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**Research Artikel**

# AN ANALYSIS OF CHEMISTRY HIGH SCHOOL END-OF-YEAR EXAMS ACCORDING TO BLOOM'S COGNITIVE COMPLEXITY

## *ANALISIS UJIAN AKHIR KIMIA BERDASARKAN KOMPLEKSITAS KOGNITIF TAKSONOMI BLOOM*

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***Abstract***

*School exams has been used by teachers to determine the success of students' learning. This research is aimed to determine the extent of students learning through an analysis of end-of-year exam items based on Bloom's cognitive complexity. The exam instruments are gathered from chemistry teachers of 5 public schools, consisting of in total 190 5-multiple-choice items. Qualitative approach and theory-driven content analysis method using Bloom's revised taxonomy of cognitive complexity were employed in the research. The result of this research showed that the majority of items (82.7%) determined students learning lower order cognitive skills (remember, understand, and apply). Skill of the analysis is the only higher order cognitive skill that has been found in the exam questions (17.3%). With regards to knowledge dimension, it was found that conceptual knowledge weighed the most among other dimensions (54.7%). It is interesting to see, however, that, the highest procedural knowledge was seen in the application skills (27.9%). This research suggests that chemistry teachers need to carefully determine exam questions according to the cognitive complexity in order to ensure the extent of students learning. For curriculum developer, this research can be used to consider the depth of students' learning outcomes as they serve as the foundation for exam development. Further research can be done to determine the gap between the exams and the expected learning outcomes. This will be beneficial to understand the extent to which schools can go higher than the minimun learning outcomes determined by the government.*

***Keywords****: Bloom's revised taxonomy, cognitive complexity, chemistry exam, chemistry learning, knowledge dimension*

**Abstrak**

Ujian sekolah telah digunakan oleh guru untuk menentukan keberhasilan belajar siswa. Penelitian ini bertujuan untuk mengetahui sejauh mana siswa belajar kimia melalui analisis materi ujian akhir sekolah berdasarkan kompleksitas kognitif Bloom. Instrumen ujian dikumpulkan dari 5 sekolah umum, yang terdiri dari 190 item soal pilihan ganda. Pendekatan kualitatif dan metode analisis isi yang digerakkan oleh teori menggunakan taksonomi kompleksitas kognitif Bloom yang telah direvisi digunakan dalam penelitian ini. Hasil penelitian menunjukkan bahwa sebagian besar soal (82,7%) merupakan soal-soal dengan tingkat kognitif rendah (mengingat, memahami, dan menerapkan). Keterampilan analisis adalah satu-satunya keterampilan kognitif tingkat tinggi yang ditemukan dalam soal-soal ujian (17,3%). Untuk dimensi pengetahuan, ditemukan bahwa pengetahuan konseptual paling banyak di antara dimensi lainnya (54,7%). Menarik untuk dilihat, bagaimanapun, bahwa pengetahuan prosedural tertinggi terlihat pada keterampilan aplikasi (27,9%). Penelitian ini menyarankan guru untuk mempertimbangkan kompleksitas kognitif untuk memastikan sejauh mana siswa belajar.

**Kata Kunci**: Bloom Revisi, Kompleksitas Kognitif, Ujian akhir kimia, pembelajaran kimia, dimensi pengetahuan.

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**INTRODUCTION**

Exam serves as a tool to assess how far students have learnt. The curriculum's learning outcome is used as the foundation to determine teachers' instruction (Davis et al., 2016) and further to develop exam items. Therefore, analyzing exam items is necessary to ensure that the exam items determine the learning outcomes and the exam results describe how far students have learnt accordingly (Chandio, 2021).

Chemistry curriculum in the Indonesian context has not been significantly changed over the past 10 years. Chemistry is often seen as a correct explanation in which students are obliged to master the concepts and theories of chemistry and no to be critical as to how the concepts and theories being implemented in real context (Roberts & Lederman, 1982). The attained curriculum or curriculum that has been seen from the perspective of students' learning was found to make students develop knowledge of science as a ladder of learning where learning science now is the preparation for learning science next. While this perspective seems right, such preparation weight most on the understanding theories rather than putting them in real context (Agung, 2013).

It is therefore chemistry has been considered as a difficult subject according to students, especially in Indonesia. Learning chemistry may not be favored by students even though those who are in the science program. Teachers are put into two difficult positions of being obey with the curriculum in which learning is directed to pass the end-of-year exam that emphasizes on understanding theories or taking out students to real life context to have direct learning experience as suggested by the global teaching paradigm. In this challenging situation, teachers however are still trying to find ways on teaching chemistry in order to develop students' enthusiasm and motivation, while at the same time ensuring that students achieve the intended learning objectives.

Assessing students' learning chemistry is not an easy task (Knaus, Murphy, Blecking, & Holme, 2011), particularly because the assessment requires the balance of cognitive complexity. Bloom defines a hierarchical level of cognitive complexity when talking about learning assessment. The complexity comes from basic knowledge and comprehension to advanced evaluation. There are six level of cognitive abilities, namely, knowledge, understanding, application, analysis, synthesis, and evaluation. The levels have a hierarchical nature, meaning that every higher level presupposes the presence of the lower levels.

Based on the need to combine the categorization of educational goals with new knowledge and thinking, Anderson and Krathwohl reformed Bloom's Taxonomy by separating the knowledge dimension from the cognitive process dimension, which was later known as the Revised Taxonomy (Krathwohl, 2002).

The knowledge dimension consists of factual knowledge, conceptual knowledge, procedural knowledge, and metacognitive knowledge. While the dimensions of cognitive processes consist of remembering, understanding, applying, analyzing, evaluating, and creating.

For the purpose of chemistry learning, Tikkanen & Aksela (2012) have determined both knowledge and cognitive processes dimension as seen in Table 1 and Table 2.

Table 1. The knowledge dimension of Bloom's revised taxonomy applied in chemistry learning

| Category | Definition | Examples |
|---|---|---|
| Factual Knowledge | Knowledge of terminology, specific details and elements | Symbolic language of chemistry<br>Names of famous scientist<br>Dates of historical chemical innovations |
| Conceptual knowledge | Knowledge of classification, categories, principles, generalisation, theories, models and structures | Periodic table of elements<br>Le Chateliers principles<br>Atomic theory |
| Procedural knowledge | Knowledge of subject-specific skills, algorithms, techniques, methods and criteria for determining when to use appropriate procedures | Laboratory skills<br>Chemical investigation methods<br>Mathematical operations in quantitative chemistry problems |

| | | |
|---|---|---|
| Metacognitive knowledge | Knowledge of cognition in general as well as awareness and knowledge of one's own cognition | Test strategies<br>Student's own strength and weaknesses |

(e.g. Anderson & Krathwohl, 2001; Tikkanen & Aksela, 2012).

Table 2 The Cognitive process dimension of Bloom's revised taxonomy applied in chemistry learning

| Category | Definition | Examples |
|---|---|---|
| Remember | Retrieve relevant knowledge from long-term memory (recognizing, recalling) | Recognizing the symbols of chemical elements<br>Recalling the dates of historical chemical innovations |
| Understand | Construct meaning from instructional messages. Including oral, written, and graphic communication (interpreting, exemplifying, classifying summarizing, inferring, comparing, explaining) | Paraphrasing chemical concepts<br>Giving an example of an organic compound<br>Classifying carbohydrates into mono-, di- and polysaccharides<br>Summarizing an article<br>Inferring a molecular structure of an organic compound<br>Comparing elements of the periodic table<br>Explaining the direction of an equilibrium reaction |
| Apply | Carry out or use a procedure in a given situation (executing, implementing) | Distillation<br>Using the ideal gas law in applicable situations |
| Analyze | Break material into its constituent parts and determine how the parts relate to one another and to the overall structure or purpose (differentiating, organizing, attributing) | Identifying the essential elements of a problem<br>Analysing a chemistry research report<br>Noticing the attitude of the author of a chemistry article |
| Evaluate | Make judgments based on criteria and standards (checking, critiquing) | Checking the reasonableness of the situation<br>Critiquing of different chemical methods |
| Create | Put elements together to form a coherent or functional whole; reorganize elements into a new pattern or structure (generating, planning, producing) | Generating a hypothesis<br>Planning a chemical method<br>Writing a chemistry essay |

(e.g. Anderson & Krathwohl, 2001; Tikkanen & Aksela, 2012).

Both knowledge and cognitive processes dimension was presented in a taxonomy table in order to explain the extent of students' learning (Anderson & Krathwohl, 2001). The above Bloom's revised taxonomy has been widely used for variety of reasons from determining educational objectives (Arievitch, 2020), learning process (Lin, Hou, Wang, & Chang, 2013), textbooks (Davila & Talanquer, 2010), and educational assessment (Assaly & Smadi, 2015; Chandio, 2021; Tiemeier, Stacy, & Burke, 2011; Tikkanen & Aksela, 2012).

With regards to the assessment, research by Davila & Talanquer (2010) was interesting in a sense that it focused on the end-of-chapter questions on textbooks. They found that most of the questions was found to be in the application dimension (41.3%) in which items on the quantitative problem solving weighed more (58.1%) than the qualitative ones (41.9%). Of all the six level of Bloom Taxonomy, items on the synthesis have no place in any textbooks in the United States. Evaluation, however, was evidence to be in the books with the lowest percentage of all (2.88%). Their research suggests that knowing the composition of the cognitive dimension in the textbooks will help teachers to determine students' practices and assessment.

Research by Tikkanen & Aksela (2012) has been closely related to the current study. They determine Finnish chemistry matriculation examination questions using cognitive complexity of Bloom Taxonomy. Analysing exams of 1996 up to 2009, their research found that the majority of the questions in the exams felt under the higher-order thinking skills (77%), with the highest percentage of cognitive skill was in the analysis (35%). It was also found that while in the higher order thinking skills, the majority of the questions required procedural knowledge (69%). The results indicate that Finnish chemistry matriculation examination are cognitively demanding and thus understanding cognitive complexity is essential prior to develop the exam items in order to ensure the fair spread of cognitive skills in the exam items.

Assessing students' learning using cognitive theory of Bloom Taxonomy has also been conducted by many Indonesian scholars (Rahayu &

Sutrisno, 2019; Setyowati & Sutrisno, 2020; Widarti, Herunata, Sulistina, Habiddin, & Nadhifah, 2020).

A research by Rahayu & Sutrisno (2019), for example, tried to determine the effect of chemistry learning on higher order thinking skills in the equilibrium concepts using analogy and non-analogy. The research used Bloom Taxonomy in order to determine the higher order thinking skills within the concept. Results of the research found that students using analogy possess better attainment in the higher order thinking skills that those not using the analogy.

Bloom taxonomy has also been used to analyse a chapter on chemical bonding in Indonesian textbooks (Setyowati & Sutrisno, 2020). The research revealed that the majority skills contained in the Indonesian textbooks were at lower order thinking (remembering, understanding, and applying). The only higher order thinking skill that was found in the books is the analysis. Yet, the percentage of this skill was considered very low.

The concept of Bloom taxonomy is also used by Widarti et al., (2020) to determine teachers' knowledge on the Higher Order Thinking Skills (HOTS). As much as forty one chemistry teachers believed that their exams have included HOTS type of questions. Wasis, Sukarmin, & Prastiwi (2017) on the other hand found that questions in Indonesian national exam put the emphases on the first two cognitive level of Bloom's, namely, remembering and understanding. This was found to be different from questions in Program for International Student Assessment (PISA) in which the three level of higher order thinking, i.e., analysing, evaluating, and synthesizing are evidence to be the highest percentage.

Chemistry is considered to be a complex field of study (Knaus et al., 2011). Assessing the extent towards students' ability to achieve learning outcomes is challenging. Teachers has a significant role to take the students to acquire what have been determined as the learning outcomes. End-of-year exam is one of the tool teachers use to identify the outcomes' achievement.

While Bloom Taxonomy has been widely used to analysing many issues in educational field, research on the use of the taxonomy to determine students' learning outcome has been less conducted, especially when the tool to determine the outcomes is in the form of exams developed by the teachers. This research is therefore trying to analysis end-of-year exam questions using Bloom Taxonomy. The analysis was conducted to determine the extent of cognitive dimension and knowledge acquisition of students.

**Context of the study**

This study is conducted in the context of Indonesian educational policy. Students learning assessment in Indonesia has come in two forms, namely, school exam and national exam. The former is developed by subject teachers while the later comes from the ministry of education, research and technology. The subject teachers' exam provides necessary information in order for the students to pass to higher class while the national exam is to determine students' capability to go for further education (e.g. elementary to junior to senior).

It has been almost four decades that the role of national exam has been very crucial. National exam is put as solely assessment to determine students' ability to continue to higher education. Thus, failing the exam will create a disaster for students. This situation has changed lately through a new reform in education. The ministry of education, research and innovation has just launched a new policy in which national exam is no longer a solely tool to determine students' acceptance to higher education. Students' performance is seen from teachers' exam results. The role of teachers' exam is therefore important to ensure that students reach the minimum standard of learning and that the result is well accepted by further education.

The context of this research is more about student assessments developed by teachers for final year exams that determine students' graduation to move to a higher grade, that is, exam for grade 10 students to move up to grade 11 and exam for grade 11 students to move up to grade 12. The development of end-of-year exam questions at this level is entirely the responsibility of the subject teacher, in this case is the chemistry teachers. However, it is common for the teacher to work together with other teachers who teach the same subject. For example, a grade 10 teacher works with a grade 11 and 12 teacher.

The results of the end-of-year exams become the target of the teacher to see whether Minimum Completeness Criteria or KKM has been achieved. The KKM defines standard setting or cut score (Mardapi & Herawan, 2019) set by teachers in order for the students to achieve within two semesters of study. According to Haladyna & Downing (2006), standards setting defines cut scores in an exam. To set the standards, it is required to consult with experts that understands the learning outcomes (Tien, Roth, & Kampmeier, 2002), students' performance, and the meaning of scoring systems for specific subject (Haladyna & Downing, 2006). If a student has a score below the KKM, he has not reached the minimum target of competencies. This means that he does not meet the requirements to advance to the next level. In this case, the teacher will generally provide students a second chance to do remedial or repetition program (Ching, Dizon, An, Lubguban, & Suppes, 2018). The remedial is not always in the form of a test (Essibu, 2018). It can also be done with other tasks that are considered by the teacher to be converted into grades so that they can achieve the minimum KKM score.

In developing the end-of-year exam test, teachers rely on competency standards and basic competencies that have been set by the government in the curriculum guideline. Competency standards are general descriptions of knowledge, skills, and attitudes that must be mastered after students study certain subject at certain levels of education. Meanwhile, basic competence is a description of the minimum knowledge, skills and attitudes that students should have after participating in a learning process within a certain period of class meetings (Widiyatmoko & Shimizu, 2017).

The basic competencies are usually defined for one or more meetings. In one academic year the teacher has several basic competencies to be achieved by his students in accordance with the government's target. However, schools can add other basic compensations apart from those set by the government by taking into account the ability of schools to add them. Basic competencies are therefore important for teachers to develop learning activities, including exams.

Basic competencies generally have 3 domains, namely, knowledge, skills, and attitudes. In the context of this research, students' exams will be assessed only in the domain of knowledge. In addition, this research will only focus on the end-of-year exam given to students in grades 10 and 11 as the basis for their promotion to grades 11 and 12 respectively.

## METHOD

End-of-year exam instrument analysis research is a type of descriptive analysis content research. The instrument came from 5 public schools in the South Tangerang area, Banten province, Indonesia. Only two schools out of 8 state schools are willing to provide access to their end-of-year exam instruments. The instruments have 30 to 40 items of 5-multiple-choice questions. In total, there are 190 questions analysed in this study.

The data analysis techniques used in this study are as follows:

1. Writing the completion and answer key of the test instrument. The writing of the completion of the test instrument and the answer key serves to determine the accuracy of the delivery of the problem. The results can be used as material for analysis to determine the cognitive dimensions.
2. Determining the cognitive and knowledge dimensions of the test instrument. Determination of the cognitive dimensions of the test instrument is based on the verbs used in completing the test instrument and the level of thinking required in completing the test instrument. Meanwhile, the determination of the knowledge dimension of the test instrument is based on the type of knowledge required in completing the test instrument.

## RESULTS AND DISCUSSION

Table 3 below shows the distribution of cognitive abilities and knowledge of the items for the final school exam.

Table 3 Percentage of items with cognitive and knowledge dimensions

| The Knowledge dimension | The Cognitive dimension (%) | | | | | |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | F |
| Factual | 10.5 | 2.1 | - | - | - | - |
| Conceptual | 12.6 | 25.3 | 4.2 | 12.6 | - | - |
| Procedural | - | - | 27.9 | 4.7 | - | - |
| Metacognitive | - | - | - | - | - | - |

Note: A= remembering; B= understanding, C = applying; D = analysing: E = evaluating; F = creating.

Based on the results of data analysis and calculation, it was found that the highest percentage was in the cognitive domain with procedural knowledge abilities (27.9%). The items in this category are generally in the form of quantitative calculation questions, such as, on chemical reactions and their calculations, writing down chemical structures, and explaining phenomena in the laboratory. The second largest percentage is on the understanding with the ability of conceptual knowledge (25.3%). Items in this category require students to be able to understand concepts in the form of phenomena in the real life. An example of an item in this category is:

AgCl is a compound that is poorly soluble in water. The addition of NaCl in AgCl solution will result in...

a. the solubility of AgCl is getting smaller
b. AgCl solubility does not change
c. AgCl solubility is getting bigger
d. the solubility of AgCl is doubled
e. the solubility of AgCl is quadrupled.

Remembering with factual and conceptual knowledge were still required quite a lot, 10.5% and 12.6% respectfully. They are the very basic level of cognitive and knowledge dimension in the Bloom's hierarchy. The items are related to definition and simple memorizing facts. Examples in this category are:

Vinegar acid ($CH_3COOH$) is an acid compound. According to Arrhenius, vinegar has acidic properties because...

A. has a hydrogen atom
B. in water releases $H^+$ ions
C. in water releases $OH^-$ ions
D. can accept electron pairs
E. can donate a proton to a water molecule.

A liquid-in-liquid colloidal system is called...

A. aerosol
B. solid foam
C. gel
D. sole
E. emulsion

Although not many, the items with the need for analytical skills are quite high (17.1%) with the demand for mastery of the conceptual knowledge is higher than the procedural knowledge, 12.5% and 4.7%, respectively. Questions that require conceptual analysis are generally questions with the ability to interpret graphic presentations that describe trends in chemical phenomena that occur. Further analysis is needed to determine the concept behind the trend and the meaning of the existing phenomena to be able to predict similar phenomena in different contexts. An example of an item for this category is:

Look at the following table:

| Treatment | pH of Solution | | | | |
|---|---|---|---|---|---|
| | I | II | III | IV | V |
| **Beginning** | 1.0 | 1.0 | 4.6 | 4.7 | 3.0 |
| **+water** | 2.5 | 2.3 | 4.7 | 4.8 | 4.7 |
| **+ a little sour** | 1.0 | 1.0 | 2.4 | 4.5 | 1.5 |
| **+ a little language** | 8.5 | 8.1 | 9.8 | 4.9 | 9.6 |

A solution that is a buffer system is...

a. I
b. II
c. III
d. IV
e. V

An interesting phenomenon from the data table above is that there are no end-of-year exam questions that require students at the cognitive level of evaluation and creation. The highest level of questions only reached the level of analysis with procedural abilities (4.7% or only about 9 questions out of 190 questions). The results indicate that students' assessments are very cognitive centric, in which, concentration is still given to low level of cognitive and very conceptual knowledge, as also been evidence in several countries (Dempster, 2012).

The fact that end-of-year exam instrument in the Indonesian context that emphasizes on the lower order thinking is in fact has been predicted. The emergence of such test analysis results is actually in accordance with the minimum achievement of the basic competencies desired by the government as stated in the curriculum document. Agung (2013), in his research revealed that basically the chemistry curriculum itself does not require students to be at a high level of cognitive thinking. She found that at high school level, the highest emphases on students' competencies are in fact in the initial stage of analysis domain. Whilst, the percentage of such emphases is still low.

The result of this study found that the highest percentage of items is in application domain with the majority percentage is on the procedural knowledge (27,9%). Most of the items in this category are mainly algorithmic or numerical exercises. The application domain with procedural knowledge in the context of final assessments and assessments in general, often dominate. Prior to have exams, students often get additional times to prepare for the end-of-year exam by working on questions in this domain. During this time, students often conduct drilling exercise to solve problems in items from previous exams. Often, students are taught to solve problems in a very practical ways without necessary understand the concept behind the problem solving. This activity should be concerned as it could provide new habits for students to remember how to solve the problems. Students will then no longer have the way of thinking in the application domain as interpreted by Blooms' or Krathwol and Anderson but rather to understand easily or even remember.

Having low order thinking skills, namely, remembering, understanding and applying, has also been found in the research by Azar (2005) in Turkey. He found that Turkey's students having difficulty entering university level due to the fact that entry test of the university demands higher order thinking than those given in secondary schools. The research indicates that most of the tests in secondary schools focus on the cognitive dimension of remembering, understanding, and applying, while university entry test was on understanding, applying, and evaluating (Azar, 2005).

Items type have also been an issue in determining students' level of thinking. Some say that lower order thinking skills may be able to assess using multiple choice item test (Kastner & Stangl, 2011). Meanwhile, higher order thinking skills is favoured to have essay or open-ended items (Risnita & Bashori, 2020). However, Tiemeier, Stacy, & Burke (2011) state that close-ended items may also be possible to assess higher order thinking with additional effort is put to ensure that the targeted cognitive level skills can be determined in the items. Items in the application domain with procedural knowledge seem to be the higher order thinking that can be developed in close-ended type of items.

Although it has been conveyed from various literature studies about the importance of teachers guiding students to understand the macroscopic and microscopic interrelationships in the real world, items concerning this issue are there are still very few. Even in the textbooks, the largest proportion of chemistry learning in textbooks focuses on symbolic things with a ratio of 8:1 with macroscopic representations (Enero & Umesh, 2019). In fact, the textbook itself is still used as a reference for learning both for teachers and for students (Davila & Talanquer, 2010). This phenomenon certainly shows how teachers still do not provide space for students to better understand the relationship between chemical theory and real life.

With regards to exam development that provide adequate cognitive complexity, Knaus, Murphy, Blecking, & Holme (2011) offer a cognitive complexity rating instrument in which quantifying the cognitive demand of chemistry items. The instrument is valid and reliable using rubric as a guidance for grading the items.

The results of this study suggest the importance of considering the development of questions to provide a deeper assessment of students' thinking abilities. Furthermore, this research is also expected to be an evaluation material for teachers to think more about the main goals of chemistry learning by considering the cognitive domain and knowledge that students should have after graduating from the chemistry lesson.

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## CONCLUSION

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