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Bridging Theory and Practice: Application of Constructivist Tenets to the Teaching of Reaction Stoichiometry

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Abstract

Active engagement of the learner with the learning environment, focusing on the learner rather than teacher, and acknowledging (as well as challenging) learners' understanding/intellectual development are useful pedagogical strategies that can facilitate meaningful learning of reaction stoichiometry. In consonance with this fact, constructivist believed that students must play active roles in their learning if it is to occur deeply, endure, be enjoyable, and transfer to contexts beyond the classroom. Constructivism as a theory of learning is still gaining popularity as a new paradigm for learning science. Yet translating a theory of learning into a theory of teaching (before it can be operationalized) has proven to be quite difficult for teachers. This paper provides helpful insight into how constructivist instruction can be implemented when teaching reaction stoichiometry.

Keywords: stoichiometric problems, problem-solving instruction, constructivist tenets, constructivism.

Introduction

Chemistry curriculum and instructional strategies are changing. One component of the current redevelopment of Chemistry curriculum is the shift in focus of instruction from the transmission curriculum to a transactional curriculum. In a traditional curriculum, a teacher transmits information to students who passively listen and acquire knowledge. In a transactional curriculum, students are actively involved in their learning to reach new understandings. In consonance with the transactional curriculum, constructivist theory sees learners as the builders and creators of meaning and knowledge through active involvement in the leaning process. Constructivism is a view of learning based on the belief that learners "construct" their own knowledge on the basis of what they already know. Constructing an understanding requires that students have opportunities to articulate their ideas, test those ideas through experimentation and classroom discussion, and consider connections between the phenomena they are examining and other aspects of their live (Wilhelm, Friedman & Erickson, 1998).

The classroom teacher needs a theory that can be applied, discussed and modified in his/her teaching career. Such a theory is constructivism which has been an influential movement in education and psychology over the past few decades (National Research Council (NRC) 1999). The primary purpose of including theoretical educational studies in the teacher education programme is for the student teachers who will later transform into potential teachers to be able to convert theory into practice. Among the numerous learning theories included in the teacher education curriculum is constructivist learning theory. Unfortunately for teachers, principles of instruction that derive from constructivist explanations for learning have not organized into any comprehensive widely applicable models (Lester and Onore 1990), Brewer and Daane (2002) have cautioned that although constructivist theory is attractive when the issue of learning is considered deep-rooted problems arise when attempts are made to translate it into daily classroom practice. This is not only because constructivism is a theory of learning rather than of teaching; but also because the implied precepts for instruction break radically form the traditional education model in which teachers themselves were schooled making it especially difficult for them to visualize constructivist pedagogy. Adding to the problem of applying constructivist theory is the fact that the pre-service student teachers at both universities and colleges of education are being taught constructivism through teacher centred tradition approach. This in turn makes it difficult for teachers to make personal sense of constructivism as a basis for instruction.

While it may inform and influence practice, constructivism is a theory of learning, not a theory of teaching as previously observed, and translating theory into practice is both difficult and imprecise (Mackinnon and Scarf-Seatter,1997). However, abound in education literature are several large- and small-scale efforts to operationlise constructivist philosophy in the classroom (Richardson 1997). Surprisingly, many educators (Applebee, 1993; Skolt, 2004: Andrew, 2007) still believe that those efforts were not satisfactory enough. This is due to the fact that previous works have failed to show in detail how the theory can be implemented in the classrooms and that specific guidance on how to teach in a constructivist manner is not well documented. Still lacking in the literature are both theoretical and empirical papers on how constructivist principles can be implemented in reaction stoichiometry lessons. Although, there is a number of studies (though fewer in number) focusing on applications of constructivist theory in teaching science. In attempt to fill this void, this paper presents a model for the application of constructivist theory in teaching reaction stoichiometry. This topic was selected because it appears to be difficult for teachers to teach and for students to learn (Olmsted, 1999; BouJaoude and Barakat, 2000; Fach, de Boer, and Parchmann, 2007; Evans, Yaron and Leinhardt, 2008). The reasons for the learning difficulties associated with reaction stoichiometry are due to the complexity of conducting these calculations that require an understanding of the mole concepts, constructing and balancing chemical equations, algebraic skills, and interpretation of a word equation into procedural steps that lead to the correct answer. The teaching difficulties associated with reaction stoichiometry in due to the fact its teaching requires possession adequate knowledge of teaching methods suitable for identification of students' misconceptions and planning effective intervention instruction in changing misconceptions.

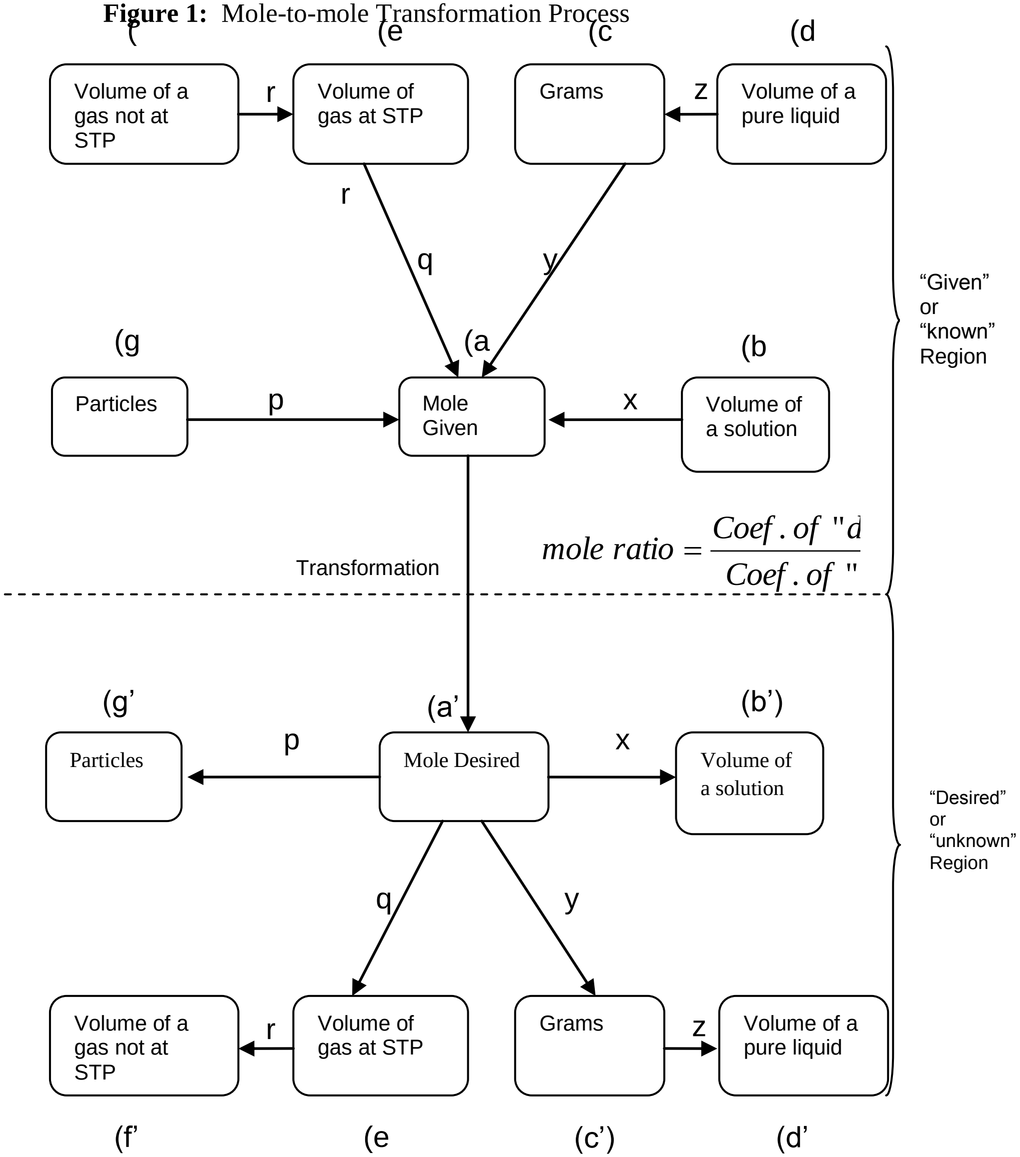
Stoichiometry problems

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 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 (Okanlawon, 2008). In Nigerian the issue of stoichiometry is being introduced in the first and second year of senior secondary school; and the objectives for it inclusion in the Chemistry curriculum are to enable students to:

1. define stoichiometry and distinguish between composition and reaction stoichiometry.
2. identify the major types of reaction stoichiometry problems
3. perform mol-mol,mol-mass, mass-mol, and mass-mass stoichiometric calculations given ideal condition
4. Use stoichiometry methods to deduce the limiting reagents excess reagent, the amount of expected product produced, and the amount of excess reagent left over upon completion of the reaction given the mass (number of moles) of each reactant in the chemical equation.
5. use stoichiometry methods to predict the theoretical yield and percentage yield given the mass (number of moles) of each reactant and the actual yield of a reaction.

Solving stoichiometric problems require stringing together many steps using conceptually organized knowledge. This type of knowledge assists a problem solver to: (i) interpret the information given in the problem statement. (ii) identify the entity to be calculated (iii) build a representation of the problem situation and to plan a possible pathway to a solution. To provide a comprehensible solution pathway with line of reasoning to a given stoichiometric problem, the use of mole-to-mole transformation process (Figure 1) is required.

Figure 1: Mole-to-mole Transformation Process



Key:

r	=	P, T adjustment (i.e. $\left(P/_{Pstp}\right)\left(Tstp/_{T}\right)$ adjustment)
q	=	molar volume (V_m)
p	=	Avogadro's constant
x	=	molar concentration ©
y	=	molar mass
z	=	Density

For instance, a solution pathway which reads as:

$$mMg \xrightarrow[mMgO]{M_{Mg}} nMg \xrightarrow{SMgO/Mg} nMgO \xrightarrow{MmgO}$$

1st step *2nd step* *3rd step*

Is required in solving a sample stoichiometric problem given as:

Find the mass of magnesium (II) oxide produced when 15.4g of magnesium ribbon is burn in excess oxygen according to the equation.

$$Mg_{(s)} + {}^{1}/_{2}O_{2(g)} \longrightarrow MgO_{(s)}$$

Stoichiometric problems take on different forms (e.g, mole-mole problems, mass-mass problems, gas volume-gas volume problems, limiting reagent problems, percentage yield problems) to the extent that they cannot be solved by learners with incoherent knowledge base. Learners who learn primarily by rote store information in a compartmentalized way and are unable to transfer what is learnt in one context or setting to another context or setting and hence encounter difficulties in combining pieces of information in order to reach the solution state when solving stoichiometric problems.

Mole-to mole transformation process is based on the interconnectivity among knowledge required in solving stoichiometric problems. When meaningful learning of prerequisite knowledge skills takes place that implies that information has been well-represented and well- connected. Within the constructivist tradition it is acknowledge that learning result from the addition of new elements of knowledge to pre-existing knowledge structures and the re-organization of prior structures to accommodate new elements. When information is regrouped into well integrated categories, it is stored and retrieved more efficiently that when it exists as isolated facts and strings. The case is true with stoichiometry where previously learnt materials are integrated together in solving stoichiometric problems.

The constructivist model

Due to repeated failures of existing pedagogical models and the limits of behaviourist model, several constructivist models have been developed over the past fifty years (von Glasersfeld, 1995). As far back as in 1932, Bartlett pioneered what became the constructivist approach to teaching and learning (Good and Brophy, 1990). Constructivism is based on the belief "thatchildren actively construct their knowledge, rather than simply absorbing ideas spoken to them by teachers" (Lunenburg, 1998, p.76). Thus, science teaching activities should be regarded as actions to facilitate subject matter learning through transformation of subject matter knowledge into comprehensible form. According to constructivist ideas of the acquisition of knowledge as contained in the works of Driver (1989) and Osborne and wittrock (1983), teaching activities require helping student carry out activities which will lead then to construct an understanding of the subject matter at hand. Thus, learners are responsible for building their own knowledge and understanding.

Constructivism, as applied to classroom practices, is a theory of learning rather than a theory of teaching and denotes a wide array of possible approaches to any given topic in the syllabus (Cooper, 1993; Andrew, 2007). Constructivist approaches to teaching typically make extensive use of hands-on, investigative laboratory activities, open-ended questions, inquiry – oriented discussion, co-operative learning, open –ended inquiry and performance assessments as pedagogical tools. Many benefits can be derived from using the above student – centred instructional strategies. For example, they are capable of developing students' understanding beyond simple memorization of facts. Another benefit is that they enable students acquire analytical skills that can be applied to another problems and situations, rather than accept their teachers' explanations, Constructivists generally maintain that when information is acquired through transmission models, it is not always well integrated with prior knowledge and is often accessed and articulated only for formal academic occasions such as examinations

(Richardson, 1997). Constructivist approaches, in contrast, are regarded as producing greater internalization and deeper understanding than traditional methods.

It can be concluded from the preceding discussion on constructivism that the primary idea of constructivism is that what a person' knows' is not passively received, but actively assembled by the learner. But how do teachers apply this primary idea in their classrooms? The following principles that emerge from this primary idea provide helpful guidance for teachers.

1. Learning requires mental activity. The learner should be an active contributor to the educational process since knowledge is not a thing that can be simply given by the teacher at the front of the classroom to students in their desks.

2. Learners' current knowledge and experience are critical in new learning situations and need to be taken into account. In other words, there is need for teachers to search out students' understanding and prior experiences about a concept before teaching it to them.

3. Learning occurs from dissatisfaction with present knowledge. For meaningful learning to occur, students must be put in situations that might challenge their previous conceptions and that will create contradictions that will encourage discussion; and thereafter bring about cognitive restructuring.

4. Learning has a social component; learners construct knowledge not only by physically and mentally acting on objects but also through social interactions with others. Cognitive growth results from authentic student-student and student- teacher dialogue. Learning is facilitated by 'real talk' in which domination is absent while reciprocity, co-operation and collaborative involvement are prominent.

5. Learning requires application. Applications must be provided which demonstrate the utility of the newly acquired knowledge. Learning should closely relate to understanding and solving real life problems.

Adopting a constructivist framework in structuring problem-solving activities in stoichiometry lesson

From each of the preceding postulates, a corresponding generalization and specific implications for structuring problem-solving activities follows.

Learning requires mental activity: therefore structure problem-solving instruction to increase the cognitive activity of the learner.

1. Have the students read the problem statement slowly and carefully, identifying exactly what is being asked.
2. Have the students identify relevant information that are pertinent to the solution of the problem.
3. Have the students restructure the problem or if possible subdivide the problem into smaller problems
4. Have the students devise a plan for solving the problem.
5. Have the students carry out the plan.
6. Have the students solve the problem in another way (if possible).
7. Have the students summarize what they did to solve the problem.

In leading students to solve a specific type of stoichiometric problem presented as:

What mass of hydrogen is given off when 4.15g of sodium are added to cold water?

A knowledgeable Chemistry teacher is expected to actively engage his students in the lesson through asking the following suggested questions:

(a) what is the first thing that you will do in solving this problem?.

(b) why is the reaction equation so important in finding solution to this problem?

(c) what do you think are the reactants involved this reaction?

(d) predict the product(s) of the reaction between sodium metal and cold water

(e) what form (i.e., physical state) do the product(s) take?

(f) write a balance equation for the reaction between sodium metal and cold water

(g) identify the reactant- product pair that will supply the required stoichiometric ratio for calculations

(h) what is the mass of sodium given in the problem statement?

This is necessary because retention of knowledge is enhanced when learners are actively involved in problem –solving instruction.

Naïve theories affect learning: therefore structure problem solving instruction in accordance with students' preconceptions and misconceptions.

Research has indicated that students bring with them to science classrooms certain ideas, notions and explanations of natural phenomena that are not in alignment with the ideas accepted by the scientific community (Osborne and Freybers, 1985; Wandersee, Minitezes, and Novak, 1994). According to the constructivist view of learning, which is relatively a new approach in science instruction, learner's existing ideas formed the foundation upon which all knowledge is individually and socially constructed. These existing ideas are often strongly held, resistant to traditional teaching and form coherent though mistaken conceptual structures (Driver and Easley, 1978). To address these naïve ideas about the world, teachers need to first identify and evaluate their students' naïve conceptions. Thereafter, corrective measure can be taken to assist students substitute them with (or modify them into) more scientifically acceptable concepts. Senior secondary school Chemistry is difficult for many students, and stiochiometry is often a particularly difficult topic (Bello, 1990; Olmsted, 1999). Students bring misconceptions to the study of stiochiometry (Wood, 1990; Gauchon and Meheut, 2007). Students' conceptions in stiochiometry have been the topic of many recent studies. There is a wealth of literature on the misconceptions students held in stiochiometry (Mitchell and Gunstone, 1984; Schmidt, 1990; Huddle and Pilley, 1996; BouJaoude and Barakat, 2000; Fach, de Boer and Parchmann, 2007; Gauchon and Meheut, 2007).

Conceptual difficulties commonly encountered by students when solving stoichiometric problems as revealed in those literature include, for example:

(i) not being able to determine the reactant- product pair or reactant – reactant pair or product pair or product – product pair that will yield the relevant stoichiometric relationship for calculation.

(ii) not realizing that all chemical reaction equations must be complete and must be correctly balanced to be of any use at all.

(iii) not knowing how to relate the moles of given substance to the moles of the desired substance

(iv) believing that one mole means he same as one particle

(v) not being able to identify a limiting reagent from a non – stoichiometric mixture of reactants

(vi) cannot predict the products of chemical reactions given the reactants.

It should be recognized that a learner's prior knowledge may help or hinder the construction of meaning. Learner's prior knowledge comes from their past experiences, culture, and their environment. Generally prior knowledge is good, but sometimes misconceptions and wrong information can be a hindrance. Realizing this, time must be created for correcting flaw prior knowledge before new learning can occur. Being able to recognize a learner's erroneous knowledge base regarding a specific abstract concept (e.g., mole concept) is necessary before teaching additional science content (Ward and Wandersee, 2002).

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 term as the 'mole', 'molar mass', 'molar volume', 'amount of substance', number of particles which sound similar and frequently introduce within the stoichiometry lesson. In addition, sufficient time should be given to review those terms whole practicing stoichiometric problems.

Constructivist teaching is a process of helping students mobilize their prior understandings and reorganize them in light of current experience (Anderson, 1992). In practice, this may involve, among other approaches, small-group discussions to foster contrasting ideas, encourage reflection on experimental data, and motivate a reevaluation of prior ideas in relation to emerging evidence. This is an active construction of new knowledge. It can be enhanced or hindered by the students' prior conceptions and organization of extant knowledge structures.

Learners must be dissatisfied with their present knowledge: therefore design problem-solving activity in such a way that students will be exposed to challenging questions so as to confront their present problem solving capabilities

When giving class work or home assignment efforts should be made by the teachers to use practice problems which are not analogous to thee worked-out examples and the same time true problems. This instructional strategy will make students give attention to both the problem solving strategy and the knowledge base behind the strategy during classroom instruction. True problems are more challenging and may require several cycles of interpreting, representing, planning, execution and evaluation. Wheatley (1984) proposed an anarchistic model of problem solving that describes what successful problem solvers do when they work on novel problems (i.e true problems). This problem solving model has the following stages:

1. Read the problem.
2. Now read the problem again.
3. Write down what you hope is the relevant information.
4. Draw a picture, make a list, or write an equation or formula to help you begin to understand the problem.
5. Try something.
6. Try something else.
7. See where this gets you.
8. Read the problem again.
9. Try something else.
10. See where this gets you.
11. Test intermediate results to see whether you are making any progress toward an answer.
12. Read the problem again.
13. When appropriate, strike your forehead and say, "son of a….."

14. Write down ‘an’ answer (not necessarily ‘the answer’)
15. Test the answer to see if it makes sense.
16. Start over if you have to, celebrate if you don’t.

As viewed by Bodner and Domin (2000), this model of problem solving is cyclic, reflective, and might appear irrational because if differs so much from the approach a subject matter expert would take to the task.

For instance, after developing in students the necessary problem – solving skills to solve a sample stoichiometric problem presented as:

A 3.37- g sample of a mixture of MnO and Mn_2O_3 is treated with $H_{2(g)}$ under conditions in which only the Mn_2O_3 reacts as follows:

$Mn_2O_{3(s)} + H_{2(g)} \longrightarrow 2MnO_{(s)} + H_2O_{(l)}$

The reaction yields 0.165g of H_2O. What is the percentage by mass of Mn_2O_3 in the mixture?

Then, a stoichiometric problem (true problem) of this type,

A chemist dissolves a 1.00-g sample of a mixture of KBr and $MgBr_2$ in H_2O and precipitates the Br^- from solution as $AgBr_{(s)}$ with $AgNO_{3\,(aq)}$. A precipitate is a solid insoluble substance.

$Ag^+_{(aq)} + Br^-_{(aq)} \longrightarrow AgBr_{(s)}$

‘If 1.63g AgBr is isolated, what is the percent of each component in the mixture?’ can be given as classwork or home assignment.

Learning has a social component: therefore design problem solving activity to involve group and whole class activities.

Cooperative learning is a method of active learning where students are involved in some activity beyond listening to the teacher (Cardellini, 2006). Traditionally, chemistry problem solving has been taught through textbooks or lecture by providing example problems and their solutions (Lyle and Robinson, 2001). This instruction tends to focus on the sequence of steps to solve the problem rather than the knowledge needed to recognize a problem and the skills (Cognitive strategies) used to solve it (Taconis, 1995). In contrast, cooperative learning approach actively engaged students in the instructional process. Students engage in problem solving activities in groups. The group determines what each member will contribute to find solution the problem. For instance, each member must be responsible for carrying out a well-define role within the group.

a. The chairperson ensured that only one person spoke at a time.

b. The reader read the question to be answered and also help in retrieving atomic masses from the periodic table.

c. The checker checked the schematic diagram of the steps needed to solve the problem as well as the result (solution) and understanding of the solution path.

d. The calculator's role is to input the initial data (i.e information given in the problem) into the calculator and later gives the output.

e. The recorder recorded a group answer/conclusion.

f. The summarizer assimilated the group's reasoning and restated its approaching arriving at a sound conclusion.

g. The task enforcer ensured that all group members fulfilled their part in the cooperative process and that the rules were upheld.

h. The material keeper ensured that the group materials are well kept. These material are textbooks, question paper, answer sheets, periodic table chart, scientific calculator etc.

It is important to note that for every new problem, the roles must be rotated and this strategy will allow every student to improve his/her capacity in the interpreting, representing, planning, execution and evaluation processes.

In creating cooperative learning groups, Mc Cormick and Pressley (1997) suggested the following guideline. These are:

1. ensure that the groups are well structured so that a high percentage of students participate. For example, place high-ability and medium-ability students together. Similarly, place medium-ability and low-ability students together.

2. make sure that the groups are gender balanced. If possible, try to make the groups racially or ethnically balanced as well. If gender balanced is attained, girls are more likely to be interactive and achieve higher. In addition, Heller and Hollabaugh (1992) and Reid and Yang (2002) recommended that the reasonable and optional

group size of promoting student interactions is three members. If the group has just two members a student could feel embarrassed with an uncooperative partner. If the size of the group is too big, some students might not participate at all.

If the preceding guidelines are properly followed by instructor, students will surely benefit a lot from this approach to learning. While developing cooperative learning approach for mathematics instruction, Bassarear and Davidson (1992) believed that cooperatively interacting to solve problems can be a transformative experience for many students, with advantages that include the following:

1. students come to value the process of problem solving rather than production of a correct answer.
2. mathematics anxiety is reduced when students work in cooperative groups.
3. cooperative instruction permits more challenging and less conventional problems to be presented to students.
4. cooperation fosters students' explanations and re-explanations to one another, which is important since explaining difficult ideas to others is a very effective method of forcing people to understand the ideas fully. The discussions bring to light misconceptions, which can sometimes be resolved via discussion. Students make connections to other knowledge as they discuss a problem, with different students offering varying insights about how the mathematics being learned connects to the world.
5. multiple representations of problem situations are offered in discussions, which is very important, since good mathematicians and problem solvers realize that any situation can be represented in a variety of ways.

Learning needs application: therefore design problem solving activity in such a way that students are require to deal with more stoichiometric problems that revealed applications of stoichiometric principles in chemical analysis.

Efforts should be made by teachers to assign practice problems that involved application of stoichiometric principles in chemical analysis. A wide variety of fields such as agriculture, chemical analysis, pharmaceuticals, food chemistry, inhalation therapy, nutrition, forensic science and geochemistry make use of quantitative information about chemical reactions, which is only available through its stoichiometry. Examples of problems illustrating application of stoichiometry principles are given as:

1. *A sample of an analgesic drug was analyzed for aspirin, a monoprotic acid, $HC_9H_7O_4$, by titration with base. A 0.500g sample of the drug required $21.5cm^3$ of $0.100mol/dm^3$ NaOH. What percentage of the drug (by mass) was aspirin?*

2. *In a titration, $10cm^3$ of 0.010mol. dm^{-3} sodium hydroxide solution were required to neutralize $25cm^3$ of wine. Given that two moles of sodium hytdroxde will neutralize one mole of tartaric acid (one acid present in the wine), calculate the number of moles of tartaric acid in the volume of wine used in the titration, and the concentration of tartaric acid in mol. dm^{-3}.*

Student interest, and success, can be increased by showing how stoichiometry relate to everyday life and industrial processes, hence there is need for chemistry teachers to make connections between students everyday experiences and chemical principle taught in the classroom.

Conclusion

This article has attempted to provide helpful insight into how the gap between educational theory and practice can be bridged with respect to the teaching of stoichiometry. By adopting teaching and learning strategies structured on constructivist learning theory, chemistry teachers will become more effective in designing and helping students to carry out activities which will lead them to construct an understanding of stoichiometry concepts. This will also enhance the development of sound knowledge base, effective problem – solving skills and positive attitude in their students, and improve the future generation of chemistry teachers. The gaining popularity and the efficacy of constructivist teaching are a product of the improvement in understanding about how students think and learn; the positive response of student to the methods, and the enthusiasm of many teachers. Brophy (2002) advises that further efforts in the evolution and implementation of constructivist teaching should be geared toward more research on the practice paying particular attention for whom and why constructivist approaches should be used when and why other approaches would be better.

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