that could be used in representation and in "problems-solving" strategies: the species' nature involved in the reaction, the equation, the stoichiometric conditions or the physical conditions.

When the performance of Moroccan pupils in solving chemistry problems is not satisfactory, some questions may be asked about knowledge and skills that they would master, especially the macro-skills (assimilate, analyze, and achieve): Are pupils mastering certains macro-skills and knowledge needed to solve chemistry problems involving chemical concepts such as: equation of reaction, complete reaction, molar mass, amount, volume, concentration, RICE table, and dilution? Is the pupil's failure in mastering these skills due to the non understanding of chemical concepts (conceptual knowledge), to the weakness in solving algorithmic problems (Lack of strategies and logical reflexes)? Are pupils considered as "novice problem solvers", who are enrolled in the course for the first time, without strategies in chemistry problem-solving?

The main purpose of the study is in one hand to find out if sucess (failing) in problem solving in chemistry is due to mastering (lack) of macro-skills (assimilate, analyze and achieve) as defined by Noirfalise & Porte (1990) in regard to conceptual knowledge, strategy and logical reflexes, and in other hand to elaborate correlations between the macro-skills and the 1st, 2nd and 3rd degrees skills as defined by Rey et al. (2003).

This study is based on analysis of written productions of pupils, considered as novice in solving problems, which include progressively simple to complex tasks' character (Ouasri, 2017a; 2017b; 2017c; 2017d; 2017e). Each question of the problems (Appendix) is divided into tasks (steps) to be realized by pupils without giving them the explicit steps. The decomposition of questions into different tasks is made to justify whether or not pupils master the macro-skills in coorelations with skills of 1st, 2nd and 3rd degree. The purposed correlations are: (assimilate ® 1st degree skill, analyze ® 2nd degree skill, and achieve ® 3rd degree skill).

The macro-skills that pupils would master to complete the different tasks are identified and assigned based on the tasks' nature (simple or complex), which requires pupils to use assimilate, analyze, or achieve skills, tacking into acount the associated capacities of each skill as defined in Table 1. The written outputs of pupils' are counted, classified, and discussed in terms of succeeded, failed and unprocessed tasks, with recourse to knowledge and skills, required by pupils to complete responses to the problems' questions. This may provide some explanations, and help to analyze the performance and difficulties of Moroccan pupils at the first year (common curriculum) of high-school in mastering knowledge and macro-skills, used in chemistry problem-solving.

For reason of simplicity, we focus analysis in terms of macro-skills and knowledge on comparing percentages of correct answers; this highlights implicitly a comparison between percentages of untreated and failled responses.

Table 1. Synthesis of (assimilate, analyze and achieve) skills, and associated capacities

Skill	Examples of associated capacities
Assimilate the problem (Extract and use wise information)	● Establish a model scheme for a situation ● Identify the relevant physical quantities, assign them a symbol. ● Evaluate quantitatively unknown and unspecified physical quantities. ● Relate the problem to a known model situation.
Analyze (Establish a solving strategy)	● Break down the problem into simple tasks. ● Start with a simplified version. ● Explicit the chosen modeling (definition of system, etc ...). ● Identify and enunciate the physical laws that would be used.
Achieve (Implement the strategy)	● Develop the process to the end to explicitly answer the question. ● Carry out efficiently analytical calculations and numerical translation. ● Use a dimensional analysis.

Conceptual framework

Problem-solving as privileged teaching tool enables pupils to develop their abilities, capacities and skills. It serves pupils not only to master basic knowledge and skills, but to combine and reorganize data before reaching the desired goal. In learning situation, pupils should perform two tasks: solve the problem and learn from solving. But, acquiring knowledge in one context does not mean that a learner can use it at the appropriate time; the ability to use knowledge is then fundamental to solve problems. The conceptual framework discusses knowledge, skills and capacities that pupils could call up to realize tasks in problem-solving.

Declarative, procedural and conceptual knowledge in problem-solving

The cognitive psychology being instrumental in learning processes with problem-solving (Newell & Simon, 1972; Gagné, 1985; Glover et al., 1990) has provided concepts and approaches to analyze and understand teaching/learning processes. Acquiring knowledge involves three distinct steps (Neves & Anderson, 1981): encoding of declarative knowledge, proceduralisation (procedural knowledge), and composition or organization. The production of procedural knowledge is divided into three non-discreet steps, which characterize different moments in qualitative skills' evolution (Anderson, 1983; 1995): (a) *in cognitive step*, a learner can identify the information needed to solve problems by following directions, applying general problem-solving operators, and using analogies between declarative knowledge and anterior behaviors; (b) *in associative step*, the declarative knowledge is transformed into a procedural one, and errors inherent to cognitive steps are detected and eliminated. The transformation ability is made with little errors, and then becomes faster and better coordinated; (c) *in autonomous step*, the ability becomes more automated, faster and involves little cognitive intervention; it is then a step of adjustment and refinement of productions.

Building complex knowledge could be made by articulation of procedural and declarative knowledge (Anderson, 1983; 1995). In the way, building skills is a cumulative process that enables a learner to acquire knowledge elements and use appropriate skills in the situation that he had to treat. According to works interested in progression from novice to expert problem solvers (Larkin et al., 1980; Larkin & Simon, 1987), the selection of appropriate knowledge depends on an activation process reflecting a successful skill's level in particular context. The major distinguish between an expert and a novice problem solver is the organization of knowledge domain at the expert, which allows him to access many stored problem schemata. Success in problem-solving depends on two factors: knowledge base within a particular domain (ideal gas law) and general or common knowledge, and skills base consisting of specific cognitive activities or abilities (rearrange equations to isolate a variable...) (Gick, 1986; Taconis et al., 2001). A person that has both strong bases in a domain is able to solve quickly problems relevant to this domain, with a high accuracy degree. Combination of knowledge and skills is characteristic of an expert problem solver (Larkin et al., 1980).

In addition, pupils should have not only declarative and procedural knowledge, but also conceptual knowledge, which help them to solve chemistry problems based on what they have learned on chemical substances and concepts. Understanding and application of chemical concepts (conceptual knowledge) and problem-solving (procedural knowledge) are very important to solve correctly a problem (Cracolice et al., 2008). Conceptual knowledge reflects understanding of conceptual chemistry ideas, while procedural knowledge concerns how to apply learned concepts in problem-solving (Wolfer, 2000).

Others studies show that although many pupils were able to solve algorithmic problems, they did not understand such chemistry concepts (Chiu, 2005). Students who have not built algorithms for some steps in a problem, such as converting between grams and moles, will never solve the problem (Bodner, 1987). Algorithms are useful for solving usual questions or exercises, as well as for providing a pack of rules mainly for calculating a specific answer and solution to an objective (Bodner, 1987). Accordingly, solving an exercise involves reading the exercise and recalling the appropriate algorithm; while solving a problem involves reading and understanding the problem, formulating a strategy, applying the strategy to produce a solution, and then reflecting on the solution to ensure that it produced an appropriate result.

Nurrenbern et al. (1987) showed that the ability to solve problems in stoichiometry and the gas laws does not imply conceptual understanding of the topics. Students that were presented with questions including a traditional equation-based problem as well as a conceptual non-mathematical problem showed greater success with traditional problems than the conceptual ones. The authors conclude that teaching students how to solve problems does not lead to conceptual understanding of the topic.

Cracolice et al. (2008) showed that most students relied on algorithm problem solving techniques, and claimed that students can successfully solve problems, by using an algorithm, as compared to answering interview questions based on the involved concepts. They were only able to memorize and remember the formula and the processes involved without understanding the concepts. This was found by Bunce & Heikkinen (1986) who studied students with intellectual abilities to solve problems, but did not use it effectively. Accordingly, students did not need to use conceptual knowledge and understanding to solve mathematical problems in chemistry.

Chemistry is a science containing formulae, rules, principles, and issues to be understood and solved. Scientific formulae being in the form of a combination of numbers, letters, and symbols are useful in solving problems, but difficult to be learned. Hence, pupils need to master conceptual knowledge in chemistry. It is to note that the ability to recall and select appropriate formulae to solve chemistry problems is an ultimate challenge in the pupils' lives (Aziz & Moi, 2000; Lee et al., 2001).

Capacities and skills

In pedagogy, the capacity notion is inherent to the skill one, which is the ability to use know-how in such situation. It is difficult to distinguish the two concepts, since the capacity definition implies that a skill would be defined at the same time. Educational institutions use frequently the skill word linked to the ability one. According to Meirieu (1988), a capacity is a reproducible intellectual activity in various knowledge fields, whereas a skill is an identified knowledge involving one or more abilities in a notional or a disciplinary field. This suggests that skill is an appropriate combination of different abilities in such situation. For Gillet (1991), students should develop their capacities through learning, which will be expressed in situations others than those involving skills. Hence, a capacity is considered as a transversal ability, i.e., a decontextualized know-how that can be developped in different professional or social situations.

A skill is regarded as potential behaviors (cognitive, affective and psychomotor) set, which enables a person to perform an activity, generally complex. Linked to a professional or a social situation of reference, a skill includes knowledge, expertise, and know-how. In cognitive terminology, a skill involves simultaneously declarative, conceptual and procedural knowledge, and attitudes. These three dimensions, not coherent at a novice, become together powerfully combined at "the expert" level. The skill and capacity words are therefore not synonymous. A skill refers to an individual ability, which would be engaged in cognitive process to understand, and solve problems without an obvious solution method; while the capacity includes individual willingness that a person could engage in such situation to exploit his potential as a constructive and thoughtful citizen.

Pedagogically, problem-solving is similar to a complex task whose solving leads learners to use internal (knowledge, skills ...) and external (documents, help methodologies, protocols, research ...) resources. The realization of a task requires learners to implement various macro-skills and capacities; the Table 1 illustrates some of the macro-skills, with associated capacities (Noirfalise & Porte, 1990).

It is to note that the studied macro-skills were identified in IGEN document. [(1)] Indeed, there are some invariants relating to problem-solving where a learner, faced to a specific question, is led to: (i) Articulate data from personal experience, knowledge and documents. Useful data are not provided by the problem statement, but can be arranged in group together at the beginning or the end of the problem-solving activity; there may be missing data that learners will need to identify and possibly estimate their value (assimilate and analyze skills); (ii) Schematize, identify and name quantities, mobilize physical models, considered relevant for doing previsions and/or providing arguments (assimilate and analyze skills); (iii) Build and implement a strategy that can use experience (analyze and achieve skills).

There are different levels of mastering skills in solving complex tasks. Considering the pupils' productions when solving problems, four levels could be identified, and described as:

– Level A: the indicators chosen are totally observed (successful task as indicator)

– Level B: the indicators chosen are partially observed (untreated task as indicator)

– Level C: the indicators chosen are insufficiently observed (untreated task as indicator)

– Level D: the indicators chosen are absents (failled task as indicator)

The four levels would be assigned taking into acount if pupils completed, untreated and failled the asked tasks derived from the problems' questions.

Tasks and skills

A simple task mobilizes only one capacity, and makes it possible to verify the acquisition of know-how or procedures. In the way, a question implies explicitly a domain in which a task would be realized. The restitution of knowledge characterizes the simple task. Solving complex task is not a simple application of an automated procedure, but requires pupils to develop a strategy, and to implement combination of simple, automated, and known procedures, in the way that each pupil can adopt an individual approach to solve the complex task. The task's complexity is related to others characteristic elements of a task. The register transformation (moving from a curve to a numerical value, and then to a qualitative interpretation, etc.) can be assigned to a complex question. It should be noted here that complex does not mean difficult.

According to Rey et al. (2003), a task is a human action with purpose and utility, which can be reduced to an action or extended to a combination of actions; but it differs from the behavior by its purpose perceived by the subject. The authors highlight three situations corresponding to three levels of a skill: (i) *Procedures*: Procedural issues involving knowledge and automated rules; (ii) *Elementary skill* with framing is used when, faced to novel tasks, necessarily contextualized, a pupil must choose an appropriate procedure; such situation requires interpretation by the pupil (iii) *Complex skill* is necessary to perform complex tasks as new situations requiring choice and combination of several procedures. The pupil must invent a solving process that is not given in instructions; the pupil has to interpretate the situation that determines his solving approach.

For Rey et al. (2003), a skill has three degrees: (1) *1st degree skill*: Know-how to perform an action in response to a preset signal, after training; this is the elementary skill or procedure. (2) *2nd degree skill*: Know-how to choose from known procedures the appropriate one to a situation or to an unknown task; this is a basic skill with interpretation (or framing) of the situation considered as the elementary skill with framing. (3) *3rd degree skill*: Know, among the known procedures, to choose and combine those that are suitable for an unknown or complex situation or task; this is the complex skill.

The authors indicated that two conditions are necessary to solve complex problems: the mastery of the required procedures to solve tasks, and the ability to determine the relevant traits, needed to solve the proposed task; this last condition refers to the framing.

Organization of tasks in problem-solving

Various works have been carried out on the impact of tasks' organization on knowledge development. Generally, there are three important approaches:

(A). The contextual interference approach observing a prevalence of variability on consistency in problem-solving (Carlson & Yaure, 1990; Schmidt & Bjork, 1992; Van Merriënboer et al., 2006). This approach suggested that the tasks' organization is considered as a factor that influences learning in problem-solving; (B). The instructional design approach takes into account the cognitive load in tasks' development in problem-solving, and emphasizes the importance of how tasks are organized (Pass & Van Merriënboer, 1993; Salden et al., 2006; Pass et al., 2003; De Croock & Van Merriënboer, 2007). This approach is interested in organization learning of a skill/knowledge, so that a learner may develop this skill/knowledge with success, retention, and understanding, with little error and good elaboration of schemata; (C). The third approach suggests the prevalence of a hierarchy of problems from the simple to the complex (Gagné, 1962; 1968; Frederiksen & White, 1989), and considers that a competency is based on prerequisites or basic skills that must be acquired before more complex skills (Gagné, 1962). The learner has to master a new task (knowledge or skill) gradually at an increasingly hierarchical level until reaching the final level of this task.

Frederiksen & White (1989) purposed a mode of instruction based on decomposition of a task into sub-goals, and on setting up of situations allowing gradual acquisition of skills relating to the sub-goals. They showed that learners being subjects to this type of organized instruction were more successful than others who directly realized the task.

Methodology

Target population, ethics, investigation methods, and data collection instruments are illustrated in the following part.

Target population

The target population contains 165 pupils (16 – 17 years) of four classes of common curriculum year, in Moulay Youssef and Hassan II high schools of Rabat city (Morocco). The classes' pupils take advantage of six hours of physics and chemistry courses per week (three sessions of two hours). As in all Moroccan high schools, a weekly program of continuous teaching, from 8 h at 6 h, with a pause of two hours from 12:00 to 14:00 h, is adopted within these schools. The choice of this population (common curriculum year) is made taking into account the importance of the "problem-solving" approach for pupils in ongoing assessments, and in the year-end examination. The pupils, subjected to chemistry problems including several chemical concepts (equation of reaction, complete reaction, molar mass, amount, volume, concentration, RICE table, and dilution), are considered as novice problem solvers, who are enrolled in the course for the first time. Solving the purposed problems requires the pupils to master certains macro-skills with regard to conceptual knowledge (understanding chemical concepts), and strategies and logical reflexes (algorithms).

Ethics

The participating pupils were subjected to problem-solving test from their teachers in coordination with the author; the test was used both as an assessment tool as well as to provide the data for this study. The school administration was well informed and approved the use of this test. In addition, the pupils were informed about the goals of the test and that their responses to the problems' questions would be used in a research study. The test was administered to the pupils after the completion of courses corresponding to the transformations of matter. The test completed by those pupils who agreed to participate was given to the author by their teachers. It should be noted that pupils' names were not provided (Taber, 2014).

Investigation method and instruments

This study seeks to analyze Moroccans pupils' performance in chemistry problem- solving involving complete chemical reactions. The written outputs of pupils are studied in terms of succeeded, failed or unprocessed tasks (Tables 2 and 3) to identify some pupils' difficulties in "problem-solving" activities. The tasks are identified and constructed by breaking down the questions of problems 1 and 2, submitted to pupils; this makes it possible to analyze blockages and errors encountered by pupils during "problem- solving" activities. It is to note that the breaking tasks were not submitted to pupils; they used only in developing analysis.

The two chemistry problems (Appendix), submitted to pupils, include questions on chemical systems, mass, amount, volume, and concentration. Pupils were asked to answer the problems' questions containing implicitly different tasks, which are used as indications of mastering (assimilate, analyze, and achieve) skills. The problems were given in French to the subject pupils who are "second-language learners". It is worthy to note that the instruction languages are Arabic as first language and French as the second language of instruction.

Table 2. Problem 1: results on fabrication of germanium
(As: Assimilate, An: Analyze, Ac: achieve)

Q	Tasks to be done (Ti)	succeeded	failed	untreat-ed	As	An	Ac
1	**T1:** Identify the chemical species involved in the reaction.	144	21	0	*		
	T2: Identify the reactants and products	144	21	0	*		
	T3: Write the equation of reaction	144	21	0		*	
	T4: Balance the equation of reaction	140	25	0			*

2	**T5:** Calculate the GeO_2 molar mass	146	17	2	*	*	*
	T6: Use the n = m/M relationship	142	14	9	*	*	
	T7: Verifiy unites' homogeneity	116	40	9			*
	T8: Numeric application	115	41	9			*
3	**T9:** Establish the RICE table	126	20	19	*	*	
	T10: Determine limiting reactant	82	40	43	*	*	*
	T11: Determine the maximal reaction advancement (X_m)	82	40	43		*	*
4	**T12:** Determine by using the RICE table the relationship between X_m and the H_2O product amount (mole)	63	59	43		*	*
	T13: Numeric application	60	62	43			*
5	**T14:** Determine from the RICE table the relationship between X_m and the minimal amount of H_2 needed to react with GeO_2	20	44	101		*	*
	T15: Use n = V/V_m relationship	26	40	99	*	*	
	T16: Numeric application	19	6	140			*
6	**T17:** Determine from the RICE table the relationship between X_m and germanium (Ge) product amount	28	47	90		*	*
	T18: Use n = m/M relationship	28	47	90		*	
	T19: Numeric application	23	7	135			*

Table 3. Problem 3: results on paracetamol
(As: Assimilate, An: Analyze, Ac: achieve)

Q	Tasks to be done (Ti)	succeeded	failed	untreated	As	An	Ac
1	**T1:** Identify the paracetamol chemical formula	150	15	0	*		
	T2: Establish the expression of the molar mass of paracetamol	148	15	2	*	*	
	T3: Numeric application	148	15	2			*
2	**T4 :** Use n = m/M relationship	140	15	10	*	*	
	T5: Verifiy units' homogeneity	135	2	28			*
	T6 : Numeric application	135	2	28			*
	T7 : Use n = N/N_A relationship	146	10	9	*	*	
	T8 : Numeric application	135	20	10			*

3	3.1	**T9:** Establish the relationship calculating the total consumed mass during one day: $m_T = 6$ m	120	20	25	*	*	
		T10: Numeric application	120	20	25			*
	3.2	**T11:** Establish n = m_T/M relationship calculating amounts of six consumed drug tablets	56	45	64		*	
		T12: Numeric application	53	48	64			*
		T13: Compare the obtained and the experimental value	50	48	67			*
		T14 : Deduct if the person did or not respect the instructions	50	48	67			*
4	4.1	**T15 :** Use C = n/v relationship	61	39	65	*	*	
		T16: Verifiy units' homogeneity	53	23	70			*
		T17: Numeric application	53	23	70			*
	4.2	**T18:** Use C_1 ´ V_1 = C ´ V relationship	41	18	106	*	*	
		T19: Numeric application	41	18	106			*
	4.3	**T20:** Establish $V_1 = V + V_{eau}$ relationship	13	28	124		*	
		T21: Numeric application	13	28	124			*

Results

Based on the hierarchy approach, the pupils' productions are analyzed in terms of decomposed questions (i.e., tasks (T1, T2, ...) considered as ranging from a simple to a more complex level in solving chemistry problems). The tasks carried out by the targeted pupils are identified and analyzed according to whether their answer requires pupils to master (appropriate, analyze and achieve) skills (Tables 2 and 3).

Analysis and discussion

Analysis in terms of tasks

Using Excel software, the results given in Tables 2 and 3 are transformed into graphs (Figs. 1a, 1.b, 2.a and 2.b) representing the succeeded, failed, and unprocessed tasks by pupils in terms of percentage.

Problem 1: Synthesis of germanium

The percentage representation (%) of pupils that succeeded, failed and did not treat the tasks of the problem 1 concerning the germanium fabrication is given in Figs. 1.a. and 1.b.

The T1 and T2 tasks (question 1) aim at identifying the chemical species involved in the reaction, and the chemical reactants and products, respectively. These

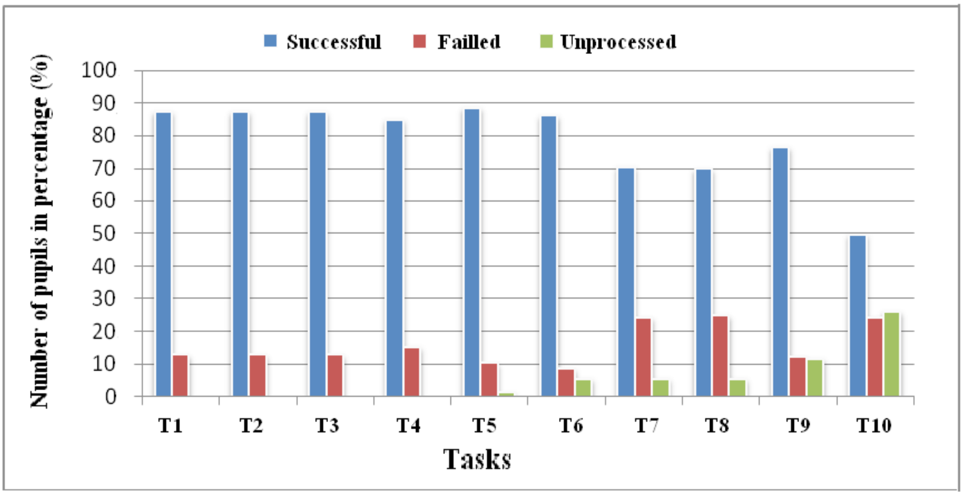

Figure 1.a. Performance of pupils in tasks on fabrication of germanium (T1 – T10)

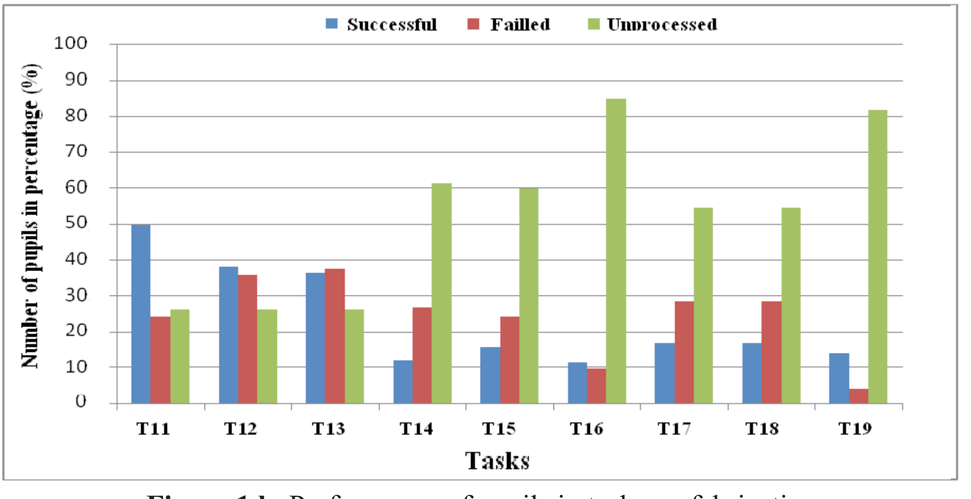

Figure 1.b. Performance of pupils in tasks on fabrication of germanium (T11 – T19)

tasks requiring pupils to master only "assimilate" skills were succeeded at a high-score (87.3 %). The T3 task, aiming to write the equation of reaction (analyze skill), was performed at 87.3 %, while the T4 one aiming to balance the equation of reaction (achieve skill) was completed at 84.9%.

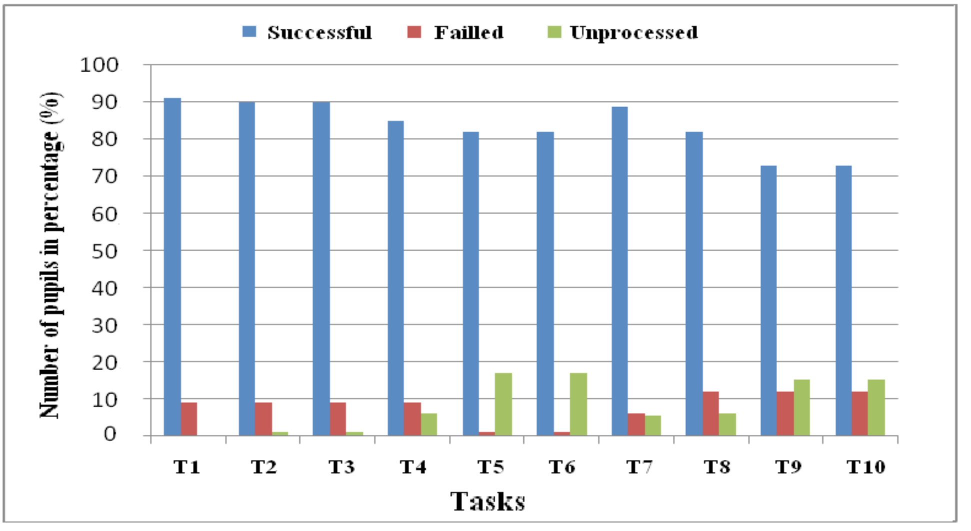

Figure 2.a. Performance of pupils in tasks on paracetamol (T1 – T10)

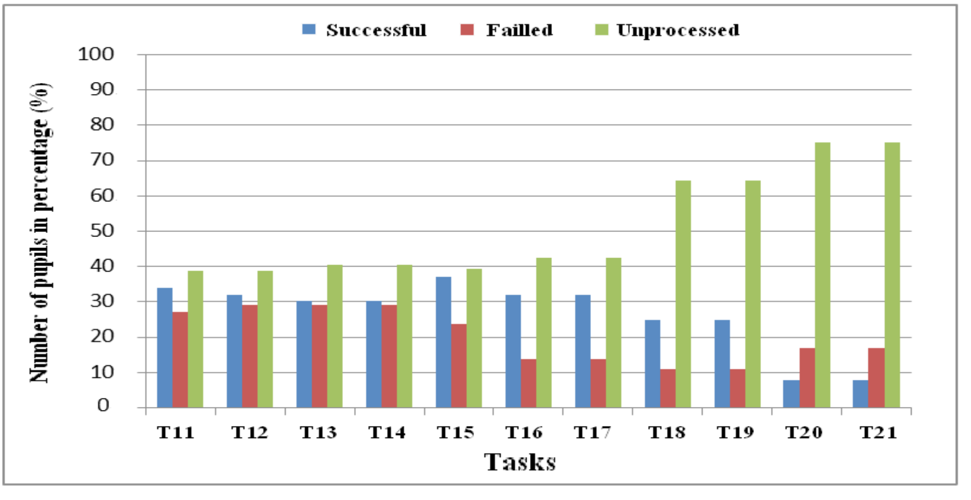

Figure 2.b. Performance of pupils in tasks on paracetamol (T11 – T21)

Question 2 (T5 – T8 tasks): The T5 task, involving (assimilate, analyze and achieve) skills on calculation of GeO_2 molar mass, was performed at a high score 88.5%. The T6, requiring (assimilate and analyze) skills on using $n = m/M$ relationship, was completed at 86.1%. The T7 and T8 tasks, aiming to verify the units' homogeneity, and to do numerical calculation (achieve skills), were completed at comparable scores (70.3% and 69.7%, respectively). The percentage of pupils completing "achieve" tasks is relatively decreased.

Question 3 (T9 – T11): The T9 task completed at 76.4% requires (assimilate and analyze) skills on how pupils establish the RICE table. The T10 task realized at 49.7% aims to determine the limiting reactant, and requires pupils to master the three studied skills. The T11 task, succeeded at 49.7%, concerns the determination of the maximal reaction advancement X_m, and requires pupils to mobilize two skills (analyze and achieve). The T10 and T11 scores imply that a moiety of pupils is not able to complete tasks involving algorithms and mathematical tools that help them to exploit correctly the established RICE Table. This may be due to lack of strategies and logical reflections at pupils, which need to supplement the use of algorithms with conceptual understanding of the entire process of problem solving (Bodner, 1987).

The T12 and T13 tasks (question 4), completed either with low scores 38.2% and 36.4%, aim to use the RICE Table to establish the relationship between X_m and the H_2O product amount (mole), and to calculate this amount; these tasks required pupils to master (analyze and achieve) skills on how exploit the RICE table, and do correctly numerical calculations. This implies that using algorithm (RICE Table) without conceptual understanding of what means X_m does not improve a pupils' problem solving skills, especially analyse and achieve skills.

Question 5 (T14 – T16 tasks): The T14 task, requiring (analyze and achieve) skills on how pupils use the RICE table to determine the relationship between X_m and the minimal amount of H_2 needed to react with GeO_2, was completed with a low score (12.1%). Establishing the relationship between X_m and reactants seems to be more difficult rather than that between X_m and products. The pupils seem to have not a strong conceptual understanding of this topic (RICE Table), which lets them to assimilate the similarity of the two cases of products and reactants. The T15 task, that requires mastering of (assimilate and analyze) skills on $n = V/V_m$ relationship, was performed with a low score (15.8%). The T16 task performed with an even lower score (11.5%) is a numerical calculation (achieve skills). It is to note a disconnection between conceptual understanding in the case of gas amounts and problem solving skills. Mastering their knowledge base, the pupils would understand that T15 task can be solved using the gas law, and to solve this task they must distinguish V and V_m variables. The pupils do not use correctly their skills base to express the gas amount as function of volume.

One can state that among 60 pupils (36.4%) succeeding task T13, only 20 (12.1%) pupils were able to complete T14 task, which seems to be decisive in question 5. The remaining 40 pupils, who failed this task, are not able to perform (T15 and T16) tasks, since the T14 task requires conceptual understanding on linking X_m with the minimal amount of a reactant needed to react with another reagent during a complete reaction.

The above results reveal that the majority of pupils have difficulties in completing unusual tasks (determining the minimal amount of a reactant during a complete reaction), more than in tasks aiming to determine the final product's amounts. The pupils are not able to determine the reactants' amount, by using the maximal advancement X_m value from the RICE table. So, the pupils did not mastered skills on using the RICE table to determine the reactants' amount as a function of X_m. Failing the tasks means that most pupils did not acquire automated and fast skills, and then did not reached the autonomous step considered as a higher step in building procedural knowledge process (Anderson, 1983; 1995).

Question 6 (T17 – T19 tasks): The T17 task, succeeded at a low score (17%), requires pupils to master (analyze and achieve) skills to determine the relationship between X_m and the germanium product amount from the RICE table. The T18 task, that requires mastering of (assimilate and analyze) skills on using n = m/M relationship, was also performed at 17%. While the T19 task corresponding to a numerical calculation (achieve skill), was performed with an even lower score (14.5%). Comparing the scores of T6 (86.1%) and T18 (17%) tasks, one can state that the same task (using n = m/M relationship) is not usually performed with a same score, and this may be explained by a lack of concentration and motivation at pupils in the end of the problem-solving.

The obtained results show that whole pupils have completed what considered as simple tasks (T1 – T9) involving concepts, relationship, schemata, and models that seem to be understood, and applied without remarkable difficulties by pupils in chemistry problem-solving; while more than the moiety of pupils were lacking conceptual understanding (limiting reactant and the maximal reaction advancement X_m), and then problem-solving strategies (algorithms) to deduce and exploit efficiently data, by using the RICE table (T10 – T13 tasks). The pupils were found to be unable to relate the various inputs to perform the tasks, considered as relatively complexes. Hence, a minority of pupils perform (T14 – T19) tasks aiming to determinate the final reactants and products' amounts in a complete reaction by using the RICE table.

The majority of pupils encounter then difficulties to complete complexe tasks at the end of problem 1. This implies that pupils did not master "analyze" and "achieve" skills, i.e. algorithms, strategies and logical reflections to establish the amounts' expression as a function of X_m from the RICE table, and to do correctly the unit's homogeneity and numerical calculations. The failure in giving and using $n = V/V_m$ in the case of gas species implies that pupils are lacking not only algorithms, but either conceptual understanding. Then, few pupils are able to combine knowledge and skills, i.e. have what considered as a strong knowledge base and skills base in chemistry area, which allows them to solve the problem with a high degree of accuracy. This combination is a characteristic of an "expert problem solver" (Larkin et al., 1980; Gick, 1986; Taconis et al., 2001). In their study of students' understanding of the mole concept and its use in problem solving, Staver & Lumpe (1995) argued that there are three barriers to successful chemical problem solving: (i) insufficient understanding of the concepts involved, (ii) use of memorized algorithms or rules, and (iii) inability to transfer understanding between the atomic/molecular and the macroscopic levels in solving chemistry problems.

Problem 2: Paracetamol (acetominophen)

The result illustrated in terms of percentage of pupils that succeeded, failed and did not treat tasks of the problem 2 is given in Figs. 2.a and 2.b.

Question 1 (T1 – T3 tasks): The T1 task, aiming to identify the paracetamol chemical formula, and requiring pupils to master only appropriate skills, was succeeded with a high score (90.9 %). The T2 and T3 tasks, aiming to establish the molar mass expression of paracetamol (assimilate and analyze skill), and calculating its molar mass value (achieve skill), were realized too at the same score with 89.7 %.

Question 2 (T4 – T8): The T4 and T7 tasks, requiring pupils to master (appropriate and analyze) skills on using $n = m/M$ and $n = N/N_A$ relationships, were carried out at 84.9% and 88.5%, respectively. The T5, T6 and T8 tasks aiming to verify units' homogeneity and realize numerical calculations (achieve skills) were completed at 81.8%. This score has slightly decreased in comparison with the scores realized for three precedents tasks.

Question 3.1 (T9, T10): these tasks realized at 72.7% aimed to establish the $m_T = 6M$ relationship, which allows pupils to calculate the consumed paracetamol mass during one day (assimilate and analyze skills). The realized score implies that a quarter of pupils have difficulties to mobilize mathematical tools to calculate the paracetamol mass, consumed in the determined duration.

Question 3.2 (T11 – T14): The T11 task completed at 33.9% requires pupils to use to establish $n = m_T/M$ relationship, and to calculate the six consumed drug tablets' amounts (analyze skills). The T12 task, aiming to calculate the n (mole) amount and requiring pupils to mobilize achieve skills, was realized at 32.1%. The T13 aims to compare the obtained and the experimental values; the T14 task has as a goal to deduce whether or not the person respects the instructions. These two tasks requiring pupils to master achieve skills were performed by an even lower score (30.3%).

Question 4.1 (T15 – T18): the T15 task, requiring pupils to master (assimilate and analyze) skills to use $c = n/V$ relationship, was realized at 37%; T16 and T17 tasks, requiring "achieve" skills to perform the units' homogeneity and the numerical calculation, were completed at 32.1%. Question 4.2 refers to T18 and T19 tasks that have been realized at more lowly score (24.9%); T18 task requires pupils to master (assimilate and analyze) skills on using $C_1 \times V_1 = C \times V$ relationship, while T19 task involves "achieve" skills on numerical calculation. For the question 4.3, the T20 and T21 tasks, realized too at a very weak score (7.9%), aim at establishing $V_1 = V + V_{eau}$ relationship (analyze skills), and doing a numerical calculation (achieve skills), respectively. The low scores observed for these tasks imply that most pupils have difficulties when they are faced tasks involving conceptual understanding, algorithms, and mastering mathematical tools, which are needed to solve correctly these "complex" tasks.

The success of T1 – T10 tasks (72 – 91%), considered as simple tasks, involves conceptual understanding of relationships that pupils apply in problem-solving without serious difficulties. The low score of (T11 – T21) tasks (7 – 34%) implies that the most pupils did not have strategies and logical reflections (algorithms) and conceptual understanding of chemistry relationships to calculate a solution concentration (c = n/V), a diluted solution concentration ($C_1 \times V_1 = C \times V$), and the added water volume to obtain a diluted solution ($V_1 = V + V_{eau}$). Hence, pupils are found to have difficulties to master and arrange (assimilate, analyze and achieve) skills, so as they can answer the asked questions by completing implicit tasks. The pupils are lacking conceptual understanding on solution concentration, and dilution of solution.

For the problems 1 and 2 too, the majority of pupils encounter difficulties to complete the end "complexe" tasks. This may be due to several reasons such as: lack of pupils' motivation at the end of the problems, the absence of a clear and good representation of matter levels, the non-understanding of certains chemistry concepts, the inability to elaborate algorithms and schemata needed to perform problem solving process. This expects the pupils to understand the problem's goal, and then to complete the different implicit complex tasks (Sweller, 2003). Further, failing the end tasks means that most pupils cannot acquire automated and fast skills within the autonomous step, considered as a higher step in building procedural knowledge process (Anderson, 1983; 1995). Accordingly, the pupils seem to be unable to link conceptual and procedural knowledge to build complex skills in cumulative process by acquiring knowledge elements and using skills according to the purposed problems.

Some pupils have been classified as "failled" perform "true" answers, but not for the corresponding tasks; so, the pupils' representations of problems were inconsistent with the chemical reality described, and they evidently didn't realize what is really asked in the problems (Herron & Greenbowe, 1986). This implies that pupils encounter the difficulties in representing matter in chemistry, which is characterized by three to four levels, as has been described in the conceptual framework.

According to the "Instructional design" approach (Pass & Van Merriënboer, 1993; Salden et al., 2006; Pass et al., 2003; De Croock & Van Merriënboer, 2007) that emphasizes the importance of tasks' organization in learning of skills/knowledge, one can state most pupils can develop their skills and knowledge with conceptual understanding, and good elaboration of schemata (algorithms), just for tasks considered as simples. It seems that pupils cannot categorize correctly a problem to retrieve pertinent information from long-term memory for use in solving it (Bunce et al., 1991)

Analysis in terms of skills, capacities and knowledge

The success of pupils in problem-solving depends on ability to mobilize their knowledge and skills. The indicators of pupil's success are studied in chemistry problem-solving in terms of skills (assimilate, analyze and achieve) that pupils master to solve the purposed problems, with regard to associated capacities (Noirfalise & Porte, 1990). For reason of simplicity, only succeeded tasks were considered in the presented results. Table 4 shows the tasks' classification made in terms of skills categories, the average number of puils mastering each skill, and the average percentage of success of the skills. Further, the analysis is developped considering the skills' categories as have been defined by Rey et al. (2003).

Table 4. Average percentage of success skills (appropriate, analyse and achieve) of purposed problems

Skills	Total number of skills	Average number of pupils validating skills	Average Percentage of success (%)
Assimilate	14	116	70.3
Analyse	19	84.8	51.4
Achieve	24	78.3	47.5

The two problems contain 40 tasks that have been identified in Tables 2 and 3. Among these tasks, 14 were considered as tasks requiring pupils to master assimilate skills, 19 as tasks that required mastering of analyze skills, and 24 as tasks that required mastering of achieve skills. The representation of the results is given in Fig. 3. Hence, the majority of pupils mastered "assimilate" skills at 116/165 (70.3%) in solving chemistry problems, a moiety of pupils mastered "analyze" skills at 84.8/165 (51.4%), and fewer pupils mastered "achieve" skills at 78.3/165 (47.5%).

This can attest to a mastering level of the different skills by pupils faced to chemistry problems solving. The level A (indicators chosen are totally observed) of mastering tasks is corresponding to succeeded tasks as indicators, and then it is realized at 70.3 % for assimilate skills, at 51.4 % for analyze skills, and at 47.5 % of achieve skills. The pupils with level A, did not have difficulties to master the different macro-skills, especially the "assimilate" skills in solving chemistry problems, and then they may be considered as "expert" solver problems with understanding chemistry conceptual knowledge and with abilities to develop strategies and logical reflexes to approach problem solving activities.

The B (indicators chosen are partially observed) and C (indicators chosen are insufficiently observed) levels are too corresponding to untreated tasks; and this make

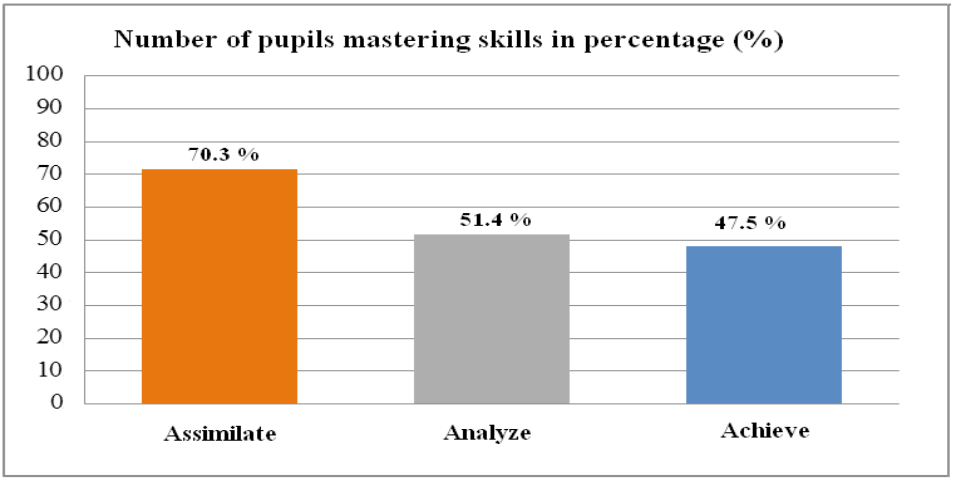

Figure 3. Representation of pupils mastering skills in terms of percentage (%).

it difficult to identify the B and C levels of mastering with an exact percentage, in the framework of this study. Concerning the level D, where the indicators chosen are absents (failled tasks as indicators); the percentage may be calculated based on the faille tasks (Table 5). Indeed, the level D of mastering is realized at 16.9 % for assimilate skills, at 30.1 % for analyze skills, and at 33.3 % of achieve skills.

Table 5. Average percentage of mastering (assimilate, analyse and achieve) skills at level D

Skills	Total number of skills	Average number of pupils failled skills	Average percentage of mastering at level D (%)
Assimilate	14	27.8	16.9
Analyse	19	49.7	30.1
Achieve	24	54.9	33.3

The pupils, with level D, encounter difficulties to master the different macro-skills, especially the "analyze" and "achieve" skills in solving chemistry problems. The pupils with level D are novice solver problems without understanding chemistry conceptual knowledge and without abilities to develop strategies and logical reflexes to approach problems. As has been stated elswhere (Aziz & Moi, 2000; Lee et al., 2001), the pupils' abilities to recall and select appropriate formula to solve chemistry problems is an ultimate challenge in the pupils' lives.

The obtained results are relative since the problems presented to pupils are considered as relatively simples, and built of questions that could guide pupils in problem-solving. The validation percentages show that pupils develop "assimilate" skills (70.3%) more than "analyze" (51.4%) and "achieve" (47.5%) skills during chemistry "problem-solving" activities; what seems to be expected and normal. Taking into account the percentages of pupils that have validated the different skills, one can find that a majority of the pupils have mastered "assimilate" macro-skill at the level A, with regard to conceptual knowledge (understanding chemical concepts as equation of reaction, complete reaction, molar mass, amount, volume, concentration, RICE table, and dilution). Only 16.9% of pupils have found to be of D level of mastering assimilate skills. In terms of capacities (Table 1), the pupils with A level are able to: (i) establish a model scheme for a situation in chemistry problem-solving; (ii) identify the chemical concepts with their symbol (Identification of the reactants and products during a reaction, identification of a species' chemical formula); (iii) relate the problem to a known model situation: the fact that pupils considered as novice problem solvers have this capacities, this means that pupils have understood the situations learned in the course for the first time, and are able to remember such situation in solving problems.

A moiety of pupils mastered "analyze" skills at the level A, and about 30.1 % of pupils undergo the D level, with regard to conceptual knowledge and strategies and logical reflexes (algorithms). Based on the Table 1, the pupils with level A are found to have the following capacities: (iv) divide the problems' questions into simple and implicit tasks to reach the final goals, and answer to tasks ranging from the simple to complex ones; (v) explain the chosen modeling (definition of the chemical system, writing of associated reactions, establishing the RICE table...); (vi) identify and enunciate the used chemical laws. The pupils are found to be able to identify several laws relating to chemical amounts as: $n = V/V_m$ and $C = m/M$ relationships.

This implies that these pupils, considered as novice problem solvers, have reasoning attitudes that enable them to build problem-solving strategies.

Fewer pupils have "achieve" skills at the level A, and the majority at the level D, with regard to strategies and logical reflexes (algorithms). Based on the table 1, only the pupils with level A have the following capacities: (vii) develop a process until the end to answer explicitly implicit asked tasks. As an indicator of this capacity, the pupils are able to determine by using the RICE table the relationship between X_m and the different amount (mole) as well as the products and the reactants species; (viii) carry out efficiently analytical and numerical calculations; this implies some capacities as balancing the equations of reactions, developing mathematical tools to solve correctly complex tasks); (ix) use a dimensional analysis: as an indicator of this capacity there is the homogeneity of unites in the international system.

The low percentage of pupils mastering "achieve" skills shows that most pupils have difficulties when they are faced complex tasks involving conceptual understanding, algorithms, and strategies.

Considering the (assimilate → 1st degree skill, analyze → 2nd degree skill, and achieve → 3rd degree skill) correlation, one can conclude that: (x) a majority of pupils masters the 1st degree (elementary) skills involving declarative and conceptual knowledge, and automated rules in chemistry problem-solving; (xi) a moiety of pupils masters the 2nd degree skills (elementary skills with interpretation) that enable pupils to choose an appropriate procedure (procedural knowledge) in solving chemistry problems; (xii) fewer pupils have 3rd degree (complex) skills, which are necessaries to accomplish complex tasks. Hence, the majority of pupils are unable to do a choice and a combination of several procedures to solve complex tasks considered as new situations for pupils.

According to Heyworth (1999) that divided the students into expert and novice, one can classify the moiety of pupils who made no procedural errors and had a good conceptual understanding as "expert problem solvers"; the remaining pupils with largely erroneous procedures and with a poor conceptual understanding were classified as "novice problem solvers". The "expert" pupils seem to follow a well-worn path to answer to what would be considered as routine problems for them. For novice pupils, the problems didn't seem to be familiar or have a recognizable solution path. Herron & Greenbowe (1986) show that successful problem solvers have a good command of basic facts and principles, construct appropriate representations, have general reasoning strategies that led to logical connections among the problems' elements, and verify a number of strategies to insure so that the representations of the problems are consistent with the given facts. The solution is then logically sound, the computations are error-free, and the problems solved are those presented.

Generally, several pupils with level D have failed to master the studied skills, and this may be result in blockages, errors, and difficulties to perform asked tasks, especially the complex ones at the end of the problems, which involve generally "analyze" and "achieve" skills. Validation of a skill cannot be done only by acquiring declarative, procedural and conceptual knowledge. Taking into account the relationship between knowledge, abilities and attitudes, the skills are conceived in the tasks' complexity found generally at end of the problems, where the majority of pupils cannot perform these tasks; this can be due to different reasons: (xiii) lack of understanding of chemistry concepts (conceptual understanding), difficulties to exploit laws and chemistry principles, etc.; (xiv) lack of mental representations due to the inability to develop schemata to solve the problems (procedural knowledge). Several pupils did not categorize some implicit tasks to elaborate the appropriate schemata that would allow them to complete successfully the complex tasks; (xv) lack of strategies and logical reflexes (algorithms) enhances several pupils to organize and arrange declarative, conceptual and procedural knowledge in logical way to answer questions.

Concerning the impact of tasks' organization on knowledge development, the findings reveal a decreasing in percentage of pupils that achieve "complex" tasks at the end of problems, which require combination of strong base of knowledge and strong base of skills. As indicated, the most pupils considered as novice problem solvers (Level D) did not master acquired knowledge and skills at a significant hierarchical level to reach the final level (complex) tasks. This agrees with the approach suggesting the prevalence of problems' hierarchy from the simple to the complex (Gagné, 1962; 1968; Frederiksen & White, 1989).

The learners being subjects to problems with direct questions (i.e., with implicit tasks) are generally less successful in "complex tasks" at the end of the problems. Based on Frederiksen & White (1989) approach, the authors purpose to develop a future study on pupils taking in acount the decomposition of questions into sub-goals (explicit tasks) and the setting up of situations allowing gradual acquisition of skills relating to such task.

Conclusions and implications for instruction

The goal of this work is to study mastering of certaines macro-skills at pupils (16 – 17 years) of first year of Moroccan high-school in solving chemistry problems in relation to knowledge on chemical concepts (equation of reaction, complete reaction, molar mass, amount, volume, concentration, the RICE table, dilution). Methodologically, the written productions of pupils considered a priori as "novice problems solvers" in problem-solving activities were analyzed and discussed.

The pupils' performances were analyzed and discussed in terms of (assimilate, analyze and achieve) macro-skills, with regard to the (first, second and third degree) skills, which pupils could master to complete implicit tasks of the purposed chemistry problems. Pupils were found to be able to mobilize "assimilate" skills more than (analyze and achieve) ones, and to have difficulties to perform tasks considered as complex at the end of problems, especially at pupils with level D of mastering skills, considered usually as "novice problems solvers". The impact of tasks' organization on knowledge and skills development among pupils seems to be verified as indicated by the approach privileging prevalence of a hierarchy of problems from the simple to the complex ones.

As a remediation, it will be benefit to purpose to novice pupils, especially those with level D, the problems with questions containing explicit tasks (intermediate tasks) to help them in developing functional problem-solving strategies; this may enable pupils to move forward to build their knowledge, and to their "analyze" and "achieve" skills, particularly in the case of complex tasks, i.e. purpose to pupils an instruction based on decomposition of tasks into sub-goals allowing gradual acquisition of skills relating to the sub-goals.

Chemical-equilibrium problems involve not only unique concepts, but also other concepts such as the mole and reaction stoichiometry, the RICE table, gases and the ideal gas law. It is not surprising that pupils encounter difficulties in solving problems containing these concepts. In stoichiometric calculations, analogical reasoning is involved, and this is an ability lacking or not well developed with some pupils. Further, pupils find it hard to understand that the change in the total number of moles that may occur as a result of a reaction is due to a different grouping of atoms in the reactants and the products. When gases are involved, pupils have extra difficulties, apart from the one related to the change of the total volume.

The chemistry educators should pay special attention to all these concepts (the mole, stoichiometry, gas laws, chemical equilibrium etc. elaboration and exploitation of the RICE tables) when dealing with the theory of chemistry. It is then recommended for teachers to give practical lessons regarding integration of levels to different teaching methods in chemistry. If representations and explanations at the symbolic, microscopic, and macroscopic levels are done during instructions in classrooms, then pupils' difficulties in using the three levels can be overcome. The task of thinking about chemical phenomena at sub-microscopic level is aided by using macroscopic and symbolic representations when used in an integrated way. The pupils need to be remediated in skills related to algebra to allow them doing numerical calculations without any difficulties.

To improve the problem solving skills of pupils, educators must focus on developing pupils' knowledge base and skills base. Without these tools, pupils will never succeed in true problem solving. Emphasis should be placed on conceptual understanding of topics, and on carrying out and completing exercises and problems. According to Domin & Bodner (2012), the pupils have to apply two simple ideas to accomplish problem-solving in chemistry: (i) organization of the problem-solving process around a drawing that captures the physical reality of the system and the relevant information extracted both from the statement of the problem, and the thought process applied to working the problem; (ii) when pupils are in doubt, they have to try something, and see where it gets them.

As a perspective of this work, it will be important to assess the pupils on their "logical-thinking ability", by carrying out the TOLT (Test of Logical Thinking) and GALT (Group Assessment of Logical Thinking) tests to more develop the correlations analysis made between the three skill degree categories of and the pupils' success, failure, and unprocessed skills. This would be a useful contribution to the teaching of problem-solving.

APPENDIX

Problem 1: Synthesis of Germanium

Germanium (Ge) is used in electronics industries; it is prepared by reaction of germanium dioxide (GeO_2) and dihydrogen (H_2), giving germanium and water. A mass m = 1000 kg of GeO_2 is reacted with an excess amount of dihydrogen. The reaction is considered total.

1 – Write the equation of reaction and balance this equation.

2 – Calculate the molar mass of dioxide germanium, and deduce its reacted amount.

3 – Give RICE table of reaction, calculate the maximal advancement of this reaction.

4 – Determine the amount of the formed water at the end of reaction.

5 – Calculate the minimal volume used of dihydrogene (V_{H2}).

6 – Calculate the mass of the obtained germanium.

Given data: M(Ge) = 72.6 g/mol M(O) = 16 g/mol M(H) = 1 g/mol Vm = 24 L/mol

Probleme 2: Paracetamol also known as acetaminophen

Paracetamol is an active principle of certain drugs such as doliprane of formula $C_8H_9O_2N$. The information sheet contains the following informations: (i) each tablet contains 500 mg of paracetamol; (ii) it should not exceed 2.65×10^{-2} mol paracetamol per day, with a minimum duration of four hours between two uses.

1 – Calculate the molar mass of paracetamol.

2 – Calculate the amount of paracetamol in one tablet. Deduce the number of molecules that contains this tablet.

3 – A person consumed six tablets of doliprane for one day.

3 – 1. Calculate the mass of paracetamol consumed by this person.

3 – 2. Did this person follow the indicated instructions?

4 – A doliprane tablet is dissolved in V = 50 ml of distilled water, to obtain a solution (S).

4 – 1. Calculate the concentration of the prepared solution.

4 – 2. The solution (S) is diluted by adding a volume V_e of distilled water, and a solution S_1 of concentration $C_1 = 10^{-3}$ mol.L^{-1} is obtained. Find the volume of the S_1 solution, and deduce the volume V_e of the added distilled water.

Given data: M(O) = 16 g/mol ; M(H) = 1 g/mol ; M(C) = 12 g/mol ; M(N) = 14 g/mol; $N_A = 6.022 \times 10^{23}$ mol^{-1}; Volume molar volume in experimental conditions: $V_m = 22.4$ L$\times$mol^{-1}

NOTES

1. http://eduscol.education.fr/fileadmin/user_upload/Physique-chimie/PDF/Recommandations_pour_l_epreuve_ecrite_du_bac_S_15-12-2013.pdf

REFERENCES

Aka, E.I. Güven, E. & Aydoğdu, M. (2010). Effect of problem solving method on science process skills and academic achievement. *J. Turkish Sci. Educ.,* 7(4) 13 – 25.

Ambrus, A. (2014). Teaching mathematical problem-solving with the brain in mind: how can opening a closed problem help. *CEPS J., 4,* 105 – 120.

Anamuah-Mensah, J. (1986). Cognitive strategies used by chemistry students to solve volumetric analysis problems. *J. Res, Sci. Teaching*, *23*, 759 – 769.

Anderson, J.R. (1983). *The architecture of cognition*. Cambridge: Harvard University Press.

Anderson, J.R. (1995). *Learning and memory: an integrated approach*. New York: John Wiley & Sons.

Aziz, N. & Moi, S. (2000). Student style of remembering formula in science problem solving. *Bull. Assoc. Sci. & Math. Educ., 10*, 62 – 68.

Bodner, G.M. (1987). The role of algorithms in teaching problem solving. *J. Chem. Educ., 64*, 513 – 514.

Bodner, G.M. (2003). Problem solving: the difference between what we do and what we tell students to do. *Univ. Chem. Educ.,* 7, 37 – 45.

Bunce, D.M. & Heikkinen, H. (1986). The effects of an explicit problem-solving approach on mathematical chemistry achievement. *J. Res. Sci. Teaching*, *23*, 11 – 20.

Bunce, D.M., Gabel, D.L. & Samuel, J.V. (1991). Enhancing chemistry problem solving achievement using problem categorization. *J. Res. Sci. Teaching*, *28*, 505 – 521.

Caillot, M. (1988). *PROPHY: une méthode pour résoudre des problèmes de physique.* Paris: Université de Paris VII.

Carlson, R.A. & Yaure, R.G. (1990). Practice schedules and use of component skills in problem solving. *J. Exp. Psych., 16,* 484 – 496.

Chi, M.T.H, Feltovitch, P.J. & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Sci., 5*, 121 – 152.

Chiu, M. (2005). A national survey of students' conceptions in chemistry in Taiwan. *Chem. Educ. Int.*, *6*(1) 1 – 8.

Cracolice, M.S., Deming, J.C. & Ehlert, B. (2008). Concept learning versus problem solving: a cognitive difference. *J. Chem. Educ., 85*, 873 – 878.

Crahay, M. & Lafontaine, D. (1986). *L'art et la science de l'enseignement*. Bruxelles: Labor.

De Croock, M.B.M. & Van Merriënboer, J.G. (2007). Paradoxical effects of information presentation formats and contextual interference on transfer of a complex cognitive skill. *Computers Human Behaviour, 23*, 1740 – 1761.

De Ketele, J.-M. & Gerard, F.-M. (2005). La validation des épreuves d'évaluation selon l'approche par les compétences. *Mesure & Eval. Educ.,* 28(3), 1 – 26.

Del Pozo, R M. (2001). Prospective teachers' ideas about the relationships between concepts describing the composition of matter. *Int. J. Sci. Educ.,23*, 353 – 371.

Domin, D. & Bodner, G.M. (2012). Using students' representations constructed during problem solving to infer conceptual understanding. *J. Chem. Educ.*, *89*, 837 – 843.
Drummond, H.P. & Selvaratnam, M. (2008). Students' competence in intellectual strategies needed for solving chemistry problems. *S. Afr. J. Chem., 61,* 56 – 62.
Dumas-Carré, A. & Goffard, M. (1997). *Rénover les activités de résolution de problème en physique: concept et démarches*. Paris: Armand Collin.
Frederiksen, J.R. & White, B.Y. (1989). An approach to training based upon principled task decomposition. *Acta Psychologica, 71*, 89 – 146.
Gagné, R. (1962). The acquisition of knowledge. *Psych. Rev.*, *69*, 355 – 365.
Gagné, R. (1968). Learning hierarchies. *Educ. Psychologist*, *6*, 1 – 9.
Gagné, E.D. (1985). *The cognitive psychology of school learning*. Boston, Toronto: Little Brown Company.
Gick, M.L. (1986). Problem solving strategies. *Educ. psychologist*, *21,* 99 – 120.
Gilbert, J.K. & Treagust, D.F. (2009). Macro, submicro, and symbolic representations and the relationship between them: key models in chemical education (pp. 1 – 8). In: Gilbert, J.K. & Treagust, D.F. (Eds.). *Multiple representations in chemistry education.* Dordrecht: Springer.
Gillet, P. (1991). *Construire la formation.* Paris: ESF.
Giordan, A. (1998). *Une didactique pour les sciences expérimentales*. Paris: Belin.
Gkitzia, V., Salta. K. & Tzougraki, C. (2011). Development and application of suitable criteria for the evaluation of chemical representations in school textbooks. *Chem. Educ. Res. Practice, 12*, 5 – 14.
Glover, J.A., Ronning, R.R. & Brunning, R.H. (1990). *Cognitive psychology for teachers.* New York: Macmillan.
Gock, T. (2010). The general assessment of problem solving processes and metacognition in physics education. *Eurasian J. Phys. & Chem. Educ., 2*(2), 110 – 122.
Goffard, M. (1994). *Le problème de physique et sa pédagogie*. Paris: ADAPT.
Greiff, S., Holt, D.V. & Funke, J. (2013). Perspectives on problem solving in Educational assessment: analytical, interactive, and collaborative problem solving. *J. Problem Solving, 5*(2), 71 – 91.
Hamza, M.K. & Griffith, K.G. (2006). Fostering problem solving and creative thinking in the classroom: cultivating a creative mind. *Nat. Forum Appl. Educ. Res. J.,19(*3), 1 – 32.
Herron J.D. & Greenbowe T.J. (1986). What can we do about sue: a case study of competence. *J. Chem. Educ., 63*, 526 – 531.

Heyworth R.M. (1999). Procedural and conceptual knowledge of expert and novice students for the solving of a basic problem in chemistry. *Int. J. Sci. Educ.*, *21*, 195 – 211.

Hinton, M.E. & Nakhleh, M.B. (1999). Students' microscopic, macroscopic, and symbolic representations of chemical reactions. *Chem. Educator*, *4*, 158 – 167.

Jonnaret, P. (2002). *Compétences et socioconstructivisme – un cadre théorique*. Bruxelles: De Boek.

Johnstone, A.H. (1982), Macro-and micro- chemistry. *School Sci. Rev., 64*, 377 – 379.

Johnstone, A.H. (1993). Introduction. In: Word, C. & Sleet, R. (Eds.). *Creative problem solving in chemistry*. London: RSC.

Kaufman, L., Schwartz, B., Salustri, C. & Williamson, **S**.J. (1990). Modulation of spontaneous brain activity during mental imagery. *J. Cognitive Neuroscience*, *2*, 124 – 132.

Kaufman, L., Cycowicz, Y.M., Glanzer, M. & Williamson, S.J. (1992). Verbal and imaging tasks have different effects on spontaneous activity of cerebral cortex. In: *Annual technical report: cognition and the brain*. New York: New York University.

Larkin, J. & Simon, H.A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Sci.*, *11*, 65 – 99.

Larkin, J., McDermott, J., Simon, D.P. & Simon, H.A. (1980). Expert and novice performance in solving physics problems. *Science*, *208*(4450) 1335 – 1342.

Lee, K-W.L., Tang, W-U., Goh, N-K. & Chia, L-S. (2001). The predicting role of cognitive variables in problem solving in mole concept. *Chem. Educ. Res. & Practice Europe*, *2*(3), 285 – 301.

Mazouze, B. (2016). Des difficultés en résolution de problèmes de physique : quelles aides pour les élèves. *Educ. J. Univ. Patras, 3*, 258 – 268.

Meirieu, J. (1988). *Apprendre, oui, mais comment*. Paris: ESF.

Nakhleh, M.B. & Krajcik, J.S. (1994). Influence of levels of information as presented by different technologies on students' understanding of acid, base, and pH concepts. *J. Res. Sci. Teaching*, *31*, 1077 – 1096.

Neves, D.M. & Anderson, J.R. (1981). Knowledge compilation: mechanisms for the automatization of cognitive skills (pp. 86 – 102). In: Anderson, J.R. (Ed.). *Cognitive skills and their acquisition.* Hillsdale: Lawrence Erlbaum.

Newell, A. & Simon, H.A. (1972). *Human problem solving*. Englewood Cliffs: Prentice-Hall.

Noirfalise, N. & Porte, J. (1990). Résolution de problème en second cycle. *Repères*, *1*, 51 – 67.

Nurrenbern, S.C. & Pickering, M. (1987). Concept learning versus problem solving: is there a difference. *J. Chem. Educ., 64*, 508 – 510.
Orange, C. (2005). Problème et problématisation dans l'enseignement scientifique. *Aster, 40*, 3 – 11.
Ouasri, A. (2016). Study of the appropriation by the pupils of second Baccalaureate year of knowledge objects relating to acid-bases titrations. *Chemistry, 25*, 695 – 717.
Ouasri, A. (2017a). Analyse des difficultés des élèves de deuxième année Baccalauréat marocain en résolution de problèmes de Mécanique. *Educ. J. Univ. Patras, 4*(2), 39 – 57.
Ouasri, A. (2017b). Analyse des connaissances des de troisième année du collège marocain en activités de résolution de problèmes de l'électricité (loi d'Ohm, puissance et enérgie électrique). *Eur. J. Educ. Studies, 3*(7), 94 – 120.
Ouasri, A. (2017c). Study of Moroccan pupils' difficulties at second baccalaureat year in solving chemistry problems relating to reactivity of ethanoate ions and to copper-aluminium cell. *Chem. Educ. Res. Practice*, *18*, 737 – 748.
Ouasri, A. (2017d). Analyse des difficultés des élèves marocains de 15 – 16 ans en résolution de problèmes de mécanique (mouvement et repos, interactions mécaniques et forces, poids et masse). *Rev. Sci. Math. & ICT Educ.*, *11*(1), 69 – 92.
Ouasri A. (2017e). Konstantinos Ravanis; *analyse* des compétences des élèves de Tronc commun marocain en résolution de problèmes d'électricité (Dipôles actif et passif). *Eur. J. Educ. Studies, 3*(11), 1 – 28.
Overton, T., Potter, N. & Leng, C. (2013). A study of approaches to solving open-ended problems in chemistry. *Chem. Educ. Res. Practice, 14,* 468 – 475.
Paas, F. & Van Merriënboer, J. (1993). The efficiency of instructional conditions. *Human Factors*, *35,* 737 – 743.
Paas, F., Renkl, A. & Sweller, J. (2003). Cognitive load theory and instructional design: recent developments. *Educ. Psychologist*, *38*(1) 1 – 4.
Perrenoud, P. (1997). *Construire des compétences dès l'école*. Paris : ESF.
Reid, N. & Yang, M.-J. (2002). The solving of problems in chemistry: the more open-ended 33problems. *Res. Sci.* & *Tech. Educ., 20*, 83 – 98.
Reif, F. (1983). Understanding and teaching problem solving in physics (pp. 15 – 53). In : Delacôte, G. & Tiberghien, A. (Eds.). *Recherche en didactique de la physique*. Paris: CNRS.
Rey, B., Carette, V., Defrance, A., Kahn, S. & Meirieu, P. (2003). *Les compétences à l'école : apprentissage et évaluation.* Bruxelles: De Boeck.

Salden, R.J.C.M., Paas, F. & Van Merriënboer, J.G. (2006). A comparison of approach to learning task selection in the training of complex cognitive skills. *Computers Human Behaviour, 22*, 321 – 333.

Schmidt, R.A. & Bjork R.A. (1992). New conceptualizations of practice: common principles in three paradigms suggest new concepts for training. *Psych. Sci., 3*, 207 – 217.

Staver J.R. & Lumpe A.T. (1995) Two investigations of students' understanding of the mole concept and its use in problem solving. *J. Res. Sci. Teaching*, *32*, 177 – 193.

Sweller, J. (2003). Evolution of human cognitive architecture (pp. 215 – 266). In: Ross, B. (Ed.). *The psychology of learning and motivation.* San Diego: Academic Press.

Surif, J. Ibrahim, N.H. & Dalim, S.F. (2014). Problem solving: algorithms and conceptual and open-ended problems in chemistry. *Procedia, 116*, 4955 – 4963.

Taber, K.S. (2014). Ethical considerations of chemistry education research involving human subjects. *Chem. Educ. Res. Practice*, *15*, 109–113.

Taconis, R., Ferguson-Hessler, M G.M. & Broekkamp, H. (2001). Teaching science problem solving: an overview of experimental work. *J. Res. Sci. Teaching*, *38*, 442 – 468**.**

Talanquer, V. (2006). Commonsense chemistry: a model for understanding students' alternative conceptions. *J. Chem. Educ., 83*, 811 – 816.

Tardif, J. (2006). *L'évaluation des compétences-documenter le parcours de développement*. Montréal: Chenelière Education.

Teichert, M.A. & Stacy, A.M. (2002). Promoting understanding of chemical bonding and spontaneity through student explanation and integration of ideas. *J. Res. Sci. Teaching, 39*, 464 – 496.

Treagust, D.F., Chittleborough, G. & Mamiala, T. (2003). The role of submicroscopic and sym-bolic representations in chemical explanations. *Int. J. Sci. Educ., 25*, 1353 – 1368.

Van Merriënboer, J.G., Kester, L. & Paas, F. (2006). Teaching complex rather than simple tasks. *Appl. Cognitive Psych., 20,* 343 – 352.

Zoller, U. & Pushkin, D. (2007). Matching higher-order cognitive skills (HOCS) promotion goals with problem-based laboratory practice in freshman organic chemistry course. *Educ. Res., 8*(2), 153 – 171.

Wang, J-Z., Kauffman, L. & Williamson, S.J. (1990). Imaging regional changes in the spontaneous activity of the brain: an extension of the minimum-norm lest-squares estimate. *Electroencephalography & Clinical Neurophysiology*, *86*, 36 – 50.

Williamson, V.M. & Abraham. M.R. (1995). The effect of computer animation on the particulate mental models of college chemistry students. *J. Res. Sci. Teaching, 32*, 521 – 534.

Wolfer, A.J. (2000). *Introductory college chemistry students - understanding of stoichiometry: connections between conceptual and computational understanding and instruction: PhD. thesis*. Corvallis: Oregon State University.
Wu, H.-K. (2003). Linking the microscopic view of chemistry to real-life experiences: intertextuality in a high-school science classroom. *Sci. Educ., 87,* 868 – 891.

✉ **Dr. Ali Ouasri**
Département de Physique-Chimie
Centre Régional des Métiers de l'Education et de la Formation
Madinat Al Irfane
Souissi, BP 6210 Rabat, Morocco
E-mail: aouasri@yahoo.fr