

Analysis of senior school certificate examination chemistry questions for higher-order cognitive skills

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Abstract

Assessment as classroom activities is a fundamental process required to determine the extent to which intended learning outcomes has been achieved. Whatever form of assessment is employed to measure students' learning, they should include tasks that are authentic, relevant and approximate skills students will need in real-life situations. These skills are well accentuated in the advocacy of the current reforms in science education to develop students' higher-order cognitive skills (HOCS) through question-asking, critical thinking and problem solving. Therefore, this research analyzes chemistry questions of senior school certificate examination conducted by the National Examination Council (NECO) within the framework of Bloom's revised taxonomy of cognitive objectives. The source of data consisted of 257 questions drawn from 5 years examination, from 2010 – 2014. The results from this research indicated that about 80% and 44% of the questions require lower-order cognitive skills (LOCS) and factual knowledge respectively. The results further revealed that there was no question in the evaluate category of the HOCS, and none of the questions required students to apply metacognitive knowledge. The research concludes that the chemistry questions were not as cognitively demanding as they should be, and it is recommended that, examination should ensure that examination questions reflect the dual perspective of the Bloom's revised taxonomy of cognitive process skills and the knowledge dimensions.

Keywords: higher-order cognitive skills, Bloom's revised taxonomy, cognitive process skills, knowledge dimension, chemistry questions.

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1. Introduction

Assessment as part of classroom activities is a fundamental process required to promote learning and ultimately achievement. The main purpose of assessment is to determine the extent to which intended learning outcomes (ILOs) has been achieved (Olorundare, 2014). Assessment tasks provide students with opportunities to demonstrate their achievement of the units' learning outcomes and how well they have achieved them. For the teachers, assessment provides feedback about the success of their teaching.

Assessment could be diagnostic, formative and summative. Diagnostic assessment aims to classify students according to performance grade or level or to diagnose students' learning difficulties and their causes. It sometime includes the use of psychometric tests to measure particular functions and capacities of students that are often used with predictive purposes. Formative assessment is carried out during a course and to provide feedback to the students on their learning; and to the teacher about the learning gains. It is useful in seeking reasons for the learning outcomes and in designing interventions aimed at improving learning. Summative assessment provides the overall evaluation of the student by the instructor at the end of the course.

Whatever assessment task is used to determine learning outcomes, they should be tasks that are authentic, relevant and approximate skills students will need in their future workplace and to solve real life problems. According to Bloom (1956), such assessments employ more cognitively demanding tasks which require students to demonstrate application, analysis, synthesis, evaluation and not merely, tests of memory (that require demonstration of knowledge and comprehension).

1.1 Public Examinations in Nigeria

The West African Examinations Council (WAEC) was established by the British government in 1952 to maintain a uniform standard of education in its colony of Anglophone countries like Nigeria, Ghana, Sierra Leone, Gambia and later Liberia. The WAEC conduct the General Certificate of Examination (GCE) and the West African Senior School Certificate Examination (WASSCE). From 1952 till when Nigeria's National Examinations Council (NECO) was established, the WAEC has enjoyed the monopoly of conducting Senior School Certificate Examination (SSCE) in Nigeria.

The National Examinations Council came into existence in April 1999, when the Nigeria government directed that the National Board for Educational Measurement (NBEM) should be transformed into a new examination outfit, and to be known as NECO. The Federal government also saddled the new council with the responsibility of the conduct of SSCE in Nigeria starting from the year 2000.

The need for the establishment of NECO was connected to the fact that all countries of the world determined their educational objectives, which are in line with their national aspirations. It is important to note that there are no two countries that have the same educational objectives, even though, they may be similar. This is because national interest and aspiration differs from country to country. Since education has been regarded as a potent tool to attain national set goals, it becomes imperative for nations to set up their assessment outfits for the realization of such goals. To buttress this assertion, Table 1 presents some selected countries and their respective examination outfits.

Table 1. Some Selected Countries and their Respective Examination Outfits

Country	Examination Outfits
Cameroun	Cameroun GCE Board
Namibia	National Examinations and Assessment
Kenya	Kenya National Examinations Council
Zimbabwe	Zimbabwe School Examinations Council
Mauritius	Mauritius Examination Syndicate
Scotland	Scotland Examination Board
USA	Educational Testing Service
Britain	University of Cambridge Local Examination Syndicate and others
Australia	Australia Qualifications Authority
South Africa	Independent Examinations Board

Source: Adapted from "Public Examinations in Nigeria" by Ojerinde, 2011.

In Nigeria where NECO is fully in operation, the law that established the NECO stipulated several functions for the council. The council is to be responsible for:

- i. Revising and considering annually, the examinations to be held for admission into the Federal Government colleges and other allied institutions;
- ii. The general control of the conduct of Senior School Certificate Examination (SSCE) in Nigeria;
- iii. Conducting a Standard National Assessment of educational performance at the junior secondary school level;
- iv. Conducting researches leading to a national improvement in the testing and examination procedures at the junior and senior school levels, among others (Ojerinde, 2011).

The certificates issued by NECO attract national acceptability, as well as international recognition. Like the WAEC, the NECO has international connections, because the Council enjoys institutional membership of International assessment bodies like the Association for Educational Assessment in Africa (AEAA) and the International Association for Educational Assessment (IAEA). The National Examinations Council (NECO) is a qualitative and reliable examination in Nigeria that has a strong influence on learning, teaching of; and assessment in chemistry.

In Nigeria, the senior secondary school education spans a period of three years from senior school 1 to senior school 3. In the revised national policy of education, chemistry is a non-vocational elective subject, but all students who seek to make a career out of science-related courses, must offer chemistry as a compulsory subject in the senior secondary school (Federal Republic of Nigeria, 2013). Chemistry textbooks, curriculum and syllabus are the main resources for the teaching and learning of chemistry in the senior school. Each chemistry teacher is given copies of the recommended textbooks and a copy of the curriculum to guide for scope and content of the topics to be taught. For the students, each one of them is given a copy of the textbook the teachers intend to use in a particular academic session. There are 4 – 5 periods of chemistry instruction in a week for a class, and each period is 40 minutes long.

There are three school terms in one academic year: September to December, January to April, May to August, and each term is about 12 – 13 weeks long. By the end of the senior school education, students would have taken 120 hours of chemistry instruction. At the end of senior school III, students sit for either SSCE conducted by either WAEC or NECO, equivalent of examination outfits in other countries for certification, university admission, training and employment (See Table 1). In chemistry, there are three examination papers – paper 1 with 50 multiple choice questions, paper 2 with four structured and essay questions and paper 3 with two lab experiments and one question on general practical knowledge. The national chemistry examinations are prepared by experienced chemistry teachers and university chemistry

lecturers in conjunction with the National Examination Councils in Nigeria. The examiners use the NECO syllabus, curriculum and textbooks as guides for preparing examination questions.

2. Conceptual Framework

This research is anchored on a conceptual framework of the taxonomy of cognitive domain provided by Bloom's (1956) and revised by Anderson and Krathwohl (2002). The taxonomy designed as an assessment tool has provided a framework for learning, teaching and assessment that has been adopted in almost all environments where learning takes place. This may have influence its adoption in the design of science curricula, instructional and assessment systems in Nigeria.

Anderson and Krathwohl (2001) updated and redefined Bloom's original classification, which is the specific taxonomy employed in this research to classify and analyze chemistry examination questions conducted by the National Examinations Council (NECO). The revised taxonomy promotes two dimensions to guide the processes of developing learning objectives, and instruction that will lead to sharper, and more clearly defined assessments, which will consequently, provide a stronger connection of assessment to both the learning objectives and instruction. The two-dimensional taxonomy of Anderson and Krathwohl (2001) emphasizes on the need to assess higher order cognitive processes and metacognitive knowledge for all who are engaged in the field of assessment. The two dimensions of knowledge and cognitive process as shown in (Table 2) have the noun component that provides basis for the knowledge dimension; and verb components that forms the basis for the cognitive process dimension (Krathwohl, 2001).

Table 2. The Revised Taxonomy Table

The Knowledge Dimension	The Cognitive Process Dimension					
	Remember	Understand	Apply	Analyze	Evaluate	Create
Factual knowledge						
Conceptual knowledge						
Procedural knowledge						
Metacognitive knowledge						

Source. Adapted from "A Revision of Bloom's Taxonomy: An Overview" by D. R. Krathwohl, 2001, *Theory into Practice*, 41(4).

In the original taxonomy, cognitive processes assume a hierarchical order that increases from left to right (as in Table 2). In the same vein, the category of the knowledge dimension also follows a continuum from factual knowledge through to metacognitive. Like the original, the revised taxonomy assumed a hierarchical structure in the sense that the six categories of the cognitive process dimension differs from one another in their complexity, with *remember* being less complex than *understand*; *understand* less complex than *apply*; in that order. However, because the revised taxonomy gives greater weight to textbook authors in the developing in-chapter and end-of-chapter questions, the requirement of a strict hierarchy has been relaxed to allow the categories to overlap one another, in such a way that a chemistry question classified under the category of *understand* (for instance, a question that require students to explain chemical concept), may be more complex a questions in the *apply* category, that require students to execute/perform a routine algorithm to arrive at the possible solution.

3. Review of Related Literature

In the recent years, research studies that pertain to cognitive process skills and knowledge dimension have been carried out in the sciences, and particularly, chemistry education (Karamustafaoglu, Sevim, Karamustafaoglu & Cepni, 2003; Tsaparlis & Zoller, 2003; Azar, 2005; Zheng, Lawhorn & Freeman, 2008; Edwards, 2010; Tikkanen & Aksela, 2012).

Karamustafaoglu et al. (2003) compared university entrance examination questions with Turkish high school chemistry examination questions from three different schools of Ordinary, Anatolian and Vocational in the cities of Trabzon and Amasya, Turkey. 403 questions were obtained from 17 high school chemistry teachers and analyzed. It was found that 96% of the questions were of the LOCS type, and statistical tests showed that the question types were related to the school types. When these questions were compared with the University entrance examination questions, the results showed that more than half of the university entrance examination questions were of the HOCS type. These results revealed the wide discrepancies between assessment at the high schools and at the university entrance exams.

Tsaparlis and Zoller (2003) conducted three research studies on students' performance in chemistry examinations that require HOCS or LOCS at the high school and university levels in Greece and Israel. The research indicates that the chemistry examination used for entry into higher education in Greece selects the best LOCS-performing students because LOCS-type of questions were emphasized in the examination. A different pattern of students' performance on examination questions that require HOCS was compared with questions that require LOCS. The results revealed that a high performance on the LOCS-type of questions does not necessarily guarantee a high performance on questions that require HOCS. The results further revealed that many students did not perform any better on the purportedly easier LOCS questions when compared with their performance on HOCS questions. The researchers attributed this finding to insufficient pre-examination preparation based on the analysis of the research data. In the Israeli study conducted within an introductory freshman general and inorganic chemistry course, it was found that, when the top performing students were given a free choice between HOCS- and LOCS-type questions, they preferred to select and answer the LOCS-type questions. This finding indicates that a short-term HOCS-oriented instruction is not sufficient to determine students' examination attitudes or behaviour with respect to LOCS and HOCS learning.

Azar (2005) compared high school physics and the university examination questions using the framework of Bloom's taxonomy. The examination questions were obtained from two sources: 76 physics questions from the university entrance examinations conducted between the years of 2002 and 2003; and 556 physics questions were obtained from physics teachers in the Kdz. Ereğli of Turkey. The results of this comparison revealed that physics questions asked at the university entrance examinations taps into students higher order cognitive skills (of *analyze*, *evaluate* and *create*), while the high school questions only measure the students lower order cognitive skills (of *remember*, *understand* and *apply*).

Zheng, Lawhorn and Freeman (2008) classified biology examination questions using Bloom's taxonomy. The biology questions were drawn from AP biology; undergraduate majors' introductory biology courses from three universities in the United States; the biology parts of the Medical College Admission Test (MCAT) and the Graduate Record Examinations (GRE); and the first-year medical courses from an institution that operates a traditional curriculum. Findings from this study indicated that majority of the questions were at *comprehension* level; followed by the *application* level of the taxonomy. Though, there were questions at *analysis* level in all the questions, but the percentages of those questions were quite small. The researchers further observed that, while there were comparatively few questions at *synthesis* level, no question could be classified into the *evaluation* level in all the examination questions.

Edwards (2010) conducted a qualitative study to analyze the alignment of Grade 12 physical sciences (physics and chemistry) examination papers for 2008 and 2009 with the core curriculum in South Africa, using the framework of the Bloom's revised taxonomy. The results showed discrepancies in the cognitive levels and content areas of both physics and chemistry.

While the chemistry and physics questions were under-represented in the cognitive level, *remember*; the cognitive levels *understand* and *apply* were over-represented in the chemistry examination questions.

Tikkanen and Aksela (2012) conducted a study to determine cognitive skills and knowledge measured by the Finnish chemistry matriculation examination questions using Bloom's revised taxonomy of cognitive objectives. The research indicated that the examinations were cognitively demanding, with majority (77%) of the questions requiring higher order cognitive skills (HOCS). Though, the questions were not evenly distributed among *analyze*, *evaluate* and *create* categories of the cognitive process dimension.

From the literature reviewed, these studies have reported that chemistry examination questions for entry into higher education were predominantly of the lower-order cognitive domain, and comparatively few questions on HOCS (Tsaparlis & Zoller, 2003; Edwards, 2010). If the current reforms in science education have advocated for the development of students' higher-order cognitive skills (HOCS) through question-asking, critical thinking, decision making and problem solving, then, there is the need for a paradigm shift from the prevalent traditional algorithmic exercises to HOCS-promoting assessment methodologies that can lead to improved students' problem solving capabilities. If these reforms are an implied aim of science teaching, then, summative chemistry examination questions ought to be questions that are carefully designed to tap into students' HOCS. This study, therefore, analyze chemistry examinations questions conducted by NECO using the two-dimensional framework of the Bloom's revised taxonomy. This study was guided by a research question on: What type of cognitive process skills and knowledge dimensions are measured by the chemistry examination questions?

4. Methods

The data source for this research consisted of 259 chemistry questions drawn from the senior school certificate examinations conducted by the National Examination Council for a period of 5 years from 2010 – 2014. In each year, there are usually four questions with many parts for students to answer. For ease of analysis, each part of the main question was taken as a single question to be analyzed.

This research study employed a mixed method approach and content analysis to classify the 259 chemistry questions. The study adopted the framework of the revised Bloom's Taxonomy to classify the chemistry questions into the knowledge and cognitive process dimensions because of its revision that is based on current educational research and its suitability for analyzing test items (Anderson & Krathwohl, 2001). The examination questions were also classified into LOCS and HOCS.

In order to ascertain the reliability of the research, 10% of the analyzed chemistry questions randomly selected were independently re-analyzed by one of the researchers and a Professor of science education who understand the Bloom's revised taxonomy and its application for classifying assessment items. The values of Kappa's measure of agreement were calculated based on the classification of the peer reviewers, for each of the cognitive process and the knowledge dimension. The Kappa-values for the cognitive process and knowledge dimensions were .66 and .89 respectively. The substantial values ($\kappa > .65$) for the two dimensions indicated a good measure of agreement between the two raters, which guaranteed a high reliability for the research.

5. Results and Discussion

Table 3 presents the distribution of the 259 chemistry questions of the senior school certificate examinations conducted by the National Examinations Council (NECO) according to the years of the examinations and the cognitive process skills the questions were designed to measure. An approximate of about 20% of the chemistry questions were at the higher levels of

the cognitive domain (8.5 % at *analyze* level and 11.2% at the level of *create*). None of the questions require students to *evaluate*. On the other hand, 80% of the questions were at the lower levels of the cognitive domain (36.7%, 35.1% and 8.5% of the questions require students to *remember*, *understand* and *apply* respectively).

Table 3. Frequency and Percentage Distribution of Chemistry Questions according to Examination Year and Cognitive Process Skills

Year	Remember		Understand		Apply		Analyze		Create		Total	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
2010	8	22.2	13	36.1	5	13.9	4	11.1	6	16.7	36	13.9
2011	31	57.4	9	16.7	2	3.7	4	7.4	8	14.8	54	20.8
2012	14	26.4	23	43.4	4	7.5	6	11.3	6	11.3	53	20.5
2013	16	28.1	28	49.1	4	7.0	5	8.8	4	7.0	57	22.0
2014	26	44.1	18	30.5	7	11.9	3	5.1	5	8.8	59	22.8
Total	95	36.7	91	35.1	22	8.5	22	8.5	29	11.2	259	100

Figure 1 shows a bar chart of the frequency of chemistry questions that measures the six main categories of the cognitive process skills. An inspection of the shape of the bar chart shows that the frequency of questions is not normally distributed among the six categories of the cognitive process skills across the 5 examination years. For each year, the questions are skewed to the left, where majority of the questions only require students to recall relevant chemical knowledge from long-term memory and to construct meaning for chemical concepts.

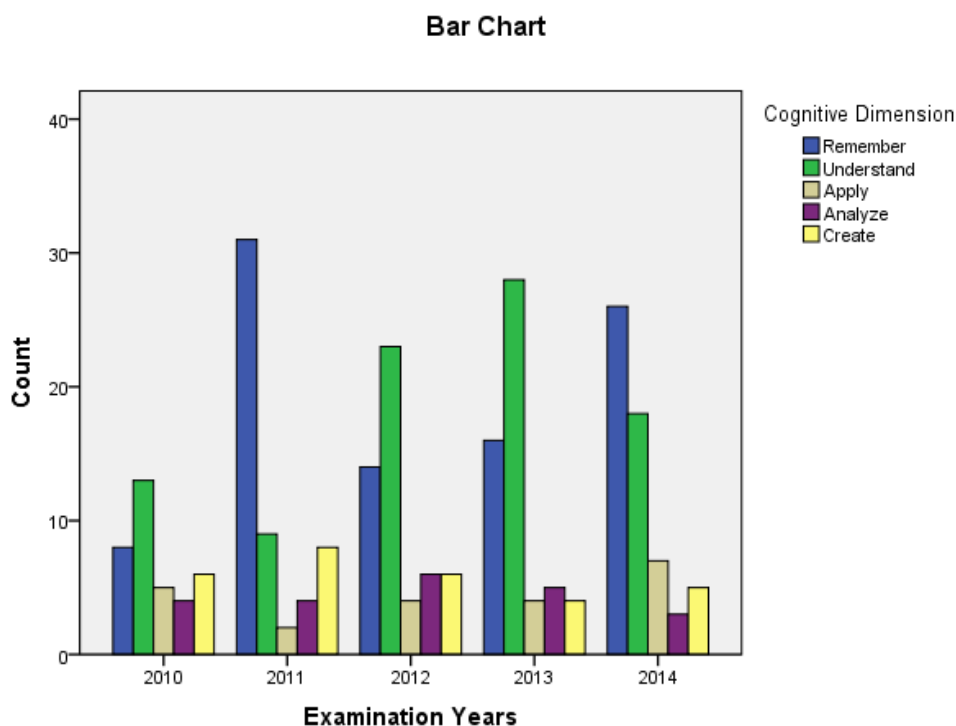


Figure 1. Frequency of Questions according to the Categories of the Cognitive Process Skills and the Examination Years

Table 4 presents the frequency and percentage distribution of chemistry questions obtained from the senior school certificate examinations conducted by the National Examinations Council (NECO) according to knowledge dimensions for the years 2010 – 2014. From Table 4, a total

percentage of 22.4% of the chemistry questions require *procedural knowledge*, while 43.6% and 34% of the questions measured *factual* and *conceptual knowledge* respectively. A closer look at Table 4 shows that the numbers of questions that measure *factual* and *procedural knowledge* seem to have steadily increased from 2012 – 2014. However, the questions that require procedural knowledge appear to have fluctuated between years 2010 – 2014.

Table 4. Frequency and Percentage Distribution of Chemistry Questions according to Examination Year and Knowledge Dimension

Year	Factual knowledge		Conceptual Knowledge		Procedural Knowledge		Total	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
2010	8	22.2	19	52.8	9	25.0	36	13.9
2011	31	57.4	11	20.4	12	22.2	54	20.8
2012	24	45.3	18	34.0	11	20.8	53	20.5
2013	24	42.1	19	33.3	14	24.6	57	22.0
2014	26	44.1	21	35.6	12	20.3	59	22.8
Total	113	43.6	88	34.0	58	22.4	259	100

Figure 2 provide a quick summary of the frequency of chemistry questions that only measures three out of the four categories of the knowledge dimension for a period of 5 years. The shape of the Bar chart for each year shows that the frequency of questions is not normally distributed among the three categories of *factual*, *conceptual* and *procedural knowledge*. The chart suggests that the questions were more of conceptual and factual, except for year 2010 where the frequency of question that measured conceptual knowledge was higher than procedural and factual knowledge.

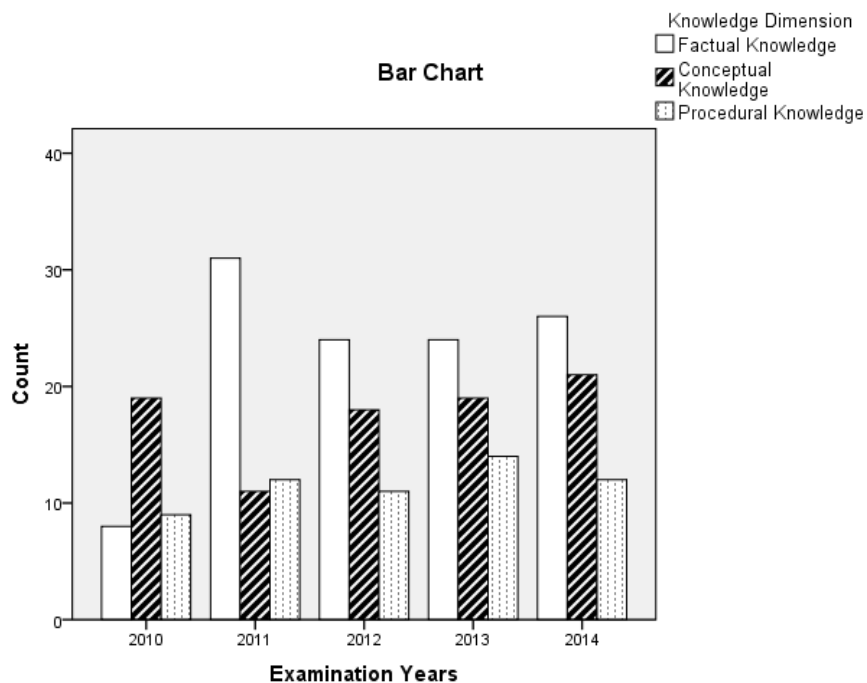


Figure 2. Frequency of Questions according the Categories of the Knowledge Dimension and the Examination Years

In this research study, we sought to analyze the chemistry questions from senior school certificate examination conducted by the National Examination Council (NECO), to determine whether these summative assessments aligned with the current reforms in science education that advocates for HOCS assessment methodologies in science education.

Table 3 presents the results of the cognitive process skills measured by the chemistry questions for a period of 5 years, from 2010 – 2014, where only about 20% of the questions require HOCS. The other 80% were LOCS-type examination questions where 36.5% were at *remember* category, 35.1% and 8.5% were at the categories of *understand* and *apply* respectively. There was no question in the category of *evaluate*. These results are fairly consistent with the findings of Tsaparlis and Zoller (2003), but contradict the results of Tikkanen and Aksela (2012), which indicated a summative assessment that only requires lower-order cognitive skills. Tikkanen and Aksela (2012) carried out a similar research on summative assessment in chemistry and found out that, the large proportion of the Finnish chemistry matriculation examination questions were adequate for the assessment of HOCS. Contrary to the findings of this study where the largest percentage of questions falls into the LOCS category, particularly, *remember* category with 36.5%, the Finnish examination questions did not include any questions that require *remembering*. These differences could be because the advocacy of the current reforms in science education is not well accentuated or articulated in the assessment goals of the National Examination Council (NECO). Hence, the chemistry examination questions used in a summative assessment like the SSCE for a period of 5 years has consistently require LOCS to solve.

Table 4 and Figure 2 show the percentage distribution and graphical representation of the categories of the knowledge dimension measured by the chemistry examination questions. About 22.4% of questions require students to apply *procedural knowledge* to solve majorly algorithmic questions, while 34% and 43.6% of the chemistry questions measured *conceptual* and *factual* content knowledge respectively. These findings contradict the findings of Tikkanen and Aksela (2012), where a larger proportion of the questions measured *procedural knowledge*, but differs significantly from proportion of question that measure *conceptual knowledge* in our study. This means that in the Finnish matriculation examination, emphases were on *procedural knowledge* than on *conceptual knowledge*. In this study, none of the questions require *metacognitive knowledge*. Such questions could be demanding to develop; and to assess in students' metacognitive stages in a formal and summative assessment like the SSCE (Krathwohl, 2002; Tikkanen & Aksela, 2012).

6. Conclusion and Recommendations

From the results of this research, we can conclude that the chemistry examination questions in the senior school certificate examination conducted by NECO are not as adequately demanding tasks, as they should be. The percentage of the SSCE chemistry questions that requires LOCS is very large and consistent with school-based assessments discussed in the literature (Karamustafaoglu, Sevim, Karamustafaoglu & Cepni, 2003; Tsaparlis & Zoller, 2003; Azar, 2005; Zheng, Lawhorn & Freeman, 2008; Edwards, 2010). The results further shows that majority of the questions requires remembering and understanding factual and conceptual knowledge, while a few of the questions require the application/analysis and creation of conceptual knowledge.

Based on the findings of this study, we recommend that:

- examination bodies like the National Examination Council (NECO) should ensure that examination questions reflect the dual perspective of the Bloom's revised taxonomy of cognitive process skills and the knowledge dimension; so that students are ever presented with questions that require them to *analyze, evaluate* and *create* and even to apply their cognition, which will tap into their HOCS;
- since the development of students' HOCS competence is a major objective of the current reforms in science and chemistry education, then corresponding HOCS-orienting

teaching and learning strategies, and assessment methodologies must become the focus of chemistry teaching and learning in schools; and

- summative assessment such as the SSCE chemistry questions should be sufficiently challenging, and suitable for preparing students for entry into higher (university) education chemistry learning.

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