Problems
Задачи

TWO INVESTIGATIONS OF EXAMINERS' PERCEPTIONS OF PRIOR KNOWLEDGE REQUIRED FOR SOLVING STOICHIOMETRIC PROBLEMS AND ITS RELATIONSHIP TO STUDENTS' PRIOR KNOWLEDGE

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Abstract. The aim of this paper is to examine three interrelated research questions: (1) what prior knowledge do examiners perceive as required for solving a stoichiometric problem considered in this study; (2) which of the perceived prior knowledge are needed to be primed (activated) based on students' performance in a diagnostic test; (3) which of the perceived prior knowledge are needed to be taught based on students' performance in a diagnostic test. Research question (1) was examined firstly by a phenomenographic analysis of the transcripts of the examiners' interview using coding categories. Seventeen participants were engaged in the first investigation. Their participation in this research was voluntary. Semi-structured interviews were employed as the main instrument for collecting statements about prior knowledge required for solving a sample stoichiometric problem. Prior knowledge needed for solving a stoichiometric problem considered in this study as perceived by the examiners was reported as a diagrammatic representation. Deciding instructionally on whether those perceived prior knowledge are to be activated or taught is based on students' performance in a diagnostic test and this also prompted a follow-up study in which the author included research questions (2) and (3). In the second study, the subjects are 281 second year senior secondary school students in science classes obtained from five randomly selected schools. They were subjected to diagnostic testing using Stoichiometry Prior Knowledge Achievement Test (SPKAT) to determine the presence or absence of examiners' perceived prior knowledge in students' schema. The author qualitatively analyzed the content of students' written solutions to obtain information about students' capabilities using content analysis. Results of the second study indicate that many of the students demonstrated proficiency in the following skills: interpreting chemical equations, writing mole-mole factor, calculating partial pressure of a gas and calculating number of moles of a gas from given quantities of gas. So, these content areas are to be activated only. However, most students need to develop proficiency in areas identified as critical prerequisites such as balancing of redox equation, determination of molar concentration, and construction of appropriate mole-mole ratio and its further application in calculation. So, these content areas are to be taught. Results of both investigations are discussed in terms of chemistry instruction.

Keywords: Problem solving instruction, examiners' perceptions, students' prior knowledge, knowledge components, stoichiometry

Introduction

As chemistry students move from lower classes to higher classes in senior secondary school and learn increasingly complex topics and concepts, new knowledge and competencies must build on and integrated with previous knowledge. By the time students begin learning stoichiometry, they must have possessed a network of organized knowledge that are relevant and sufficient to solve stoichiometric problems. For instance, ability to integrate knowledge and understanding relations between concepts and application of such understanding is required when solving stoichiometric problem. Thus, for a teacher to teach stoichiometry effectively, possession of a good knowledge of students' pre-existing knowledge is required in addition to the knowledge of the subject matter to be taught. This is because recognizing students' prior knowledge base at the beginning of the learning process influences the choice of instructional strategies employed to teach subject matters and as well provides a natural starting point for teaching (Thompson & Zamboanga, 2003; Eggen & Kauchak, 2007).

Stoichiometry, one of the quantitative areas of chemistry, involves determination of the amount (in mole or gram) of materials consumed or produced in a chemical reaction. Calculating these quantities is dependent on mastery of concepts of mole and ability to construct and balance chemical equations. In addition, conceptual understanding gas laws and the concept of solution constitute essential prerequisite knowledge needed when dealing with gas and solution stoichiometry. Reaction stoichiometry receives much attention in the senior secondary school chemistry curriculum because attainment of high degree of proficiency in solving stoichiometry problems is needed for dealing with chemical equilibrium and acid – base titration problems. Unfortunately, stoichiometric calculations have always been difficult for students (Fach et al., 2007; Evans et al., 2008). Two sources of students' failure at problem solving when dealing with stoichiometric problems have been identified in the literature. One of the difficulties originates from teachers' poor understanding of key issues underpinning the nature of effective teaching (e.g., addressing how and why certain activities lead to learning and what factors influence their effectiveness). The other source of failure is related to students' inability to reason stoichiometrically and poor understanding of stoichiometric principles (Olmsted III, 1999; Toth & Sebestyén, 2009).

Apart from the two factors, other factors can be attributed to the cause of poor performance in stoichiometry. Perhaps, a mismatch between the teachers' expectations of students' knowledge and the students' actual knowledge base at the beginning of instruction due to teachers' lack of awareness of students' prior knowledge. Studies have shown that students' prior knowledge is a strong factor to be reckoned with during instructional process (Thompson & Zamboanga, 2003; Toth et al., 2007). Hattie (2009) and Swan (2005) each argued for the constructive use of the students' prior knowledge, and to obtain this teachers will need to assess what their students know and can do. Clarke & Clarke (2004) recommended teachers build connections from prior lessons and experiences and use data effectively to inform learning.

In recent years, there are numerous studies focusing on the improvement of teaching and learning of stoichiometry at both secondary and tertiary levels. For instance, there are studies that deal with students' misconceptions in stoichiometry (Furio et al., 2002; Sanger, 2005). Other studies concern with the strategies employed by students when solving stoichiometric problems (Schmidt & Jigneus, 2003; Toth & Kiss, 2005). Relating to those studies are the ones that involve relationship between students' knowledge structure and the problem solving strategies employed (Arasasingham et al., 2004; Arasasingham et al., 2005; Toth & Sebestyén, 2009). In addition, other studies deal with instructional strategies for effective teaching of stoichiometry (Fach et al., 2007; Evans et al., 2008). But, what is largely missing from the chemistry education literature is teachers' perception of prior knowledge required for successful solving of stoichiometric problem and determination of students' actual knowledge base for stoichiometry instruction. In a bid to contribute to knowledge with regard to the teaching of stoichiometry, the conduct of this study is directed by three research questions that frame the analyzes in later sections: (A) what prior knowledge do examiners perceive as required in solving a stoichiometric problem considered in this study; (B) which of the perceived prior knowledge are needed to be primed based on students' performance in a diagnostic test; (C) which of the perceived prior knowledge are needed to be taught based on students' performance in a diagnostic test.

The criteria for determining whether the examiners' perceived prior knowledge are to be activated or taught is based on the fact that: if majority of the students demonstrated mastery of the prerequisites, activation of the students' prior knowledge will be needed. But if large percentage demonstrated weak acquisition of prerequisite knowledge, then proper teaching will be the best option.

Theoretical framework

Knowledge components

According to constructivist conception, learning occurs when learners make sense of new information by relating it to their prior knowledge (Ausubel, 1963). Cognitive psychologists (Anderson, 2005; Sawyer, 2006) believed that meaning can emerge from new materials only if they connect or tie into existing cognitive structure of prior knowledge. Learners may work independently or in cooperation with others to internally construct unique knowledge structure. During a problem solving process, students have to search their constructed knowledge structure for knowledge that can be used to develop a solution pathway. An individual's constructed knowledge is self-organized through various mental associations and structure. This organized knowledge has been classified by Anderson and his colleagues (Anderson et al., 2001) into four types. Factual (knowing the basic elements about something), conceptual (knowing the relationships among basic elements), procedural (knowing how to do something), and metacognitive (knowing when to use particular knowledge and awareness of one's own cognition).

Factual (declarative) knowledge consists of the basic elements students must know to be acquainted with a discipline or solve problem in it. In other words, it is knowledge that can be declared, through words and symbol systems of all kinds. This is also the kind of knowledge that students are claiming to have when they possess knowledge of terminologies (e.g., reactant, product, mole ratio, stoichiometric coefficient) and specific facts (e.g., oxidation and reduction are not independent reactions).

Conceptual knowledge refers to knowledge rich in relationships and understanding (Woolfolk, 2010). It is the product of incorporating a new idea into an established schema, or the re-organization of an existing schema to fit a new idea. It cannot be learned by role memorization. It must be learned by thoughtful, reflective learning. It takes conceptual knowledge for a student to recognize the reactant – product pair that provides the appropriate stoichiometric ratio for solving the stoichiometric problem being considered in this study. This kind of knowledge may be transferred between situations. Conceptual knowledge differs from factual knowledge that is applicable only to certain situations. If conceptual understanding is gained, then a person can reconstruct a procedure that may have been forgotten. On the other hand, if procedural knowledge is the limit of a persons' learning, there is no way to reconstruct a forgotten procedure.

Procedural knowledge refers to knowledge of how to perform certain activities (e.g., solving problem). In other words, it is knowledge that is demonstrated when a person performs a task. Possession of factual and conceptual knowledge reflects abstract understanding rather than a practical understanding which indicates procedural knowledge. Conceptual understanding in problem solving task, along with procedural skill, is much more powerful than procedural skill alone (Niedelman, 1992). Students, who claim to know how to construct and balance redox chemical equations, or how to calculate number of moles of a solute using the relationship between molar concentration and volume, are not simply claiming that they understand the concept involved in those activities. Rather, they are claiming that they actually possess the skills involved, that they are able to do these things.

Metacognitive (regulatory) knowledge is a multi – faceted construct described by Gourgrey (2001) as "… knowledge of how to use available information to achieve a goal; ability to judge the cognitive demands of a particular task; knowledge of what strategies to use for what purpose; and assessment of one's progress both during and after performance". As conceived by Schraw (2006), metacognitive knowledge is knowing how and when to use factual, conceptual and procedural knowledge. For many students this kind of knowledge is a stumbling block because at many occasions they have facts and can perform the procedures, but they find it difficult to understand how to apply what they know at the appropriate time [25]. It takes metacognitive knowledge to know when to use stoichiometric ratio to determine (Ashcraft, 2006) mole of a reactant if the mole of another produce is known.

Activating students' prior knowledge

Prior knowledge acts as a lens through which student view and absorbs new information (Pope & Watts, 1988). Students learn and remember new information best when it is linked to relevant prior knowledge. In fact, better links lead to better comprehension, and better comprehension leads to more enduring knowledge structure in memory. In short, a powerful method of teaching chemistry concepts is to base instruction on what students already know.

To teach students how to solve a stoichiometric problem, teachers must ensure that students' prior knowledge is adequately activated. Teachers can use diagnostics tests, inquiry – oriented discussions and graphic organizers to activate and illustrate student's prior knowledge. Such techniques (e.g., testing, dialoging and visualizations) encourage students to think about their thinking.

The first step in activating students' prior knowledge involves identification of essential pre-skills or prior knowledge most proximal for solving the sample stoichiometric problem. Identifying prerequisites for a skill-oriented activity of this nature is slightly more complicated because it involves identification of sub-skills that lay the foundation for the new skill. Task analysis, the process of breaking a skill into its components, can be helpful at this step. For a beginning or novice teacher a thorough understanding of the sub-problems and of relationship among them is pivotal to efficient and effective instruction and learning.

Once proximal tasks are identified, the instructor proceeds to the second step which involves determination of whether the prior knowledge needs to be primed or taught. In other words, the second step aims at determining whether priming will allow the learner to retrieve and use the information accurately and reliably. If so, then priming is appropriate instructional strategy; if not then a more thorough instructional sequence must be designed to teach the earlier identified pre-skills. To do this effectively, Nitko

& Brookhart (2007) developed a model of instructional sequence for priming students' prior knowledge.

The third step involves using priming as a prompt to elicit the correct information to prepare the learner by focusing attention on a difficult task or component of a task. For example, prior to solving the sample stoichiometric problem, students may be asked to construct, balance and interpret chemical equations depicting synthesis, decomposition, combustion, single replacement and double replacement reaction as a prompt in leading students.

Since new knowledge and skill is dependent on pre-existing knowledge and skill, knowing what students know and can do when they come into the classroom or before they begin a new topic of study, can help teachers design instructional activities build off of student strengths and acknowledge and address their weaknesses (Novak, 2002; O'Brien, 2008).

Stoichiometry

Stoichiometry, one of the quantitative areas of chemistry, is a component part of senior secondary school curriculum. In Nigeria, the topic is treated in the second year of senior secondary school and it covers stoichiometry of gas and solution. Stoichiometry is important in the sense that is can be used to: (a) establish that the chemical equations are true and not just an invention of some deranged chemists; (b) determine the composition of an unknown or new compound; (c) predict yields, or to decide how must of a reactant is required to give a certain amount of product; (d) determine percentage purity or percentage composition.

Basically, its inclusion in the secondary school curriculum would enable students to provide answers to the following questions: (1) How many grams (or moles of one starting material are necessary to react completely with a given number of gram (or mole) of another starting material? (2) How many grams (or moles) of another products are obtained when a certain amount of main product is produced? (3) How many moles (or grams) of any particular product are formed if we start with a given mass of starting material? (4) How many grams (or moles) of starting material are needed if we want to form a certain number of grams (or moles) of a certain products?

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 of a given problem.

A sample problem to be encountered when dealing with stoichiometric calculation is: *"is 3.00 g of magnesium ribbon theoretically sufficient to produce 4.50g of magnesium(II)* *oxide (MgO) when magnesium is burnt in the air"*? Solving this problem requires several steps and considerations along the solution pathway. The first step involves writing a balanced chemical equation with the correct chemical formulas for all reactants and predicted products. The second step requires determination of reactant-product pair that provide the relevant stoichiometric relationship for calculations and interpretation of the balanced reaction equation in terms of interacting mole. The third step involves determining the number of moles of magnesium present in 3.00 g of magnesium using mass-mole relationship. The fourth step requires using the determined molar proportion (i.e., two mole ratios set equal to each other) to convert the number of moles of magnesium to moles of magnesium(II) oxide. The fifth step concerns with the conversion of moles of magnesium(II) oxide to mass using mass – mole relationship. The final step involves evaluative thinking in which the mass of magnesium (II) oxide calculated is compared with the mass of MgO given in the problem statement to make appropriate decision regarding sufficiency of the given mass of magnesium.

Methodology

Research design

The research approach employed in the first investigation is called phenomenography. This particular approach emphasis that different persons may experience a similar phenomenon (e.g., stoichiometry) in different describable ways. Owning to the fact that the researcher is interested in describing different ways in which examiners conceptualize what constitute prior knowledge required for solving sample stoichiometric problem, phenomenography was considered as the most viable choice of approach.

On the other hand, descriptive survey research design was adopted for the second investigation. This design was used to obtain information about prior knowledge possessed and those not possessed by the chemistry students through the use of the Stoichiometry Prior Knowledge Achievement Test (description of the test will be presented shortly)

Participants

The target population for the first investigation comprised of thirty-five chemistry examiners who were invited for the May/June 2012 WASSCE coordination and marking exercise conducted by the West African Examinations Council (WAEC) at Ogbomoso marking venue. The sample included 17 examiners comprising eleven males and six females working as chemistry teachers in Ogbomoso Educational zone of Oyo state, Nigeria. Their participation in this study was voluntary. Their chemistry teaching experiences range from 12 to 28 years. While their marking experience range from 9 to 25. They were also assured about their confidentiality during their participation in the study. In line with that, in the reporting of findings, codes (e.g., Ex_1, $Ex_{2,}$…) were used.

For the second investigation, the researcher randomly selected five schools from a total of twenty schools from which the examiners were working as chemistry teachers. These five schools provided a total of eleven intact second year senior secondary science classes for the researcher to undertake the study. These classes consists of 281 students (male = 195, female = 86) with a mean age of 16.74 years. In researcher's view, the number of participants selected was considered sufficient for the analysis of data and to generate general conclusion.

Instruments for data collection

Two instruments were used for data collection during the first investigation. The first instrument is Problem Solving Test in Stoichiometry (PSTS) which is presented as:

> Oxygen is liberated by the reaction (in acid medium) of 30.0 mL of xmolL^{-1} $KMnO_4$ solution with H_2O_2. A volume of 0.150 L of O_2 is collected over water at $25^{O}C$ and a total pressure of 750 mmHg. At this temperature, water has a vapour pressure of 23.8 mmHg. What is the molar concentration of $KMnO_4$ solution? [R = 62.4 L torr/mol K].

This problem is a multi-concepts stoichiometric problem which requires several cycles of interpreting, representing, planning, execution and evaluation during it solving. Based on the first research question, a series of guiding questions in form of closed-ended and open-ended questions were generated to serve as the second instrument used during the semi-structured interview. This data collection strategy was employed: (1) to provide structure to the data collected through the use of closed-ended questions and (2) to give examiners a greater degree of freedom in expressing their perceptions on prior knowledge needed for solving the sample stoichiometric problem through the use of open-ended questions. Some examples of guiding questions are given as:

> Would you consider knowing the definition of molar concentration to be one of the prior knowledge needed in solving this problem? If so, why?
>
> Do you think that ability to construct and balance redox equation is required in solving this problem? If yes, give reason.
>
> How and when do you expect your students to use Dalton's law of additive pressure and equation of state during the problem solving process?
>
> Can you give examples of relevant mathematical expressions that students must recall during the problem solving process?

These guiding questions were designed, piloted and refined by the investigator before used.

Based on the nature of PSTS used in the first investigation, key prior knowledge required in the solution process of PSTS were identified to provide basis for the construction of the single instrument used in the second investigation. This instrument is called the Stoichiometry Prior Knowledge Achievement Test (hereafter termed SPKAT). A diagnostic test (SPKAT) consisting of six questions was used to determine the adequacy of students' knowledge based ahead of stoichiometry lesson. In January 2011, the initial version of SPKAT (containing fourteen test items) were moderated by two chemistry educators and one experience senior school chemistry teacher in order to ensure the face and content validity of the instrument. Based on their comments and suggestions the test items were reduced to six test items. To obtain the final version, the instrument was trialed in September, 2012 during extra lesson hours with 121 second year senior secondary school students in a neighbouring state. The trial testing was aim at verifying the clarity of problem statements and to make decision regarding test duration. Following that, the reliability of the instrument is determined to be 0.87 using the test – retest method of three weeks interval.

Data collection

The data for the first investigation was collected through semi-structured interviews. Each examiner was individually interviewed in a separated room at the marking and coordination centre. The interviewee was engaged in talking while the researcher listened keenly to identify follow-up questions that arose in the conversation. The interviews were conducted at a convenience time during the marking exercise, and each interview lasted approximately 45 to 55 minutes, and was tape recorded and transcribed. While the data for the second investigation was generated through testing 281 students using SPKAT. During the administration of SPKAT students were instructed to write their workings on the answer booklets provided.

Data analysis (for the first investigation)

Analysis of interview transcripts from the perspective of knowledge components developed by Anderson et al. (2001) led to the development of a coding scheme. The meaningfulness of the categories within the coding scheme is responsible for their choice in this study. Teachers' response to the interview questions were categorized into four groups based on the coding scheme described in detail as shown in Table 1.

Following the development of coding scheme, two experts independently coded the complete transcripts of individual participants in order to ensure reliability of results. Inter-coder reliabilities of the categorization were satisfactory since the agreement coefficient exceeded 0.80 across all knowledge components reported here. Inconsistencies found were reconsidered and resolved via discussion between coders. Following application of the qualitative coding scheme to the data collected, frequency counts for each item in the four different knowledge categories were generated and percentages calculated. To help illuminate this analysis, teachers' perceptions were then shown in diagrammatic representations including percentages.

Table 1. Coding scheme for categorizing examiners' responses to interview questions

Knowledge component	Criteria for placing teachers' responses into categories
Factual knowledge	Responses referring to students possessing knowledge concepts associated with stoichiometry and ability to recall essential mathematical expressions involved in the problem solving process
Conceptual Knowledge	Responses referring to students making cognitive connections. That is making connections between concepts that are involved in problem solving or making connections between the retrieved information from the existing cognitive and the external cues.
Procedural knowledge	Responses referring to students knowing the sequence of steps that make up the solution pathway to the problem or knowing how to solve any sub – problems that lead to the problem goal.
Metacognitive Knowledge	Responses referring to students possessing ability to decide when actions or manipulations that are valid within the process of solving the stoichiometric problem are to take place.

Table 2. Quotes from examiners about prior knowledge required for solving a sample stoichiometric problem

Examiner	Knowledge Component	Interview Passage and Page from Transcript
Ex_7	Factual knowledge	*"Okay, um, a knowledge base comprising of knowledge of Ideal gas law, Dilution law, and Daltons' law of partial pressure are needed together with…" (p.6)*
Ex_{10}		*"…knowledge of mole concept, knowledge of concept of solution as well as knowing rules for balancing oxidation-reduction reaction provide solid ground for…"(p.11)*

Ex_3	Conceptual knowledge	*"Well, good understanding of relationship among concepts involved in the…I mean, understanding that law of conservation of mass relate to balancing of the equation and that the coefficient in a balanced equation describes the relationship between the molar of any two chemical spices involved in… (p.2)*
Ex_1		*"hmmm, I think sound understanding of the oxidation-reduction relationships for the reaction of acidified $KMn0_4$ solution with hydrogen peroxide is a necessary knowledge for…More so, realizing that molarity denotes a concentration that states the number of moles of solute in exactly $1.0m^3$ of solvent are required …(p.1)*
Ex_{15}	Procedural knowledge	*"Ability to reason stoichiometrically to determine mole-mole factor and knowing how to use it for further computation; also knowing how to determine the true pressure of oxygen gas are some of prior knowledge needed to"…(p.18)*
Ex_6		*"A chemistry problem involving both gas and solution stoichiometry requires knowing how to solve for number of moles using. Ideal gas law and knowledge of molarity as a concentration unit showing the ratio of solute to volume of solution (p.5)*
Ex_5	Metacognitive knowledge	*"I think students' awareness of when and why to construct redox equation, apply equation of state, use Dalton's law and….are needed to tackle this problem" (p.4)*
Ex_{12}		*"Knowing when it is appropriate to transfer what they learned in one context to another. That is, knowing the right time to recall and apply Ideal gas equation, stoichiometric ratio, and other"…(p.13)*

Data analysis (for the second investigation)

Students' written solutions to the SPKAT were collected for content analysis. This type of analysis is a research technique for the objective, systematic and quantitative description of the manifest content of a document. In this study, the document is the students' written works. These written solutions are qualitative in nature and content analysis helps in making prior knowledge displayed by students in their workings to be codified, classified and made the data worthy of tabulation. The outcome of the content analysis yielded the contents contained in Table 2.

Results and discussions

The findings and discussions are based on analysis of (1) transcripts obtained from examiners' interviews and (2) student's written solutions to the problems that featured in the stoichiometry Prior Knowledge Test. The findings and discussions of this study will be presented according to each research question.

Research question 1: What prior knowledge do examiners perceived as require in solving a stoichiometric problem considered in this study?

The answer to this question is based on the qualitative analysis of the transcripts of the examiners' interview. For the purpose of clarity, answers will be presented according to the prior knowledge components, namely, factual, conceptual, procedural and metacognitive.

Factual knowledge

Knowledge of the basic steps for balancing redox equations, ability to recall mathematical expressions representing equation of state and Dalton's law of partial pressure, knowledge of mole concepts and knowledge of molarity as concentration unit that shows the ratio of mole of solute to volume of solution prior knowledge that were thought necessary for solving the stoihiometric problem considered in this study. Table 2 gives examples of participants' responses that reflected prior knowledge in the category of factual knowledge.

Knowledge of the rules for balancing redox equations in acidic medium and ability to recall essential formulas such as $PV = n\ RT$, $P_T = P_{gas} + P_{water}$ and $n=CV$ are background knowledge that high proportion of participants regarded as parts of the requirements for participants regarded as parts of the requirements for planning the solution strategies. This is because the problem solving process begins with writing and balancing of redox equation representing reaction between $KMnO_4$ and H_2O_2 in acidic medium. A correctly balanced redox equation gives the coefficients (i.e., numbers that disclose the proportions by mole of reactants and products taking part in the reaction). The molar rations indicating relationship between $KMnO_4$ and O_2 can be used to determine the quantity of $KMnO_4$ since the quantity (in mole) of oxygen gas liberated during the redox reaction can be determine using the equation of state and Dalton's law of partial pressure. Thereafter, recalling of the expression $n=CV$, is useful in determining the morality of $KMnO_4$ solution that reacted with H_2O_2.

Conceptual knowledge

Concerning the conceptual knowledge, nearly all (94.1%) the examiners perceived that solvers' ability to realize that all chemical equations must be complete and must be correctly balanced to be useful when solving stoichiometric problems that deal with chemical reaction is essential prior knowledge in this case. Recognizing that the coefficients in the balanced redox equation represent the quantities (in mole) of reactants and products that are involved the oxidation-reduction reaction is the issue that (88.2%) of the examiners consider as prior knowledge required to be successful in the problem-solving process. Still, high proportion (94.1%) of the examiners responses indicated that recognizing the reactant-product pair that provide the appropriate stoichiometric relationship between $KMnO_4$ and O_2 (i.e., the mole-mole factor) for the conversion of mole of oxygen gas evolved to mole of $KMnO_4$contained in 30.0mL solution as part of prior knowledge needed for solving the stoichiometric problem considered in this study. Other prior knowledge in this category that examiners perceived to be essential are: (1) interpreting chemical equations in terms of moles (2) conceptualizing molar concentration as a concentration that states the number of moles of solute in exactly 1 liter of solution; (3) realizing that the ideal gas law can be to convert the quantities (pressure, volume and temperature) of gases to moles in a chemical reaction. Illustrative quotes from two participants that reflected prior knowledge in the category of conceptual knowledge are presented in Table 2.

Conceptual knowledge is seen as the knowledge of the core concepts and principles and their interrelations in a certain domain. Domain in this case is stoichiometry. Thus, possession of well-structured, organized knowledge allows students to solve novel stoichiometric problems and to remember more information than do memorized facts or procedures. Naturally, students make connections between pieces of knowledge. When those connections form knowledge structures that are accurately and meaningfully organized, students are better able to retrieve and apply their knowledge effectively and efficiently during problem solving. In contrast, when knowledge is connected in inaccurate or random ways, students can fail to retrieve or apply it appropriately.

Conceptual knowledge assists a problem-solver to develop a meaningful representation of the problem and to develop new solution pathways or to adapt existing solution pathways to novel problem. Unsuccessful problem solvers usually have difficulty in solving problems not because they simply lack the ability to solve problems but because they lack conceptual knowledge. This kind of knowledge is assumed to be stored in some form of relational representation, like schemas, semantic networks on hierarchies (Byrnes & Wasik, 1991).

Procedural knowledge

Based on the understanding of the respondents, ability to perform the following actions during the execution of solution plan is considered as the needed prior knowledge in the procedural knowledge category: (i) knowing how to balance redox equation in acid medium (ii) knowing how to determine pressure of 'dry' gas using Dalton's law of partial pressure (iii) knowing how to solve for numbers of moles of a substance using equation of state (iv) knowing how to calculate numbers of moles of a solute using the relationship between molar concentration and volume of solution.

Procedural knowledge is characterized by ability to build up step-by-step solution plan and make logical connections between the problem state and solution state during problem solving process. In fact, it is regarded as a direct source of problem-solving knowledge in the sense that it is the knowledge of subcomponents of a correct procedure. Procedures are a type of strategy that involved step-by-step actions for solving problems (Busanz & Lefevre, 1990), and most procedures requires integration of multiple skills. For example, the procedure for solving the stoichiometric problem considered in this study requires integration of the following sub-skills: knowing how to set up a chemical equation for the redox reaction based on the information provided in the problem statement, how to use the equation of state ($PV=nRT$) and the gas constant (R) to convert gas quantities (pressure, volume, temperature) to moles of oxygen gas, how to construct molar proportion (i.e., two mole ratios set equal to each other) for the conversion of mole of gas (oxygen) to mole of solute ($KMnO_4$) and how to use $C=V/n$ to find the molar concentration of the $KMnO_4$ solution that reacted with H_2O_2 in acidic medium.

This type of knowledge allows students to solve problems quickly and efficiently because it is to some degree automated. Automatization is accomplished through practice and allows for quick activation and execution of procedural knowledge, since its application, as compared to the application of conceptual knowledge, involves minimal conscious attention and few cognitive resources (Johnson, 2003).

Metacognitive knowledge

With reference to the metacognitive knowledge, knowing when to (i) use stoichiometric ratio from balanced redox equation to determine mole of a reactant if the mole of another product is known (ii) determine pressure of 'dry' gas using Dalton's law of partial pressure (iii) solve for numbers of moles using the equation of state (iv) calculate number of moles of solute using the relationship between molar concentration and volume of solution. Illustrative quotes from two participants that reflected prior knowledge in the category of metacognitive knowledge are shown in Table 2.

Successful solving of chemistry problem requires possession of metacognitive skills. Students with high metacognitive ability know when to use a procedure, skill or strategy and when not to used it; they know why a procedure works and under what conditions it works and why one procedure is better than another. For instance, a student's armed with metacognitive knowledge is capable of recognizing that Dalton's law of partial pressure must be applied first before using equation of state to convert the given quantities (pressure, volume and temperature) of oxygen gas to mole in attempt to solve the stoichiometric problem consider in this study.

Research question 2: Which of the perceived prior knowledge are needed to be primed (or activated) based on students' performance in a diagnostic test?

The answer to this question is mainly based on the qualitative analysis of students' written solutions to the problems contained in the SPKAT.

Table 3 revealed that high proportion of the students displayed appreciable possession of the following prerequisite knowledge and skills: (1) interpreting chemical equations in terms of moles and molecules (87.2%) (2) writing mole-mole factor to express quantitative relationship between two chemical species in a reaction (83.3%) (3) calculating partial pressure of a gas in a gas mixture using Dalton's law of partial pressure (94.0%) (4) calculating number of moles of a gas from given volume, temperature and pressure using the equation of state (92.2%). Based on these findings, the following prerequisite content areas (previously perceived by the examiners) are needed to be primed or activated: (1) writing mole ratios from balanced chemical equations (2) interpreting balanced chemical equations (3) applying Dalton's law of partial pressure in gas problems (4) applying the ideal gas law equation in gas problems. Activating students' prior knowledge regarding these content areas is enough since they have mastered the specified learning prerequisites necessary for them to profit from upcoming instruction on stoichiometry. The fact that students can interpret a balanced chemical equation implies that they recognized that the stoichiometric coefficients in a balanced chemical equation represent the quantities of reactants and products in moles that are involved in the reaction. Similarly, being capable of applying both Dalton's law and Ideal gas law equation in calculations was a true reflection of their ability to recall mathematical expressions for Dalton's law of partial pressure and Ideal gas law. In addition, they realized that the Ideal gas law can be applied in converting gas quantities (P, V, and T) to mole of gas.

Research question 3: Which of the perceived prior knowledge are needed to be taught based on students' performance in a diagnostic test?

The answer to this question is also based on the qualitative analysis of students' written solutions to the problems that featured in the SPKAT.

As shown in Table 3 high proportion (73.3%) of students lack the needed skills for balancing redox equation and this is one of the subcomponent skills needed for solving the stoichiometric problem considered in this study. It was also observed that large percentage (1) of students found it difficult to: determine molar concentration (Molarity) using moles of a solute and volume of solution containing the solute (79.7%) and (2) construct appropriate mole ratio from balanced equation and apply it to determine mole of a reactant from given mole of another product (76.9%). Students' poor performance in item seven of SPKAT was due to two sources (as evidence from their workings) which are associated with application of mole concept to stoichiometric calculations. First, they were unable to identify the reactant-product pair for the construction of appropriate mole ratio for the calculation. Second, students encountered difficulty in converting mole of CS_2 to mole of SO_2 because the solution process involved the use of stoichiometric proportion which was not 1:1. Similarly, students inability to calculate molar concentration was due to their poor conceptual understanding of molar concentration (i.e., molarity). Although, the participants were able to recall correctly the mathematical expression for calculating molarity but they were unable to proceed further in solving the problem (item 5 in SPKAT). This implies that they only recognize molarity as a concentration unit that shows the ratio of moles of solute to volume of solution. Conceptually, they do not recognized molarity as a concentration that states the number of moles of solute in exactly 1 liter of solution.

Table 3. Performance of students in the Stoichiometric Prior Knowledge Achievement Test

Subcomponent skills (Prior knowledge) for solving sample stoichiometric problem		Displaying possession of needed prior knowledge		Lacking the needed prior knowledge	
		No of students	Percentage	No of students	Percentage
1	Balancing redox equations using half-reaction or oxidation number method	75	26.7%	206	73.3%
2	Interpreting chemical equations in terms of number of moles and molecules	245	87.2%	36	12.8%
3	Calculating partial pressure of a gas in a gas mixture using Dalton's law of partial pressure	264	94.0%	17	6.0%
4	Calculating number of moles of a gas from given volume, temperature and pressure using equation of state.	259	92.2%	22	7.8%
5	Determine molar concentration using moles of a solute and volume of solution containing the solute.	57	20.3%	224	79.7%
6	Writing mole-mole factor to express quantitative relationship between two chemical species in a reaction.	234	83.3%	47	16.7%

7	Constructing appropriate mole ratio from balanced equation and applying it to determine mole of a reactant from given mole of another product.	65	23.1%	216	76.9%

Diagnostic information obtained from administering SPKAT revealed that students have not mastered some essential prerequisite knowledge to a reasonable extent as earlier explained. So, attempt to activate students' prior knowledge regarding balancing redox equation, calculating molar concentration and, constructing mole ratio and its further application in calculations does not yield any results since the students' schema are devoid of those prerequisites. Therefore, there is need for the teachers to ret each these specified content areas in preparing students for the upcoming instruction on stoichiometry.

Conclusion and instructional implications

The first investigation sheds light on examiners' perceptions of prior knowledge needed for solving a sample stoichiometric problem used in this study. Interestingly, too, the second investigation provides insight into students' knowledge regarding learning of stoichiometry. Both examiners' perceptions of prior knowledge required in the problem solving process and the actual students' knowledge base as revealed in this study provide a baseline of information that might be useful for curriculum developers and chemistry educators who are committed to the improvement of teaching and learning of chemistry. In researcher's view, the results of this study have the following important implications for teaching of stoichiometry.

One important finding of this study was that high proportion of examiners perceived recalling the equation that relates the molar concentration (*C*) of a solution to the amount (*n*) of solute present in that solution as one of the prior knowledge required. This perception suggests the use of algorithmic technique, a problem solving process that requires substitution of numbers in a prescribed scheme (i.e., formula or equation). Employing algorithmic technique in leading students to determine the molar concentration in the stoichiometric problem considered in this study is an indication of limitations in examiners' pedagogical thinking skills. They should realize the danger inherent in using algorithmic technique. With algorithmic type of teaching, meaningful learning cannot occur. Leading students to determine molar concentration using the first principle based on conceptual understanding of molar concentration as a concentration that states the number of moles of solute in exactly 1 liter of solution. Thus, x mol. L^{-1} $KMnO_4$ solution is equivalent exactly to x mole of $KMnO_4$ dissolved in 1 liter (1.0L) of water. Based on this information, (2.344 x 10^{-3}/x) L of solution is equivalent to 3.0 x 10^{-2}L of $KMnO_4$ solution.

Similarly, another important implication that emerges from the study was that solving the sample stoichiometric problem is hinged on students' ability to construct semantic network (i.e., organized knowledge structure) about stoichiometric problem under consideration. This can be inferred from examiners' responses in which they perceived that (1) knowing that coefficients in the balanced chemical equation represent the quantities of reactants and products in moles that are involved in the reaction (2) knowing the usefulness of the reactant – product pair that provide the appropriate stoichiometric ratio for the determination of mole of a reactant if the mole of another product of the same reaction is known are essential prior knowledge in the category of conceptual knowledge. Realizing this, chemistry teachers should ensure that while teaching stoichiometry, information should be presented in an organized format and a meaningful context so as to enhance students learning and recalling. Information is said, to be organized when the components that make it up are linked together in some rational ways (Snowman & Biehler, 2006). Thus, teachers can facilitate their students' problem solving success by helping them to build a coherent knowledge base through the use of external representations that illustrate relationship among concepts (e.g., graphs, charts, concept maps). Of these external representations concept mapping that consist of modes representing concepts and labeled lines representing relationships among them have been found to be particularly very highly effective for problem solving (Pankratius, 1990).

Findings of this study revealed that knowing how to balance redox equation in acid medium constitute part of the required prior knowledge. This is because there is need for problem solvers to establish the mathematical relationship between the quantity of reactants and products when dealing with reaction stoichiometry. It is also clear from the findings of this study that knowing how to calculate: (1) pressure of dry gas using mathematical expression of Dalton's law of partial pressure (2) number of mole(s) of substance using the equation of state (3) mole of a reactant if the mole of another product is given using the stoichiometric ratio that is obtainable from a balanced chemical equation (4) numbers of mole of a solute using the relationship between molar concentration and volume of solution were perceived as essential prior knowledge by large percentage of examiners. These findings imply that these perceived content areas were recognized as subcomponents of the correct procedure of determining the molar concentration of $KMnO_4$ solution. These subcomponents skills must be mastered by students before exposure to solving the stoichiometric problem need in this study. So, effective problem solving instruction should focus on building students' problem solving competencies in demonstrating the acquisition of the component skills. Efficiency in component skills can free up cognitive resources for planning solution pathway to the titration problem considered and can prevent errors in execution. However, chemistry teachers should realize that students must develop not only the component skills and knowledge necessary to perform complex tasks; they must also practice combining and intergrating them to develop greater fluency and automaticity.

Another interesting finding of this study was that examiners perceived prior knowledge related to metacognition as essential to problem solving. For instance, they perceived knowing when to calculate number of moles of a solute using the relationship between molar concentration and volume of solution during the problem-solving process as needed. Considering this fact, chemistry teachers should not only emphasize strategy involved during the problem solving process but efforts should be made to provide explanations concerning when and where it is appropriate to apply a specific problem solving strategy or previously learnt materials. In addition, during problem solving instruction, teachers should ensure that useful suggestions for monitoring and evaluating whether a selected problem solving strategy is working and what to do if it is are not provided for students.

Results from the second investigation imply that chemistry concepts and principles to be learnt by students should be arranged and taught hierarchically in order of increasing complexity by the teachers. This will help student to build on prior knowledge when learning and explicit efforts made by the teacher to leverage prior knowledge can be extremely valuable in instruction. Thus, it becomes necessary for chemistry teachers to conduct a pretest before exposing their students to stoichiometry in the second year of their senior secondary school. This practice will enable teachers to identify students who lack pre-requisite knowledge skills as well as giving them the opportunity of providing advance organizer for instruction. Once students who lack pre- requisite knowledge skills have been identified, they can be provided with appropriate guidance or remediation.

APPENDIX
The Stoichiometry Prior Knowledge Achievement Test (SPKAT)

1. Complete and balance the following equations for reactions taking place in acidic solution using half-reaction method

(a) $MnO_4^- + H_2O_2 \rightarrow Mn^{2+} + O_2$

(b) $VO^+_2 + SO_2 \rightarrow VO^{2+} + SO_4^{2-}$

2. Consider the following balanced chemical equation

$2H^+_{(aq)} + 2H_2O_{2(aq)} + 2Fe^{2+}_{(aq)} \rightarrow 2Fe^{3+}_{(aq)} + 2H_2O_{(l)}$

Write the mole – mole factors for

(a) H_2O_2 and Fe^{2+}

(b) H_2O_2 and H_2O

3. Give an interpretation of the following equation in terms of: (a) number of moles (b) number of molecules

$4HCl_{(g)} + O_{2(g)} \rightarrow 2Cl_{2(g)} + 2H_2O_{(g)}$

4. A teardrop with a volume of 0.5mL contains 5.0 mg NaCl. What is the molar concentration of the NaCl in the teardrop?

5. When solid $KClO_3$ is heated, it decomposes to give solid KCl and O_2 gas. A volume of 256 mL of gas is collected over water at a total pressure of 765 mmHg and 24^{o}C. The vapour pressure of water at 24^{o}C is 22 mmHg. (a) What was the partial pressure of the O_2 gas? (b) How many moles of O_2 were in the gas sample?

6. Carbon disulphide and carbon monoxide are produced when carbon is heated with sulphur dioxide

$5C_{(s)} + 2SO_{2(g)} \rightarrow CS_{2(1)} + 4CO_{(g)}$

How many moles of SO_2 are required to produce 0.50mol CS_2?

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