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ORIGINAL ARTICLE

Examining Ghanaian Lower Secondary School Science Test through Revised Bloom's Taxonomy

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ABSTRACT

This study examined integrated science questions of the Basic Education Certificate Examination (BECE) in Ghana at the end of grade 9. Results from BECE determine which senior high school a student can attend. Science questions (n = 751) over the span of eight years were analyzed in this study and viewed under the lens of the revised Bloom's Taxonomy using content analysis. Results show that the majority of the test questions fall under the categories of remembering facts and understanding issues in the revised Bloom's Taxonomy. There were fewer questions related to applying acquired knowledge and analyzing or evaluating issues. Test questions did not include items testing the creation of new knowledge or related combinations. Questions were proportionally distributed across agriculture and environmental science, and the natural sciences (biology, physics, and chemistry). The test also contained several inquiry-related questions distributed across the taxonomy levels and various disciplines. Inquiry questions spanned remembering, understanding, applying, analyzing, and evaluating with most questions belonging to remembering and understanding. By emphasizing higher-order thinking skills such as analysis, evaluation, and creation in test questions, it is possible that the test may direct science education to enhance students' competencies in their personal and professional lives.

KEY WORDS: Inquiry-based learning; integrated science; revised Bloom's taxonomy; science learning; science test

INTRODUCTION

Science instruction and assessment are closely related. Educational authorities persistently look for better ways of assessing students' learning to ensure the accountability of public educational systems (Shute et al., 2016). The Organisation for Economic Co-operation and Development (OECD) (2013; 2021; 2023) defines assessment as making judgments on individual student performance and the extent to which learning goals are achieved. Students' achievement scores from large-scale standardized tests like the Program for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) are used as catalysts for the prediction of countries' gross domestic product (GDP) (e.g. Hanushek and Woessmann, 2012; Mullis and Martin, 2017).

The pivotal role of science in the socioeconomic development informed the Ghana Education Service (GES) and the Ministry of Education to make science a core subject for all students at the pre-tertiary level (Coffie and Doe, 2019). Science education and assessment policy form an integral part of general education policy and assessment practices of societies. Thus, assessment must be placed in the context of the aims of the curriculum and the ways in which it is taught and experienced by learners (e.g., Crato, 2021). Students are prepared with not only good academic achievements but also knowledge and skills needed for the future (Marshall and Alston, 2014; Teppo et al., 2021). Assessment questions must be in line with students' cognitive development (Hasanah and Shimizu, 2020).

Different analysis tools have been used to evaluate science tests. Bloom et al. (1956) created a cognitive model for qualitative classification of educational objectives. The model provides six cognitive levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. Knowledge forms the basis upon which the subsequent levels demonstrate skills and abilities (Furst, 1981). This means that knowledge is essential for practicing acquired skills and abilities. Bloom's Taxonomy model depicts a continuum of categories (levels) with concrete preceding abstract and simple leading to complex. Anderson and Krathwohl (2001) reexamined and updated Bloom's Taxonomy into a taxonomy for teaching, learning and assessment called the revised Bloom's Taxonomy (RBT). This research aims to apply RBT to examine Basic Education Certificate Examination (BECE) conducted in Ghana for junior high school students. The BECE serves as the basis for placement in senior high schools. The objective of this study is to evaluate BECE science test items under the lens of revised Bloom's taxonomy.

LITERATURE REVIEW

The theoretical background in this study is derived from the revised Bloom's taxonomy (RBT), which is also employed as a framework for science teaching and learning in Ghana. RBT (e.g. Krathwohl, 2002; Krathwohl and Anderson,

2010) reexamines the structure of the original taxonomy as two-dimensional, namely: cognitive process and knowledge dimensions. The cognitive process dimension is categorized into six levels: Remember, Understand, Apply, Analyze, Evaluate, and Create. In this hierarchical list, 'Understand' is seen to be more cognitively complex compared to "Remember", "Apply" is more cognitively complex than "Understand", and so on. The knowledge dimension consists of four categories including Factual, Conceptual, Procedural, and Metacognitive. Factual knowledge includes knowledge of terminology and knowledge of specific details and components. Conceptual knowledge comprises knowledge of classifications and categories, standards, generalizations and theories, models, and structures. Procedural knowledge encompasses knowledge of skills and algorithms, methods and techniques, and knowledge of criteria for determining and/or justifying "when to do what" within definite fields and area of study, knowledge about cognitive tasks, expanding to contextual and conditional knowledge as well as self-knowledge. Metacognitive knowledge covers knowledge of wide-ranging strategies applied in different tasks, prevailing conditions for using these strategies, to what extent are the strategies effective and self-knowledge. RBT rather suggests a more active understanding of categorization deviating from a partially passive image of educational objectives. Unlike the original taxonomy which adopts nouns to describe cognitive levels, RBT utilizes verbs and gerunds (Krathwohl, 2002; Krathwohl and Anderson, 2010; Seaman, 2011).

RBT is used, for example, in planning of teaching and learning activities, and through it learning materials and learning outcomes are analyzed in different disciplines and country contexts. Büken and Artvinli (2021) used RBT to study and compare geography attainment targets in social studies curricula. They concluded that Turkish geography attainment targets of the curriculum are at the lower level of thinking or cognition and exclude metacognitive levels. Other contexts for using RBT have been in life sciences and computer science. Bozdemir et al. (2019) studied science achievements in life studies course curricula of 2009, 2015 and 2018 related to their knowledge dimensions of RBT and to compare the resulting distributions. The achievements in the curricula primarily focused on remembering and applying levels with insufficient analysing, evaluating, creating or metacognitive dimensions. In programming, RBT has been applied in defining learning objectives, measuring students' knowledge, building study materials and assessment tests, and showing students what is intended to be understood (Sobral, 2021).

When RBT was adopted in the reading comprehension questions of an EFL/ESL reading textbook, it was found that the textbook reviewed lack the higher order cognitive skills emphasized in the revised version of the taxonomy (Ulum, 2022). It was recommended that textbooks could be infused with RBT for reading skill assessment. In the Indonesian context, it was found that the analyzed textbook focused more on lower order in comparison with higher order thinking questions (Laila and Fitriyah, 2022). Further, in the language context, test items in language tests were analyzed by Setyowati et al. (2022) and they found that the item tests which focus on higher order skills increasingly direct students to think analytically and thoroughly. In examining the appropriateness of the cognitive domain of textbooks' content and RBT categories, it was observed that out of 271 activities identified, 229 (84.5%) constituted lower-order thinking skills (i.e., remembering, understanding, and applying) while higher-order thinking skills (analyzing, evaluating, and creating) constituted 49 (15.5%) activities (Rustiyani et al., 2021).

Examination questions are developed and studied in the light of RBT in several contexts. Mitana et al. (2018) reviewed examination questions in Ugandan secondary schools in the light of RBT. The study revealed that while lower-order questions constituted 87%, higher order questions represented only 13% (Mitana et al., 2018). To encourage the application of higher-order thinking, Hilmi et al. (2022) developed questions based on RBT with high validity, practicality, and effectiveness. Their study revealed that 85% of students provided positive answers to the questions. They recommended that the questions should always cover both lower and higher order thinking in a proportionate manner to help students gain higher order thinking skills (Hilmi et al., 2022).

Kepceoglu and Pektaş (2023) used RBT to analyze multiple-choice science test question in Turkey. They found that most of the science test questions were conceptual low-level questions in nature. The only high-level questions they found belonged to the "analyze" category. According to Kepceoglu and Pektaş (2023), it is obvious that "create" category questions are not possible in multiple-choice exams. The main challenge is that multiple-choice questions encourage rote memorization rather than personal analysis. Therefore, to guide toward higher level learning, it is important to use also open-ended questions (Kepceoglu and Pektaş, 2023).

RBT has been used in comparing examination questions and learning outcomes. Zorluoglu and Güven (2020) examined the relationship between the levels of fifth grade science course exam questions and the fifth class learning outcomes of the science curriculum. They found that majority of learning outcomes described in the curriculum represented the conceptual knowledge dimension and most of the examination questions were in the factual knowledge dimension. In the cognitive processes dimension, learning outcomes were largely at the level of understanding while most questions were at the level of remembering. 37% of the exam questions were at the same level as learning outcomes. In addition, it was found that the questions did not cover all learning outcomes (24%) (Zorluoglu and Güven, 2020).

Endo (2019) classified test items by the aid of RBT to get a sense of what combinations of knowledge and cognitive processes are seen in biology education. RBT can help address the problem of misalignment between course objectives, instruction, and assessment in biology education because the assessments often focus too much on rote memorization rather than problem-solving abilities. Endo (2019) suggests that using biology-specific rubric-based questions in the revised taxonomy, instructors can provide clearer guidance for teachers and their students on learning outcomes. Larsen et al. (2022) suggest that both dimensions of RBT should be used, and that question prompt words, or action verbs alone are not sufficient in classifying the embedded learning objectives within assessment items. For example, while prompt words such as "describe" and "identify" are often considered in relation to the remember cognitive process, they can also be associated with the create cognitive process in an appropriate context (Larsen et al., 2022).

Sotáková et al. (2020) found that using inquiry-based science education (IBSE) based on confirmation inquiry is more effective in developing conceptual understanding compared to traditional teaching methods. This was determined through cognitive tests based on RBT, assessing students' knowledge and skills before and after revision. Results show that IBSE impacts both lower and higher cognitive processes, particularly benefiting students with lower academic performance (Sotáková et al., 2020). Poluakan et al. (2019) studied students' perceptions about lower order and higher order thinking skills and found that it is important to develop the determination criteria for lower-order and higher-order thinking skills based on both the cognitive and knowledge dimensions of RBT.

RBT was applied to analyze the questions to study the possible alteration in cognitive processes and geographical knowledge requirements in the digitalization process of the Finnish Matriculation Examination in Geography (Virranmäki et al., 2020). The results showed that the questions required insight in conceptual and factual knowledge. The study also revealed that digitalization has reduced questions that require remembering while boosting questions that involve analyzing. In addition, more comprehensive use and broad production of materials are required in the tests.

Learning activities built on RBT classification improve students' metacognitive skills (Sudirtha et al., 2022). RBT-oriented learning showed that learning activities based on the Taxonomy promote creative thinking skills (Pujawan et al., 2022). Kwandayi and Muyambo (2022) used a synthetic approach to espouse the need to apply RBT in Zimbabwean university testing. They recommended that university test items must cover all the levels of the taxonomy with a conscious effort to embed lower order questions into higher order questions.

The taxonomy itself has also been considered. Lalwani and Agrawal (2018) investigated the hierarchical nature and the overlapping behavior of RBT. A hierarchy was observed in remember, understand, and apply, while concurrently ensuring that higher order skills do not subsume lower order skills (Lalwani and Agrawal, 2018). Thompson et al. (2008) focused their study to provide consistent interpretations for Bloom's classification categories using the revised taxonomy. Analysis showed that questions could be reworded in a way to alter the cognitive level (Adams, 2015; Thompson et al., 2008). Noticeably, the benefits of RBT, both in developing and analyzing processes, are shown. In the context of inquiry-based science learning, RBT is used to assess students' experiences that promote critical thinking, problem-solving, and scientific inquiry skills (Table 1).

The use of RBT in inquiry-based science learning aligns with the idea that students' progress from basic knowledge to higher-order thinking skills through active exploration. Inquiry-based science learning promotes the development of scientific process skills, including observation, data collection, analysis, and interpretation (Sotáková et al., 2020).

In this study, we focused on the level of the examination questions in the Ghanaian tests since this high-stake examination has influenced the teaching practices of teachers (Amoako, 2019), which, in turn, affect students' learning outcomes (Amoako, 2019; Stecher, 2002). The revised taxonomy is applied in the analysis of the test questions to determine which taxonomy categories are used to assess students' learning outcomes. Specifically, this study seeks to answer the following research questions:

1. To what extent do the examination questions correspond to the classification in the revised Bloom's Taxonomy?
2. To what extent do different science disciplines appear in the examination test?
3. How is inquiry incorporated into the examination questions?

METHODOLOGY

Context of the Study

The integrated science curriculum in Ghana has been compartmentalized into a syllabus covering basic grades 7–9 of the junior high school education (JHS). The general aims of Ghana's JHS science curriculum require assisting pupils to:

- Develop a scientific way of life through curiosity and investigative habits
- Appreciate the interrelationship between science and other disciplines
- Use scientific concepts and principles to solve problems of life
- Effective use of basic scientific apparatuses, materials, and appliances
- Act appropriately for maintaining machinery and appliances used in everyday life
- Acquire the ability to assess and interpret scientific information and make inferences
- Recognize the vulnerability of the natural environment and take measures for managing the environment in a sustainable manner
- Appreciate the importance of energy to living and non-living things and adopt conservation methods to optimize energy sources
- Take preventive measures against common tropical

Table 1: The revised Bloom's Taxonomy and classification of cognitive process skills in inquiry-based science learning (modified Anderson and Krathwohl, 2001; Krathwoh, 2002)

Revised Bloom's taxonomy	Cognitive process skills in inquiry-based science learning	Example
Remember	Remember or recall scientific terminology, facts, definitions	Write down the steps of the scientific method, identification of different symbols
Understand	Demonstrate comprehension of scientific concepts by explaining ideas in own words, interpreting data, grasp the meaning of scientific concepts and principles, classification	Explain the relationship between variables in a scientific experiment, create visual representations to demonstrate understanding of key scientific idea
Apply	Use acquired scientific knowledge to solve problems, apply concepts to new situations	Design simple scientific experiments, solve scientific problems, apply concepts to explain natural phenomena
Analyze	Break down information into parts, identify patterns, and make connections between scientific concepts	Analyze data from experiments, interpret graphs, identify cause-and-effect relationships in scientific phenomena, write a research report
Evaluate	Make judgments based on criteria and evidence, assess the validity of scientific arguments, assess the validity of scientific information	Evaluate the reliability of data, review scientific articles, evaluate the reliability of data, assess the strengths and weaknesses of experimental procedures
Create	Generate new ideas, designs, solutions, create models in the context of scientific inquiry	Design a controlled experiment to test a hypothesis, self-contained essay-report

diseases
- Live a healthy lifestyle (Ministry of Education, Science and Sports, 2007).

The curriculum for each year is organized into five themes: diversity of matter, cycles, systems, energy, and interactions of matter. Since 1998, the objectives to be achieved have been stated based on profile dimensions which describe the different learning behaviors. These dimensions are used for teaching, learning and assessment (testing). The syllabus gives the following weights for each dimension: knowledge and comprehension (20%), application of knowledge (40%) and experimental and process skills (40%). Application of knowledge is subdivided into application, analysis, synthesis, and evaluation. Experimental skills involve the inquiry or investigative process for planning and designing and carrying out experiments and the ability to observe closely occurrences to identify the causes and effects of phenomena and to practically develop solutions to problems. Process skills include demonstrating the ability to manipulate tools, machines, and equipment for solving problems as well as a process of observing, classifying, drawing, measuring, recording, interpreting and reporting, and finally, proficiency in expected scientific conduct in the laboratory. The final assessment for students completing junior high school consists of 30% formative assessment, called school-based assessment, while the remaining 70% comes from the external examination conducted by the West African Examinations Council (WAEC) (Ministry of Education, Science and Sports, 2007).

Study Material

For this study, Integrated Science questions prepared by the West African Examinations Council to assess students completing JHS were examined. The BECE is primarily organized to evaluate students' performance in subjects studied at the JHS level to establish whether they qualify to pursue senior secondary education. Students' raw scores are also used for school and program placement. Students with higher raw scores usually get their preferred school and subject area of choice compared to those with lower raw scores. Each year, 40 multiple-choice questions (MCQ) and six open-ended questions (OEQ) are provided for the examination. OEQs are usually further divided into sub-questions. Students are required to answer all MCQs and five questions from the OEQ Question, one of the OEQ is compulsory and must be answered by all students. Questions from 2010 to 2017 were used for the study.

Data Analysis

The analysis utilized the revised version of Bloom's Taxonomy (Anderson and Krathwohl, 2001) and employed content analysis to examine the questions (see Krippendorff, 2019). The analysis was based on two factors: "verbs," which refer to the intended cognitive process, and the "contextual meaning" of the question. Questions without action verbs were analyzed by reading the entire text. Test items were classified through a thorough reading of the questions, and based on their contextual meaning, they were assigned to the appropriate taxonomy levels.

To increase the reliability of the research, two analyzers were assigned to classify the questions for the study. First, one of the authors (first analyzer) reviewed 20% of the questions, after which both analyzers met and agreed to use the two factors for the analysis. Then, both analyzers individually analyzed all 320 MCQs and 431 OEQs by assigning them to the appropriate taxonomy levels. The cognitive process dimension of RBT includes remembering, understanding, applying, analyzing, evaluating, and creating categories.

Both analyzers then met to reconcile the analyzed results. Differences were sorted out and one consensual result was fanalized and adopted for the study. Similarly, both analyzers individually classified test items into agreed identifiable science disciplines: biology, physics, chemistry, agriculture and environmental science, health-related, and multidisciplinary questions. By multidisciplinary questions, we mean those questions which solicit ideas from two or more science disciplines. Questions under each discipline were then classified into their respective RBT levels. For example, we chose health science as a discipline to ascertain the extent to which questions address common diseases that confront students, as stipulated in the syllabus. The questions were then categorized into disciplines to ascertain the distribution of the questions across the various disciplines. Analyzers met afterwards to reconcile the results.

In addition, both analyzers identified all inquiry-based questions from the test and grouped them into the various RBT levels. The analysis of inquiry-based questions was conducted by first identifying all questions that engage scientific inquiry. These questions are based on the idea that students can draw conclusions based on evidence, analyze data, describe observations or phenomena, and compare different sets of data or experimental results. We also analyzed the frequency of each type of inquiry-based question in the test. The classification of inquiry questions also incorporated the principles of RBT using verbs such as remembering, analyzing, and others. Finally, we identified the various disciplines of the inquiry-based questions.

We focused on the cognitive level because classification includes all crucial science skills (c.f. Hasanah and Shimizu, 2020; Jideani and Jideani, 2012). An overview of the cognitive process dimension in RBT with descriptions of the various levels and applications is shown in Table 2 with examples of the Ghana's BECE science questions.

According to Han (2013), cognitive skills are closely related to students' total ability to learn. However, the cognitive skills of many students in Ghana and other African countries fall below global mean estimates (Han, 2013). Cognitive skills can also assist students in knowledge construction, assumptions, competence, and the ability to decipher problems and communicate findings. Some researchers have opined that cognitive skills are linked to each other, either directly and/or indirectly (Lawson, 1995; Özgelen, 2012). Cognitive skills are key predictors of academic achievement and well-being in adulthood (Nunoo et al., 2023). Cognitive process skills offer a more holistic and practical approach to learning and assessment. In today's rapidly changing world, where information is easily accessible, the ability to apply knowledge effectively is important. By focusing on cognitive process

Table 2: The examples of Basic Education Certificate Examination (BECE) questions analyzed under the revised Bloom's Taxonomy during the years 2010–2017

Taxonomy level	Description of the taxonomy	Example of test questions
Lower-order thinking		
1. Remembering	Retrieving, recognizing, and recalling relevant knowledge from long-term memory. It involves recognizing and recalling.	Name four farming systems used in crop production (BECE, 2017).
2. Understanding	Constructing meaning from oral, written, and graphic messages through interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining.	Write the systematic name for each of the following compounds (BECE, 2016): (i) H_2O (ii) MgO (iii) CaO (iv) $CaCl_2$
3. Applying	Carrying out or using a procedure through executing or implementing.	Write and balance each of the following chemical equations (BECE, 2012): (i) $Fe + O_2 \rightarrow Fe_2O_3$; (ii) $Na + Cl_2 \rightarrow NaCl$; (iii) $H_2 + O_2 \rightarrow H_2O$
Higher-order thinking		
4. Analysing	Breaking materials into constituent parts, determining how the parts relates to one another and to overall structure or purpose through differentiating, organizing, or attributing.	An atom Y has atomic number 12. It loses two electrons in order to be stable (BECE, 2017). (i) State the proton number of the atom before it loses electrons. (ii) State the electron number of the atom: a. Before it loses electrons. b. After losing electrons. (iii) Name the type of ion formed by the atom when it loses two electrons.
5. Evaluating	Making judgments based on criteria and standards through checking and critiquing.	Using litmus paper, explain why water is neutral (BECE, 2015).
6. Creating	Putting together elements to form a coherent or functional whole; reorganizing elements into a new pattern or structure through generating, planning, or producing. In the questions under review, no creating questions were identified.	No example.

skills, education can better prepare students for the challenges; they will face in their personal and professional lives. The accuracy of classification between analyzers was remarkably high as we almost agreed on all taxonomy levels and inquiry-based items among questions.

FINDINGS

Questions in Cognitive Process Dimension

Levels of questions based on revised Bloom's Taxonomy (RBT) are shown in Figures 1 and 2. MCQ over the 8-year period under review were dominated by remembering and understanding questions contributing 209 (65%) questions. A comparable situation was found in the OEQ. In 2016, for instance, all test questions from both MCQ and OEQ contained only remembering and understanding. In addition, remembering and understanding were the only levels covered in the 2015 to 2017 in the MCQ. Figures 1 and 2 show the taxonomy level of questions in MCQ and OEQ, respectively.

In 2016, remembering alone accounted for 83% of the questions with understanding representing the remaining questions (18%). Four (10%) analyzing questions appeared in the 2011 MCQ, the highest in the period reviewed. There is a slight difference between the results obtained from MCQ and OEQ. In both MCQ and OEQ, none of the years under review covered all the levels of the taxonomy. From 2010–2012, four taxonomy levels were covered in MCQ. In 2010 and 2011, tests had questions on remembering, understanding, applying, and analyzing. The only evaluating question in MCQ was in 2014. Like MCQ, in OEQ 349 out of 431 questions were remembering (80%). There were 40 (12%) understanding questions. Applying and evaluating had the least number of test items with 8 (2%) and 7 (2%), respectively. There were 15 (3%) analyzing questions. In addition, there were 47 (96%) remembering and 2 (4%) understanding questions in 2016 OEQ and none of the questions covered the remaining levels of the revised taxonomy. The highest number of evaluating questions, 3 (5%), were asked in 2012. In 2010 and 2011, none of the test items represented applying and evaluating in OEQ.

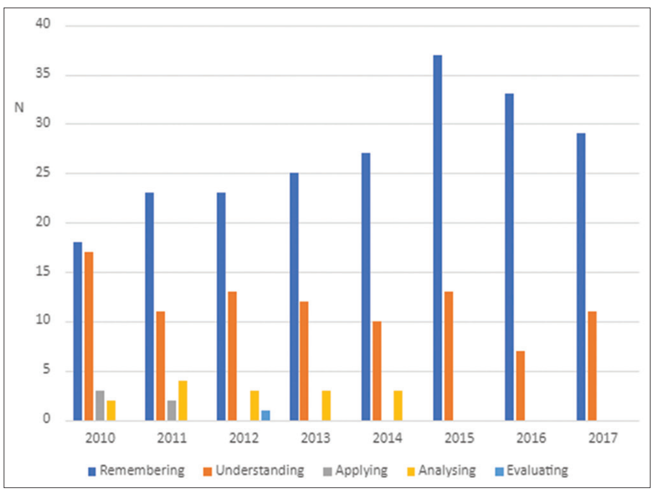

Figure 1: Revised Bloom's Taxonomy levels of multiple-choice questions for the Basic Education Certificate Examination in Ghana during years 2010–2017

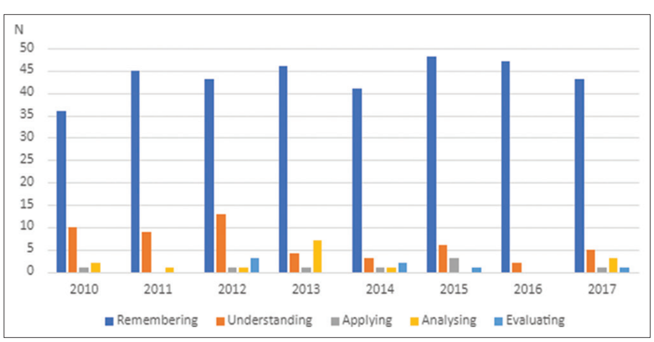

Figure 2: Revised Bloom's Taxonomy levels of open-ended questions for the Basic Education Certificate Examination in Ghana during years 2010–2017

Questions in the Various Science Disciplines

In identifying the proportion of questions in various disciplines, we categorized them under the disciplines: biology, physics, chemistry, agriculture and environmental science, health science, and multidisciplinary. Figure 3 shows the distribution of questions across various disciplines in MCQ over the review period. Figure 4 shows the distribution of questions across disciplines in OEQ over the review period.

The finding depicts an average distribution of questions across four disciplines in both MCQ and OEQ — biology, physics, chemistry, and agriculture and environmental science — with each taking an over 20% proportion of the distribution. Most of the MCQ were physics-related (26%). Consequently, health science and multidisciplinary science questions were fewer over the period, accounting for 9 (3%) and 10 (3%) questions, respectively. In 2010 and 2017, none of the questions focused on health science. Similarly, in 2013 and 2017, questions representing multiple disciplines failed to appear; however, all other disciplines were covered.

Out of the 431 OEQ questions, 117 (27%) were related to chemistry, while biology and physics questions amounted to 95 (22%) each. Agriculture and environmental science questions amounted to 94 in the examination. In 2011, a greater proportion (17) of questions belonged to chemistry while none of the questions originated from either health or multidisciplinary science. There were no questions on health science in 2011, 2013, 2015, and 2017 in OEQ. It can also be observed that a total of 18 items were health-related in both MCQ and OEQ within the period reviewed. Table 3 shows the level of multiple-choice questions in different disciplines.

Results show that remembering and understanding dominated over the review period across all disciplines in MCQ. A total of 209 (65%) questions were remembering while 90 (28%) were understanding. Analyzing and applying shared small proportions of the questions with 15 (5%) and 5 (2%), respectively. There was a single question on evaluating in the test questions. Biology, physics,

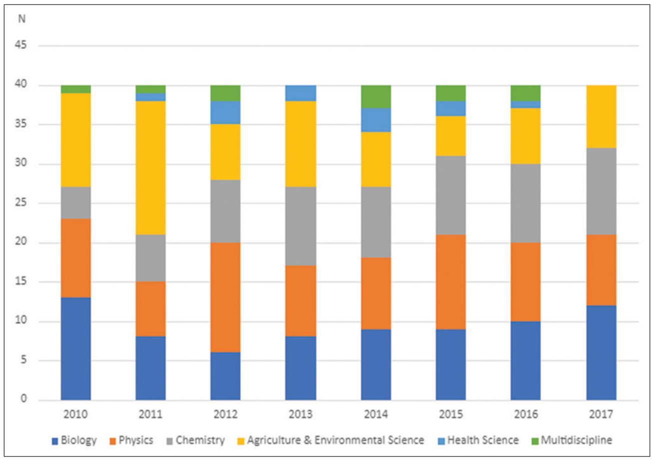

Figure 3: Multiple-choice questions distribution across identified disciplines of the Basic Education Certificate Examination of Ghana within the years 2010–2017

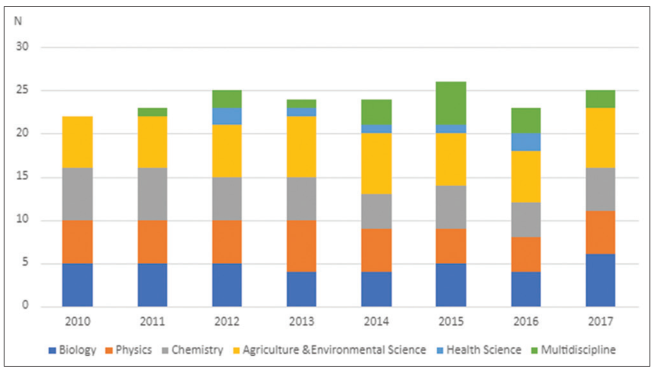

Figure 4: Distribution of open-ended questions across disciplines of the Basic Education Certificate Examination of Ghana within the years 2010–2017

agriculture, and environmental science contained more remembering questions with 58, 51, and 50, respectively. There were 39 questions belonging to chemistry. However, health and multidiscipline questions had the least shares of the questions. There were only 6 (3%) questions on health science and 5 (2%) multidiscipline questions. Results also revealed that physics, biology, chemistry, and agriculture and environmental science shared a substantial part (94%) of the questions. While 82 questions were drawn from physics, there were 69 (22%) questions drawn from chemistry, with biology and agriculture and environmental science contributing 78 (24%) and 72, respectively. Health and multidiscipline questions remained underrepresented with 9 and 10 test items. Table 4 shows the level of OEQ in different disciplines.

A substantial proportion of the OEQ was remembering and mostly from biology, physics, chemistry, and agriculture and environmental science. There were 117 (27%) questions drawn from chemistry, 96 and 95 from biology and physics, respectively, while 94 originated from agriculture and environmental studies. Twenty-two questions were multidisciplinary in nature while 8 were health related. Out of 431 test items in the questions, 345 (80%) belonged to the lowest taxonomy level remembering, while 40 (9%) items were understanding. Applying, analyzing, and evaluating, respectively, were, however, rarely seen with 15, 18, and 13 questions. Six evaluating questions were from physics while there were none for health and multidisciplinary science. Two examples of the health-related and multidisciplinary science questions from the OEQ of 2014 and 2017 examinations, respectively, are shown below in Table 5.

Table 3: Revised Bloom's Taxonomy as applied in multiple-choice questions of Ghana's the Basic Education Certificate Examination (BECE) in 2010–2017 in various disciplines

Discipline	L1, N/%	L2, N/%	L3, N/%	L4, N/%	L5, N/%	Total, N/%
Biology	58/28	18/23	1/1	1/1	0/0	78/24
Physics	51/24	23/28	1/1	7/9	0/0	82/26
Chemistry	39/19	25/36	1/1	—	1/1	69/22
Agriculture and Environmental	50/24	18/25	2/3	2/3	0/0	72/22
Health Science	6/3	2/22	0/0	1/11	0/0	9/3
Multidiscipline	5/2	4/40	0/0	1/10	0/0	10/3
Total	209/65	90/28	5/1	15/5	1/1	320/100

L1: Remembering, L2: Understanding, L3: Applying, L4: Analysing, L5: Evaluating)

Table 4: Revised Bloom's Taxonomy as applied in open-ended questions of Ghana's the Basic Education Certificate Examination in 2010–2017 in various discipline

Discipline	L1, N/%	L2, N/%	L3, N/%	L4, N/%	L5, N/%	Total, N/%
Biology	81/84	6/6	4/4	3/3	2/2	96/22
Physics	72/76	8/8	5/5	4/4	6/6	95/22
Chemistry	84/72	18/15	2/2	11/9	2/2	117/27
Agriculture and Environmental	82/87	8/9	1/1	0/0	3/3	94/22
Health Science	8/100	0/0	0/0	0/0	0/0	8/2
Multidiscipline	19/86	0/0	3/14	0/0	0/0	22/5
Total	345/80	40/9	15/4	18/4	13/3	431/100

L1: Remembering, L2: Understanding, L3: Applying, L4: Analysing, L5: Evaluating

Inquiry-Based Questions

Inquiry-based questions in BECE Science tests, revised Bloom's Taxonomy Levels and disciplines covered are shown in Table 6. A total of 62 inquiry-based questions were asked within the review period. This constitutes 8.3% of total questions asked within the review period. Majority of the inquiry-based questions were understanding questions (27) while evaluating questions counted for only three questions. Remembering questions and applying questions each contributed 11 questions to the pool. In year 2012, there was the higher levels of questions: analyzing (2) and evaluating (3). In year 2013 contributed the highest number of question (15) while four questions each were asked in 2014 and 2015. In general, Chemistry, Physics, and Agriculture and Environmental science questions appeared most in the years under review while Biology appeared once within the period. Multidisciplinary questions were not featured in the questions. While questions on chemistry appeared in five of the 7 years, Agriculture and Environmental Science appeared in three of the years.

Inquiry-based questions in BECE focus on terminology, definitions, basic principles and concepts related to the scientific topic and discipline. Remembering and understanding questions focus primarily on content knowledge but also

Table 5: Examples of health-related and multidisciplinary science questions from open-ended questions (OEQ) of 2017 in the Basic Education Certificate Examination (BECE) in Ghana

Discipline	Example of test questions
Health-related	(i) Name two diseases associated with the circulatory system of humans
	(ii) State one way of preventing each of diseases named in (i). (BECE, 2017)
Multidisciplinary	(i) State two steps used by scientists in doing their work
	(ii) Give two subjects that may be considered as applied sciences
	Give one example of chemical used in:
	(i) Medicine
	(ii) Agriculture
	(iii) Industry
	(BECE, 2017)

Table 6: Inquiry-based questions categorized based on revised Blooms' Taxonomy

Year	Number of inquiry-based questions	Number of revised Bloom's Taxonomy levels in questions	Disciplines
2010	7	Remembering 2 Understanding 2 Applying 1 Analyzing 2	Physics and Chemistry
2011	7	Understanding 4 Applying 3	Physics
2012	7	Understanding 2 Analyzing 2 Evaluating 3	Physics
2013	15	Remembering 4 Understanding 7 Applying 2 Analyzing 2	Biology, Chemistry, Agriculture and Environmental science
2014	4	Remembering 1 Understanding 1 Analyzing 2	Chemistry
2015	4	Remembering 2 Understanding1 Applying 1	Chemistry
2016	6	Understanding3 Applying 3	Agriculture and Environmental science
2017	12	Remembering 3 Understanding 7 Applying 1 Analyzing 1	Physics, Chemistry, Agriculture and Environmental science
Total	62		

(b) In an experiment, red and blue litmus papers were dipped separately into three test tubes each containing one of the test substances listed in the table below.

Test substances	***Observations***		***Conclusion***
	Red litmus paper	***Blue litmus paper***	
Lemon juice			
Calcium hydroxide solution			
Dilute hydrochloric acid			

(i) Copy and complete the table by making the necessary observation and conclusion for each substance.

(ii) Name two of the test substances that would react with each other to produce salt and water.

(iii) Write down a balanced chemical equation for the reaction in (ii) above.

Figure 5: An example of inquiry-based question from 2010 Basic Education Certificate Examination (BECE, 2010).

process skills such as observation, data interpretation, and critical thinking within the inquiry framework. While questions cut across remembering, understanding, applying, analyzing, and evaluating, a sizable number of them were low order thinking questions. Figure 5 is an example of inquiry question in the examination.

DISCUSSION AND CONCLUSIONS

The purpose of this study was to analyze multiple-choice (MCQ) and open-ended (OEQ) question of integrated science for the BECE in Ghana using the revised Bloom's Taxonomy. The additional aim of this study was to analyze how the test questions are distributed across the various science disciplines and the role of inquiry-based questions. The main results are discussed to highlight several implications for science education in the context of assessment.

The first important result is the greater proportions of questions related to remembering and understanding. Test questions did not at all cover creating new knowledge or combinations. These results are in line with previous results, for example, with the analysis of geography and life sciences curriculum in Europe (Bozdemir et al., 2019; Büken and Artvinli, 2021). The lack of higher-order questions is not only a curriculum problem. The dominance of the lower-order questions was similar with that found also in recent analysis of reading comprehension questions (Laila and Fitriyah, 2022; Ulum, 2022;), in the textbook's content (Rustiyani et al., 2021) as well as science test questions (Kepceoglu and Pektaş, 2023). The yearly decrease in the application of higher-order questions is notable and raises concern about the acquisition of higher-order thinking skills of students, as such questions consistently direct students to think critically and systematically (c.f., Setyowati et al., 2022). The decrease in higher-order questions contrasts with previous results where the aim was to develop higher-order thinking skills which help students to meet the challenges of the 21st century (Chu et al., 2017; Pujawan et al., 2022). However, the results show that the science performance test included MCQ as well as OEQ, which is in line with the PISA and TIMMS science tests (cf. Mullis and Martin, 2017; OECD, 2021; 2023).

The second important result is that the proportions of questions in the fields of agriculture and environmental science, as well as in the natural sciences (biology, physics, and chemistry) were quite the same, and there were fewer health-related questions and multidisciplinary science questions. The high proportion of the test questions originating from the natural sciences could be attributed to the importance attached to the natural sciences in the curriculum. A student who wants to study science at senior high school must pass integrated science with a high-test score. With the aid of multidisciplinary questions in the test, it is possible to prepare students for the postmodern risk society and solve many controversial social issues related to science e.g., (e.g., Sadler and Dawson, 2012). Those issues are also open-ended problems which have multiple solutions.

The proportion of test questions relating to agriculture and environmental science confirms that agriculture plays a leading role in Ghana's development as it employs about 65% of the population. The minimal representation of health-related questions could be improved to create awareness among students about the high prevalence rate of diseases, as prescribed in the curriculum. We advocate for an increase in the proportion of health questions to align with the curriculum's aims. In this study, we also identified a misalignment between the assessment criteria prescribed in the integrated science syllabus and the BECE integrated science questions. The questioning style could be reconsidered to highlight application, analysing, evaluating, and creating level questions (Hasanah and Shimizu, 2020).

In literature, examination questions have been analyzed in different contexts. This study focused on integrated science in Ghana in eight subsequent years and thus the results are important in the African science education context. The present study shows a similar tendency of a high proportion of lower-level questions like in the science discipline in Uganda (see Mitana et al., 2018). There was an imbalance between both lower- and higher-order thinking and all levels of taxonomy in a proportionate manner which could help students gain higher-order thinking skills (Hilmi et al., 2022). The results are also important in discussion of the test digitalization, as well as other educational challenges in Ghana (Nunoo et al., 2023). Ghana is steadily making progress in its efforts to revolutionize its digitalization in education. It has provided internet accessibility to all public universities and in most public secondary schools. At the lower secondary and primary levels, however, many schools, especially those in the rural areas, lack internet facilities and basic Information and Communications Technology infrastructure to participate fully in digitalisation (Ayakwah et al., 2021). It may take some time to get all schools aboard. Digitalisation could reduce questions that require remembering while increasing questions that require analysing (Virranmäki et al., 2020). In BECE, the test questions were MCQ and OEQ. More comprehensive use and more extensive production of materials would be beneficial for testing, as Virranmäki et al. (2020) suggest.

The number of inquiry questions in the BECE was quite small but the trend in the tests looks positive: In 2016 and 2017, test questions on inquiry increased compared to the previous years and they cover several disciplines. By the aid of inquiry questions, it is possible to assess students' conceptual understanding, for example, about key scientific concepts, the scientific method, the basic laws of physics, the principles of chemistry, or biological processes as well as assess students' ability to think critically and solve problems (cf. Anderson and Krathwohl, 2001; Krathwohl, 2002; Sotáková et al., 2020). Inquiry questions in the test could include more scenarios or experimental setups that require students to apply their scientific knowledge to analyze data, make predictions, propose solutions to scientific problems, and draw conclusions.

In this study, revised Bloom's Taxonomy (RBT) was a useful and suitable classification system as with previous studies (c.f. Krathwohl, 2002; Seaman, 2011; Sobral, 2021). It is important to develop the determination criteria for lower order and higher order thinking skills based on both the cognitive and knowledge dimensions of RBT as, Poluakan et al. (2019) have suggested. In this study, we only examined the cognitive level, and thus, further research is required on the knowledge dimensions. Categorizing the test questions was challenging due to the hierarchical nature and the overlapping behavior of the taxonomy (e.g., Lalwani and Agrawal, 2018). In this study, the interpretation of verbs and contextual meaning of questions were only indicative, and further research is therefore recommended. Further, the decision to only analyze the cognitive level was made with the future in mind, thus, for example, inquiry-based science skills will help determine more detailed classifications. The validity of research results was based on data analysis of two different researchers to increase confidence in the research data. The plausibility and integrity of the research was clearly exemplified by the analysis of integrated science test questions in different years.

The findings suggest that the tests include various question types and knowledge, however, most of the test questions emphasis lower order thinking skills. The study covers eight consecutive years of examination questions in integrated science and the proportion of higher-level questions remained fewer during this period. It is important that MCQ and OEQ are at levels such that students can answer these questions correctly; thus, the roles of remembering and understanding question types are also important. Nevertheless, there is also a need for more higher level questions.

To improve the ability of science tests to guide and evaluate learning, questions could move beyond asking students to simply recall facts to include case studies that require them to identify underlying issues and relationships. For example: "Analyze the factors contributing to the decline in biodiversity in the given ecosystem." To effectively visualize the factors contributing to the decline in biodiversity, science tests can utilize various types of graphs and charts. Key factors to consider include invasive species, climate change, pollution, and habitat loss. To promote evaluation, science test questions could ask students to compare different theories or viewpoints and justify their reasoning. For example: "Evaluate the effectiveness of two different catalysts in speeding up a chemical reaction and argue which one is more efficient." Test questions can include the definition of catalysts. In addition, tables with experimental data showing reaction rates with different catalysts, including reaction time and temperature, can be provided. Test questions can also incorporate comparison criteria such as environmental impact or ease of use. The science test could include questions that require students to develop innovative solutions or products. An example could be: "Design a new eco-friendly product using old jeans." The task could include background materials such as articles or videos on the environmental impact of textile waste and the benefits of recycling. In addition, background data could include surveys or reports on consumer preferences for eco-friendly products.

The inclusion of inquiry-based questions can be encouraged. Further, it would be beneficial to increase multidisciplinary science questions and health-related questions in science tests. More multidisciplinary questions will promote a positive transfer of learning across different scientific disciplines. Finally, national assessment can be linked to international assessment (e.g., PISA and TIMMS) to broaden the comparability of science test questions and give suggestions for the best science practices. Digitalization of science tests could also be considered as infrastructure continues to improve.

AUTHOR CONTRIBUTIONS

Conceptualization, S.A., S.K., and T.K.; methodology, S.A, S.K., and T.K.; validation, S.A. and S.K.; formal analysis, S.A. and S.K; writing—original draft preparation, S.A.; writing—review and editing, S.A, S.K., and T.K.; visualization, S.A.; supervision, S.K. and T.K. All authors have read and agreed to the published version of the manuscript.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article.

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