CONSTRUCTING A FRAMEWORK FOR TEACHING REACTION STOICHIOMETRY USING PEDAGOGICAL CONTENT KNOWLEDGE

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Abstract. Educators now recognize the central role that teachers have in determining the ways in which science is taught and learned in schools, a role that no curriculum by itself can fulfill. Apart from being a curriculum implementer, the effective teacher is alternatively and simultaneously a model, decision-maker, diagnostician, facilitator, innovator, experimenter, resources manager and source of knowledge. Professional development opportunities are critical in helping teachers fulfill these roles and maintain their enthusiasm. Research has shown that even when students complete a chemistry-degree programme and the pedagogical course requirements necessary for teacher professionalism they may still be found wanting as they begin teaching without a firm grasp of how to teach specific chemistry concepts. In consonant with this fact, this paper attempts to utilize those ideas on the components of pedagogical content knowledge (PCK) to formulate a framework to help clarify the knowledge that good chemistry teachers possess, and how that knowledge is applied in teaching stoichiometry.

Keywords: chemistry curriculum, students' misconceptions, representations in chemistry, pedagogical content knowledge, stoichiometry

Introduction

An important goal for chemistry education is the acquisition of problem-solving skills. Possession of superb problem-solving skills generates a sound base for good performance in different aspects of physical chemistry: chemical equilibrium, acid-base equilibrium, quantum chemistry, chemical kinetics, thermochemistry, thermodynamics and stoichiometry.

Stoichiometry, a branch of chemistry, which provides quantitative information about chemical reactions involves problem-solving where students are given the amount of one substance in a chemical reaction and are required to calculate the amount of another substance necessary to react completely with the given substance, or the amount of substances produced in the chemical reaction [1]. Sample problems to be encountered when dealing with stoichiometric calculations are (1) how much magnesium (II) oxide (MgO) will be produced if 3.00g of magnesium ribbon is burnt in the air? (2) how much magnesium and oxygen are required to produce one ton of magnesium oxide. There is a consensus among chemistry educators that learning to solve those problems require a good mastery of chemistry concept, ability to construct and balance chemical equations and using the balanced chemical equations to calculate the masses of chemical substances involved in the reactions.

Stoichiometry is regarded as one of the fundamental 'tools in the chemistry toolbox' [2] because attainment of high degree of proficiency in solving stoichiometry problems is needed for dealing with equilibrium and acid-base problems. No wonder why it receives much attention in the senior secondary school chemistry curriculum. The high frequency at which test items on stoichiometry appear in Nigerian national examinations conducted by West African Examinations Council (WAEC), National Examinations Council (NECO) and Joint Admission and Matriculation Board (JAMB) is also an indication of recognition given to the topic in the school curriculum [3]. Unfortunately, stoichiometry calculations have always been difficult for students [4-6]. The reasons for this difficulty lies in the complexity of conducting these calculations that require an understanding of the mole concept, constructing and balancing chemical equations, algebraic skills, and interpretation of a word problem into procedural steps that lead to the correct answer.

Perhaps a productive path for chemistry educators to follow in providing solution to student's difficulties in stoichiometry is what Shulman has labeled "pedagogical content knowledge (PCK)" [7]. PCK is regarded as the link between content knowledge (CK) and pedagogical knowledge (PK) [8]. CK is the subject matter to be taught; within the contents of this paper reaction stoichiometry is the content knowledge. Pedagogical knowledge refers to the broad principle and strategies of classroom management and organization that appear to transcend subject matter [9]. PCK refers to the most appealing manner in which teachers organize and present subject matter by telling, explaining, guiding, illustrating, demonstrating, and using texts, computers, media, or workbooks in order to repackage subject matter into a form that is accessible to the learners. A successful chemistry teacher is expected to provide activities, including discussions and physical experiences that will enable students learn stoichiometry meaningfully.

Undoubtedly, without knowledge about stoichiometry, teachers cannot effectively teach stoichiometry. However, knowledge about stoichiometry is not sufficient. There is growing evidence that multiple knowledge bases are involved in teaching of any subject matter [9,10]. To this effect, to teach stoichiometry a teacher must command not only a firm understanding of stoichiometry but also sound knowledge of effective pedagogical practices relative to stoichiometry and the intentions and abilities to fuse these two elements in the classroom.

Research has demonstrated the difficulties experienced by beginning secondary science teachers in transforming the content knowledge into comprehensible form [11- 14]. These reports suggest that such transformation of knowledge is strongly influenced by a variety of contextual and personal factors including classroom management, constraints of the curriculum, teachers' concern for student motivation and ability, and teaching experience. Other factors relate to teachers' stoichiometry content knowledge and subject-specific pedagogical content knowledge, such as teachers' discomfort with their understanding of stoichiometry, teachers' representational skills and teachers' knowledge of students' thinking [11-13,15].

In promoting effective teaching of stoichiometry, it is important for chemistry educators to attend to the literature concerning the knowledge systems (i.e., CK, PK, PCK) involved in teaching stoichiometry. It is not the purpose of this paper to present a critical review of literature on PCK, rather, the paper attempts to utilize those ideas on the components of PCK to formulate a framework to help clarify and elaborate the knowledge that knowledgeable chemistry teachers should possess and how that knowledge is applied in teaching stoichiometry.

Theoretical underpinning

In the section, the author has utilized two bodies of literature to construct a framework for the teaching of reaction stoichiometry. These are: (1) Shulman's articulation of the concept of pedagogical content knowledge as that special amalgam of content and pedagogy that enables teachers to transform subject matter content and (2) Grossman's four major components of pedagogical content knowledge.

A framework of knowledge systems necessary for exemplary practices regarding teaching has been proposed by Shulman [9]. The proposed systems are to be included among the domain of knowledge that contributes to a teacher's PCK for stoichiometry (Fig. 1).

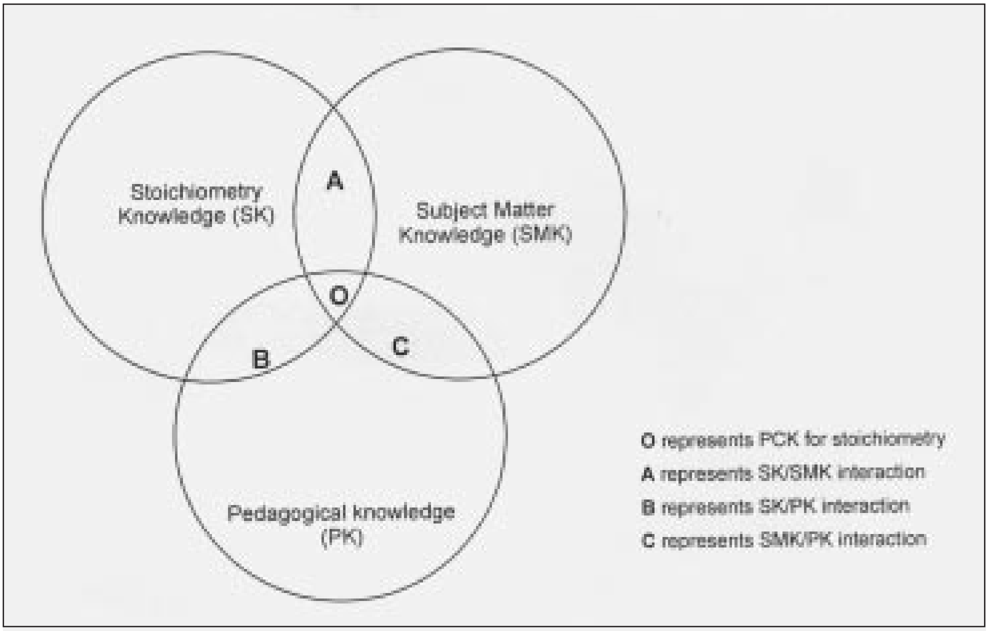

Fig. 1. Pedagogical Content Knowledge for Stoichiometry

Both SMK and PK were described previously, and little needs to be said in elaboration. Subject matter knowledge refers to teachers' understanding of the chemistry contents. This includes anchoring ideas (i.e. prerequisite knowledge skills) required in learning reaction stoichiometry. Failure to grasp these prerequisite knowledge skills gives rise to an insecure cognitive structure that in turn destabilizes or constrains learning of stoichiometry. PK refers to teachers' understanding of teaching and learning processes independent of Chemistry contents. SK is the basis of good teaching of stoichiometry. This involves the skills required to calculate stoichiometric quantities from balanced chemical equations using units of moles, mass, representative particles and volume of gases at STP. It also includes knowledge of how best to solve a specific stoichiometric problem through different methods (mole methods, proportionality method, factor-label method, mixed method) and compare these methods with each other. PCK for stoichiometry includes teachers' 'bag of tricks' and motivational 'tools' that can be used to develop in students better and more strategic problem solving techniques. It is in continuous growth and is kept constantly under review and reconstruction. It includes knowledge of how best to present stoichiometric concepts and ideas to students. It also includes knowledge of teaching strategies that could incorporate appropriate conceptual representations in order to address learners' difficulties and misconceptions regarding stoichiometry.

Subject-matter knowledge alone, stoichiometry knowledge alone, or pedagogical knowledge alone will not be sufficient for capturing the knowledge of good chemistry teachers. For teachers to successfully address stoichiometry, attention must be given to the development of "traditional" subject-matter knowledge, stoichiometry knowledge, and pedagogy as well as the interaction among these domains. As presented in Figure 1, the overlap of the individual domains represents the suggested interactions (e.g., SMK/PCK interaction, SK/PK interaction). The intersection of the domains depicted PCK for stoichiometry.

In a teacher's approach to teach stoichiometry, PCK is a recognizable factor. To bring about teaching for meaningful learning of stoichiometry, a transformation of subject matter knowledge into a form that is comprehensible to the learners is necessary. As teachers engage in the process of subject matter transformation, they have to guard continually against the danger of seriously misrepresenting it [12]. This problem of misrepresentation of the content knowledge is also regarded as "problem of conversion." [16]. Fig. 2 illustrates the transformational processes involved in teaching stoichiometry.

In transforming subject matter concerning stoichiometry for teaching, a skillful teacher uses his knowledge about students' understanding and misunderstanding, his knowledge about representations of the subject matter for teaching and instructional strategies incorporating, experimental activities and curriculum materials.

Science educators [17,18] have identified various sources from which PCK is generated and gradually developed. According to them PCK is acquired largely through classroom teaching experience, discussion with more experienced and trusted colleagues, imitation, reflection on things seen and heard, attendance at professional conferences and reading teacher journals [17,18].

It can be concluded that PCK is a very personal domain of knowledge based on the sources from which it is generated. As carefully noticed by Bindernage and Eilks, it is developed step-by-step and constantly influenced by beliefs [19]. The beliefs that are capable of influencing PCK are epistemological beliefs, general educational beliefs, content-related beliefs, beliefs about curriculum orientation and much more. In their contributions toward the manner through which PCK is nurtured Clermont, Borko and Krajcik observe that PCK growth among beginning teachers is generally slow and incremental, and is related to the time required for these teachers to plan, gather resources, teach, reflect, and reteach specific topics with increased effectiveness and fluency [13]. According to them growth of chemistry teachers' PCK also appears to be dependent on the motivation, creativity, and pedagogical reasoning skills of the teacher.

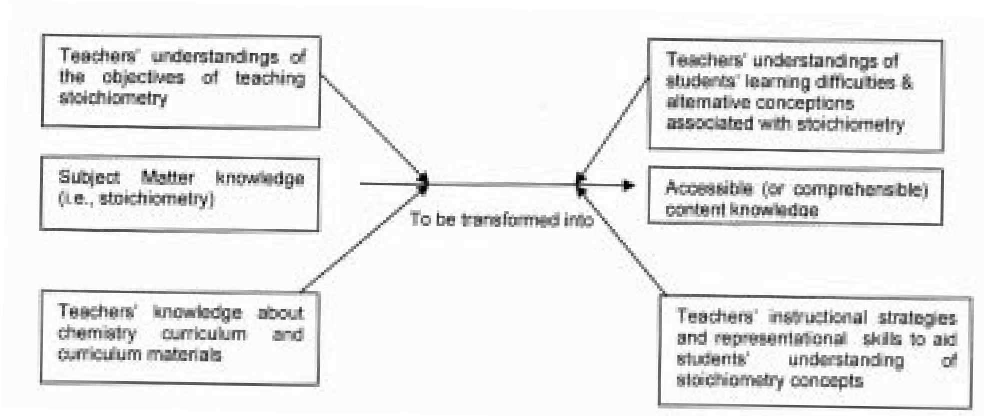

Fig. 2. The transformational process involved in teaching stoichiometry

PCK, the knowledge required in representing and re-formulating a subject matter in order to make it comprehensible to the learners has four major components as identified by Grossman: (a) knowledge and beliefs about the purpose of teaching a subject at different grade levels, (b) knowledge of students' understanding, conceptions and misconceptions of particular topics in a subject matter, (c) knowledge of curriculum materials available for teaching particular subject matter as well as knowledge about both the horizontal and vertical curricular for a subject and (d) knowledge of instructional strategies and representations for teaching particular topics [20]. Utilizing these components, four pedagogical questions which provide direction to this paper are to be deliberated upon when planning to teach reaction stoichiometry. These questions are:

1. Why teaching reaction stoichiometry?
2. What are the students' typical understanding and misunderstanding regarding reaction stoichiometry?
3. What curriculum materials would be most appropriate in the light of curriculum aims and objectives?
4. What strategies, representations, problem-solving models and illustrations would be most suitable for the students?

Objectives of teaching stoichiometry

One of the important activities to be carried out by the teacher in preparing to teach science is specification of instructional objectives. What learning goal is each student expected to reach? More precisely, what new capability should the learner possess at the completion of instruction? Objectives constitute statements of what the instructor plans to package into a lesson as well as what the learner ought to imbibe from such a lesson. The objectives may be derived from a course syllabus, stated in a textbook, taken from a curriculum guide, or developed by the teacher.

Wherever their sources, the objectives of teaching reaction stoichiometry are to enable the students to:

1. define stoichiometry and distinguish between composition and reaction stoichiometry;
2. identify the major types of reaction stoichiometry problems;
3. predict the products of chemical reactions given the reactants;
4. describe chemical reaction types and classify them;
5. write balanced chemical equations for simple reactions;
6. interpret balanced chemical equations in terms of interacting moles, representative particles, masses and gas volume at STP;
7. distinguish between products and reactants in a chemical equation;
8. determine the reactant-product (or product-reactant) pair that will provide the relevant stoichiometric relationship for calculation;
9. construct mole ratios from balanced equations and apply these ratios in mole-mole, mole-mass, mass-mole and mass-mass stoichiometric calculations;
10. calculate the amount of product expected to be formed in a chemical reaction, given the amounts of reactants used;
11. calculate the amount(s) of reactants which need to be used in a chemical reaction in order to produce a specified amount of product;
12. use stoichiometric methods to solve for composition of a two-component mixture in which only one of the components involved in the chemical reaction (e.g., an impure Na_2CO_3 treated with excess dilute hydrochloric acid solution);
13. use stoichiometric methods to solve for composition of a two-component mixture in which the two components are involved in the chemical reaction (e.g., a mixture of Na_2SO_3 and $MgSO_4$ treated with excess $BaCl_2$ solution);
14. use stoichiometric methods to identify the limiting reagent and excess reagent; and calculate the amount of expected products produced, and the amount of excess reagent left over upon completion of the reaction from a non-stoichiometric mixture of reactants;
15. use stoichiometric methods to predict the theoretical yield and percent yield given the mass (number of moles) of each reactant and the actual yield of a reaction;
16. calculate the mass (number of moles) of each reactant required given the percent yield and the mass (number of moles) of products desired..

If objectives are clearly and specifically stated, learning and teaching become objective-oriented in the sense that having a clear idea of objectives enables the teacher to select most suitable teaching/learning strategies and activities to help his students achieve the stated objectives. At the same time stated objectives enable students to be conscious of the behavioural traits and skills they should exhibit after instruction.

Students' learning difficulties with stoichiometry

A considerable amount of research has indicated that students bring with them to science classrooms certain ideas, notions and explanations of natural phenomena that are not consistent with the consensus of the scientific community [21,22]. Students' understanding of scientific concepts that do not agree with accepted scientific views are regarded as misconceptions. Terms such as preconceptions, alternative frameworks and students' descriptive and explanatory systems were used by researchers to express misconceptions [23-25]. In this paper, misconception denotes students misunderstanding of a concept whether the source of that misunderstanding is personal experience or previous science instruction while preconception represents an idea that a student holds before general chemistry instruction which is in agreement with Bodner's conception [26]. Preconception may or may not be misconceptions, depending on whether they agree with scientific understanding.

Senior secondary school chemistry is difficult for many students, and stoichiometry is often a particularly difficult topic [27,28]. Students bring misconceptions to the study of stoichiometry which strongly influence learning and understanding [29]. Students' misconceptions in stoichiometry have been the topic of many recent studies. There is a wealth of literature on the misconceptions students hold in stoichiometry [4-6, 30-32]. This literature provides ample evidence that chemistry students have misconceptions in the sense that:

a. equate the mass ratio of atoms in a molecule with the ratio of the number of these atoms, and the mass ratio with the molar mass ratio [31];
b. calculate the molar mass of a given substance by summing up the atomic masses and then multiplying or dividing this sum by the coefficient of the substance in the chemical equation; others do not understand the significance of the coefficients in a chemical equation at all [4];
c. confuse the concepts of conservation of atoms and possible non-conservation of molecules or do not take into account the conservation of atoms or mass at all [30];
d. cannot determine the 'limiting reagent' in a given problem, when one substance is added in excess [32];
e. confuse or do not know the definitions of and relationships between stoichiometric entities in general [5];
f. believe that one mole means the same as one particle [6].

The aforestated misconceptions can interfere with learning to solve stoichiometric problems, since solving stoichiometric problems requires both conceptual understanding and mathematical skills. Because, students lack understanding of the fundamental concept of chemical stoichiometry (the particle description of atoms/molecules, the mole concept, concept of solution and chemical change) and the required mathematical skills. They are unable to draw the proper relations among various concepts and the quantitative representation of these concepts. Researchers have found that success in solving mathematical, or algorithmic, exercises does not indicate mastery of chemistry concepts [33-35].

Constructivists believe that identifying and utilizing students' na?ve ideas to build toward the scientifically accepted views are important steps in developing instructional strategies and materials. Since the simple most important factor influencing learning of stoichiometry is what the student already knows, it becomes necessary for chemistry teachers to properly explain such terms as the 'mole,' 'mole ratio,' 'molar mass,' 'amount of substance,' 'number of particles' which sound similar and are frequently introduced within the stoichiometry lesson.

If we as instructors, are to improve teaching and learning of stoichiometry, we must first understand the difficulties that students experience in learning stoichiometry, what students understand (or do not understand) about stoichiometry as it is currently taught, and how students make sense of the information they are learning.

Teachers' knowledge of chemistry curriculum and curriculum materials

In traditional forms of curriculum development, curriculum is developed centrally (by curriculum experts) and disseminated to schools via directives, guidelines, or advisory bulletins. In some educational jurisdictions, the new curriculum is monitored by inspectors from Ministry of Education and Teaching Service Commission (TESCOM) (as in Nigeria) to ensure proper implementation in the classroom. In some cases, the curriculum is spelled out in remarkable details, even to the extent of giving lesson-by-lesson directions, in an effort to make its implementation effective. The curriculum developers specify the knowledge and skills required to implement the new curriculum and, in some cases, may assist teachers in acquiring them via in-service programmes or explanatory booklets. Sound knowledge of curriculum allows teachers to operationalize the plans of others, teach in a way prescribed by the curriculum developers and assess students' learning in a way that is designated by others.

However, to some extent, classroom teachers have some degree of freedom to interpret and adapt whatever official text or curriculum guide that has been prescribed. For instance, a teacher can stress certain points in a text and give scant attention to others; he/she can supplement or replace official texts with his/her own teacher-made materials; he/she can direct students to the internet or even introduce lessons or units that are completely unrelated to the assigned text. This freedom to modify the official curriculum has led many to conclude that the real curriculum is whatever teachers actually choose to do in their classrooms. It is only when the teachers have learned which topics are the most central and which are peripheral that teachers can accurately judge the depth to which a topic should be covered and hence the amount of time to spend on it. Based on the preceding discussion, it is obvious that a sound knowledge based in pedagogy, chemistry content and curriculum knowledge is essential in implementing chemistry curriculum in the classroom. The chemistry curriculum with respect to stoichiometry at senior secondary school in Nigeria includes the following topics:

1. chemical symbols and formulae with emphasis on calculations involving formulae;
2. chemical equations - types of chemical reactions, balancing simple and complex chemical equations, constructing unbalanced chemical equation;
3. mass and volume relationships in chemical reaction and their uses in determining stoichiometry of such reaction as
   a. precipitation reactions
   b. reactions involving the measurement of gas volume
   c. analysis of chlorides
   d. synthesis and reduction of metallic oxides
   e. displacement of metal ions;
4. stoichiometric calculations:
   f. mole-to-mole problems
   g. gram-to gram problems
   h. gas volume-to-gas volume problems
   i. problems extended to amount of gas expressed by volume not at stp.
   j. limiting reagent problems
   k. percentage yield problems
   l. stoichiometric problems extended to
      i. problems that involve volume and density of a solid
      ii. problems that involve a solution
      iii. typical titration problems
   m. combination of limiting reagent /percentage yield problems.

Neither assimilation nor accommodation is possible if critical prerequisite knowledge required in learning stoichiometry is lacking. Assimilation refers to the creation of new knowledge structure by reviewing and building on existing knowledge structures. Accommodation is necessary when new perceptions and experiences do not fit existing knowledge structures and knowledge structures must be reshaped in order to accommodate new experiences. Thus, what is learnt is dictated by two influences: the schemas that people already have in their heads and the information contained in the external stimuli that people respond to [36,37]. It was in an apparent realization of this fact, that Eniayeju suggested that particular prerequisite knowledge skills such as: (1) chemical symbols, formulae and equations (2) the mole concepts (3) Concepts of solution (4) Avogadro's number and (5) Mole conversion should be taught ahead of stoichiometry lesson [38].

One way to enhance teaching of stoichiometry is through provision of curriculum materials designed to be educative for chemistry teachers. Curriculum materials for teaching-learning of chemistry include textbooks and their accompanying students' guides, teachers' guides, students' solution manuals, and technology-based materials. As viewed by Kesidou and Roseman, curriculum materials are tools that allow teachers to do their best work with students [39]. They provide a coherent science programme for students based on the best thinking available in the field, and material that supports teacher in making more thoughtful and informed decisions about their own students' science learning.

Many teachers rely on textbooks to provide some or all of their content and pedagogical content knowledge, and this is especially so when the teacher is a novice or is teaching outside his or her area of expertise [40]. Educative curriculum materials are designed to support teachers' learning, as the materials are used by teachers to support students' learning. Besides, curriculum materials prescribe to teachers (especially beginning teachers) exactly what to do, when to do it, and in what order to do it. Chemistry teachers are expected to be accustomed to using such materials to plan and structure students activities when teaching stoichiometry. Stressing the importance of curriculum materials, Ball and Cohen pointed out that curriculum materials offer support for teachers in thinking about: (1) content beyond the level suggested for students (2) underlying pedagogy (3) developing content [41].

Problem-solving strategy and representations in chemistry

Having identified students' difficulties in solving stoichiometric problems in the preceding section of this paper, chemistry teachers are now in a vantage point to select effective teaching strategies in order to assist the students in achieving a high level of proficiency in solving stoichiometric problems. As observed by Hollingworth whatever approach the teacher may take to assist chemistry students develop their problem solving skills, whether it is through personal teaching or through the use of computer technology, the main aim is to guide them along the transition from novice to expert [42]. In doing this, six instructional principles have been suggested by Hartman for an effective teaching of problem solving [43]. These are:

1. Model a useful problem-solving method. Problem -solving can be difficult and sometimes tedious. Show students by your example how to be patient and persistent and how to follow a particular model of problem solving. Various scholars, elaborating on Polya's work, have proposed different problem-solving models-wheatley's model, wood's model, map model, GRASS model, which can be used for solving stoichiometric problems [44-47]. Examining those models, it seems that four important steps are required in solving chemical problems; (a) Identify what the problem is asking (b) Identify what information is given (c) Search for paths to get from what is given to what is asked (d) Evaluate the reasonableness of result;

2. Teach within a specific context. Teach problem-solving skills in the context in which they will be used (e.g., ratios and proportion in a stoichiometry lesson.) Use real-life problems in explanations, examples, and examinations. Do not teach problem solving as an independent, abstract skill;
3. Help students understand the problem. In order to solve problems, students need to define the end goal. This step is crucial to successful learning of problems-solving skills. If you succeed at helping students answer the questions "what?" and "why?", finding the answer to "how?" will be easier for them;
4. Take enough time. When planning a problem solving instruction, budget enough time for: understanding the problem and defining the goal, both individually and as a class; dealing with questions from you and your students; making, finding, and fixing mistakes; and solving entire problems in a single session;
5. Ask questions and make suggestions. Ask students to predict "what would happen if…."or explain why something happened. This will help them to develop analytical and deductive thinking skills. Also, ask questions and make suggestions about strategies that they use;
6. Link error to misconceptions. Use errors as evidence of misconceptions, not carelessness or random guessing. Make an effort to isolate the misconception and correct it, then teach students to do this by themselves. Students as well as teachers can learn from mistakes.

Since problem-solving is complex and problems take on a myriad of forms, chemistry teachers must be fully aware that instructional strategies which both enhance the quality of the knowledge base in problem solving should be of great benefits to their students. Essentially, any activity that increases conceptual knowledge encourages persistence, increases motivation, and helps students to see connections among ideas. To reflect on and check what was done, to consider alternative interpretations and to try different strategies is likely to improve problem solving.

Learning stoichiometry means mastering the skills of constructing and balancing chemical equations and applying the balanced equations to determine the masses of chemical species involved in chemical reactions. Students who are new to chemistry face problems connecting symbols that describe chemical processes with quantitative information that a formula provides; many do not recognize the reasons for the stoichiometric relationships between atoms and molecules, reactants and products and so forth [48, 49]. Even after studying chemistry, many students do not understand the role of a formula; some think that formulas are merely abbreviations for names rather than a short way to represent composition or structure and others hold the misconception that a formula is an abbreviation for a mixture. Because most students have difficulties in using and understanding chemical representations they experience difficulties in learning stoichiometry the study of quantitative, or measurable relationship that exist in chemical formulas and chemical reactions.

As applied theoretical and physical chemists, Hoffman and Laszlo claimed that representations in chemistry are symbols, or elements of chemical language and vehicles for signs or elements of chemical language and vehicle for viewing the world [50]. Johnstone suggests that students must master the three levels of representations in chemistry: macroscopic, microscopic and symbolic levels [51]. At the macroscopic level, chemistry is observable as melting butter or burning candle. To better explain these phenomena, chemists develop concepts and model of atoms and molecules. At the microscopic or molecular level, a burning candle becomes a chemical process in which carbon atoms of the wax react with oxygen molecules in the air and carbon (IV) oxides are produced. Another way to represent this process is using a chemical equation with symbols $\longrightarrow$, formulae and numbers, such as $C_{(s)} + O_{2(g)} \longrightarrow CO_{2(g)}$. As shown in this example, chemists represent sensory experiences by atoms and molecules, and translate them into symbols and formulae. Most students have difficulties interpreting chemical equations, because their understanding is constrained by the surface features of representations [52, 53]. When they see an equation, such as $C_{(s)} + O_{2(g)} \longrightarrow CO_{2(g)}$, they interpret it as a composition of letter, numbers and lines rather than a process of bond formation and breaking. The technique of balancing chemical equations makes them picture chemical equations as mathematical puzzles [54], and they can even work algorithmic without having a conceptual understanding. Thus, while chemists see symbols and letters as molecules and the arrow as the direction of reaction, many students are not able to visualize these representations.

Kozma believes that emphasis of the three levels of representations in chemistry and the associations among them will facilitate transformations students need to perform [55]. Realizing this fact, chemistry teachers should ensure that students must first thoroughly understand how to convert a symbol into meaningful information it represents. Only then can they cope with stoichiometry problems that are based on chemical equations. For instance, correct interpretation of a chemical equation leads to the formulation of a molar proportion (two molar ratios set equal to each other) which is a necessary step for solving stoichiometric problems. For effective teaching of stoichiometry, chemistry teachers should possess well-developed representational skills: the ability to see expressions with different surface features (e.g., change in colour) as representing the same chemical principle or situation, the ability to translate one representation of a chemical concept or situation into another one, and the ability to generate or select an appropriate representations to make explanation, predictions and justification.

Conclusion

The general message presented in this paper to those who are involved in professional development of chemistry teachers is that teachers need to be equipped with adequate knowledge that will enable them to vary and improve the ways and methods used in teaching a specific topic (e.g., stoichiometry). In the same vein, Gomez perceived similar need when he observed that many new teachers function in a professional desert, abandoned by the institutions and neglected by overburdened school personnel [56].

When pedagogical content knowledge is lacking, chemistry teachers result to "teach as they have been taught" or assuming that their "expertise" will get them through a class. These strategies ultimately lead to a frustrating experience for both students and teachers. Therefore, it is not a good practice to rely on individual teachers who possess the necessary chemistry content knowledge but little knowledge or preparation in pedagogy to teach stoichiometric calculations. This is so because such individuals who do not possess the necessary pedagogical content knowledge and reasoning skills would not be able to maximize students' learning of principles and concepts involved in solving stoichiometric problems. In order to be able to "transform subject matter (or content) knowledge into a form that is accessible to students, teachers need to know a multitude of particular things about the content that are relevant to its teachability [11]. Among several ways to cater for this essential need of teachers is the establishment of mentoring relationships between secondary school chemistry teachers and university lecturers with the intention of promoting their professional development. Research has suggested that in mentor-novice teacher dyads not only did the less experienced teachers learn from the more experienced one but the expert also learned from the novice [57]. Achienstein and Villar suggest also that the relationship between mentor teacher and new teacher works best when it is reciprocal in the sense that the two are involved in co-construction of knowledge, co-exploration, problem solving and critique of their work [58]. Membership of a professional association is another promising way of enhancing professional development of chemistry teachers. This is so because being a member of a professional body will allow one to know what is going on, the latest developments in teaching techniques, new emphases in programme content and many other trends that are happening continuously in a growing profession. Through associations, an effective channel of communications exists by way of the publications, meetings and announcements that are periodically made.

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