

Training of higher-order thinking skills using ChatGPT

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Abstract: *The paper presents an approach for training and assessing higher-order thinking skills using Bloom's Taxonomy. The capabilities of ChatGPT for creating assignments aimed at forming and evaluating specific types of cognitive skills, namely – analysis, synthesis, and evaluation have been experimented. The experiment focuses on training in graph databases, but the approach can be successfully used in training other disciplines.*

Keywords: Higher order thinking skills, HOTS, Bloom's Taxonomy, ChatGPT.

1. Introduction

Modern education should prepare learners to cope with the rapidly changing and complex world we live in. It is a world of new technologies, artificial intelligence, and increasingly more straightforward access to knowledge, but also a world of wars, financial and health crises. More and more futurists believe that in the next 10 years, many professions will disappear, and today's pupils will work in professions that don't yet exist. The need to stimulate creativity and innovation, actively and informedly advocate for civic positions to uphold democracy, and the ability to learn autonomously throughout one's life – all of these require creative, reasonable, and innovative thinking.

Higher-Order Thinking (HOT) can be defined as a non-algorithmic, complex way of thinking which often leads to finding multiple solutions to a problem (Barak & Dori, 2009). Higher-Order Thinking Skills (HOTS) are usually associated with critical, logical, reflective, metacognitive, and creative thinking. Many scientists categorize these types of skills into 3 categories: transfer of knowledge and skills, critical thinking, and problem solving (Brookhart, 2010).

HOTS cannot be taught to learners directly. They can be acquired through a variety of educational activities that are student-centered and involve the active participation of learners. There are many models and strategies suitable for HOTS training – problem-based learning, project-based learning, discovery learning,

problem solving, and more. Suitable activities for improving these types of skills are also group discussions, solving cases and complex interdisciplinary tasks, etc.

Over the past year, artificial intelligence tools have been increasingly used in education. The AI chatbot ChatGPT, developed by OpenAI, is particularly relevant. It can conduct conversations, answer questions, create literary works, and explain concepts and ideas. Pedagogical specialists are interested in the potential for its use in the preparation and conduct of the educational process. Naturally, the question arises whether ChatGPT can assist in the creation of educational materials that foster higher-order thinking skills.

The current paper presents an approach for training and evaluating HOTS using the knowledge metric of Bloom's Taxonomy. The capabilities of ChatGPT have been experimented with for creating assignments aimed at assessing specific types of cognitive skills. The experiment focuses on training in graph databases, but the approach can also be successfully applied to education in other disciplines.

2. Bloom's Taxonomy. Higher-Order Thinking Skills

Numerous taxonomies are described in the scientific literature, that propose various approaches to classifying and categorizing the knowledge and skills that learners need to acquire during the educational process. Examples include Bloom's Taxonomy (Bloom et al., 1956), SOLO Taxonomy (Biggs & Collis, 1982), Fink's Taxonomy (Fink, 2003), and Webb's Depth of Knowledge (Hess, 2013), etc. Bloom's Taxonomy is one of the most popular taxonomies used by pedagogical specialists to define learning objectives. It defines a hierarchy of thinking skills, in which the higher levels of thinking encompass all cognitive skills from the lower levels. The levels are six - Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation, and they are often depicted through a pyramid, with *Knowledge* at the base and *Evaluation* at the top.

- **Knowledge** – Refers to the ability to recall previously learned material. It requires knowing specific facts, terminology, concepts, functions, etc.

- **Comprehension** – The ability to grasp the meaning of the studied material. It requires understanding facts and principles, capability for generalization, explaining methods and procedures, evaluating consequences, etc.

- **Application** – The ability to use what has been learned in new situations. It requires skills to apply principles, rules, concepts, methods, theories in unfamiliar situations, and use of new methods or procedures.

- **Analysis** – The ability to break down a material into its constituent parts to understand and examine its structure. It presupposes skills for recognizing implicitly formulated ideas and assumptions; discerning logical paradoxes and sophistry in reasoning; distinguishing facts from conclusions, evaluating the applicability of data, analyzing the structure of a plan, project, experiment, etc.

- **Synthesis** – The ability to combine selected parts to construct a new whole. It implies skills for developing new ideas, devising new methods, plans, projects, systems, etc. Creative thinking is required, aimed at developing new models and structures.

- **Evaluation** – The ability to judge the value/worth of a given matter or development, with evaluations based on external or internal objective criteria or quality standards. It entails skills for evaluating the logical consistency of data and facts and the adequacy of data supporting the conclusions.

Bloom's Taxonomy allows for a formal distinction between higher- and lower-order thinking skills. LOTS are considered to be defined by the lower 3 levels of Bloom - Knowledge, Comprehension and Application, and HOTS are represented by the upper levels - Analysis, Synthesis and Evaluation.

Bloom's Taxonomy finds broad application in practice, as evidenced by numerous pedagogical and software developments described in the scientific literature. Their aim is to support the assessment process of thinking skills, in line with the levels proposed by Bloom.

A comprehensive study on the scope and role of Bloom's Taxonomy in reforming teaching-learning practices by employing a systematic balance of questions from both the lower and higher domains is presented in (Chandio et al., 2021). The authors found that in the educational resources they examined, the majority of the exam questions (around 74%) addressed the lower levels of Bloom. They recommend changes to pedagogical practices and the adoption of a systematic approach to transform education towards purposefully fostering critical thinking, solution-making, knowledge-building processes, and analytical skills.

Zhang and colleagues developed a machine-learning model to classify programming assessment questions according to Bloom's Taxonomy (Zhang et al., 2021). They use Google's BERT as the base model and the Canterbury QuestionBank as a source of questions categorized by computer education experts.

Na and colleagues explore the application of Bloom's Taxonomy in the development of formative assessment items (Na, Ji & Lee, 2021). They conducted a real-time online learning experiment with medical students. They developed Bloom's categorized formative assessment questions which they integrated into the lessons. Analysis of the results from the conducted training shows the satisfaction of the learners, who find it useful for achieving educational outcomes.

Ullah and colleagues use a new approach to assessment in programming education. They determine the learners' level of competence according to Bloom's Taxonomy by evaluating a code written by them. The assessment they conducted does not use any assignments pre-classified according to Bloom (Ullah et al., 2020).

Filho and team have developed a software application for automated formulation of test questions and creation of tests based on Bloom's Taxonomy

(Filho et al., 2018). Kusuma and Alhamri's work is in a similar direction. They use a template-based method to automatically generate test questions based on Bloom's Revised Taxonomy. The authors' experiments show a high result – about 82% accuracy of the generated questions (Kusuma & Alhamri, 2018). Amira and team present the Framework for Automatic Exam Generation based on Intended Learning Outcomes (Amria, Ewais & Hodrob, 2018). Other publications describe various developments, techniques and technologies for constructing test items based on Bloom, as well as their application in various fields – (Timakova & Bakon, 2018), (Totkov, Raykova & Atanasova, 2017), and others.

As can be seen from the conducted research, Bloom's Taxonomy, apart from being a tool for determining educational objectives, is actively used in other components of the learning process, e.g. in the development of curriculum content, teaching methodologies, systems for evaluating the educational outcomes, etc. The paper proposes an approach for using it to develop curriculum content aimed at forming and evaluating HOTS.

3. Graph databases

Graph databases are specialized databases that use network structures to model complex systems of objects and the relationship between them. A graph database consists of multiple nodes and edges. Objects from the real world are modeled through nodes, and the connections between them are modeled through the edges. Each node and edge has a unique identifier and can have multiple properties that describe its additional characteristics.

This type of database finds broad application in practice, e.g. for modeling social networks, transport and geographic networks, computer and communication networks, biological and genomic networks, Internet search engines, etc. Many tasks can be modeled with a graph and solved by implementing specific algorithms on it – e.g. finding a path between two nodes; finding optimal paths between two nodes; searching for available routes in network environments; clustering data based on their connectivity, etc. Studying graph databases by students in computer science is highly suitable for developing higher-order thinking skills. One of the most popular graph database management systems is Neo4j. It is also available as a cloud service, making it easy to use. It uses the Cypher Query Language (CQL) for queries.

4. Tasks for developing higher-order thinking skills – step by step

ChatGPT was tasked with creating a graph database. It formulated a task to create a university database, with 4 types of objects – Student, Course, Professor and Department. Specific characteristics were defined for each of the objects, as well as the relationships between them. The task is presented in Figure 1.

The next task was to write sample code for creating the database, where ChatGPT wrote multiple CQL queries to create objects and the relationships between them.

Task: Create a University Graph Database

Objective:

Your goal is to design and create a graph database that models the structure of a university. The database should represent students, courses, professors, and departments, and the relationships between them.

Requirements:

- Entities and Attributes:**
 - **Student:** `name`, `age`, `enrollmentYear`
 - **Course:** `name`, `code`, `credits`
 - **Professor:** `name`, `title`
 - **Department:** `name`
- Relationships:**
 - **Enrolled_In:** Student is enrolled in a Course.
 - **Teaches:** Professor teaches a Course.
 - **Part_Of:** Course is part of a Department.
 - **Works_In:** Professor works in a Department.
 - **Friends_With:** Optional relationship between students.

Figure 1. A task to create a graph database, created by ChatGPT

Assignment 1: Course Enrollment Analysis

Task 1.1: List all Students Enrolled in a Specific Course

Write a query to list all students enrolled in the "Algorithms" course (code: 'CS101').

Task 1.2: Count the Number of Students per Course

Write a query to count the number of students enrolled in each course and return the course name and student count.

Task 1.3: Identify Students Enrolled in Multiple Courses

Find students who are enrolled in more than one course and list their names along with the courses they are enrolled in.

Assignment 2: Department Analysis

Task 2.1: List Courses Offered by a Department

Write a query to list all courses offered by the 'Computer Science' department.

Figure 2. Assignments for training HOTS, created by ChatGPT

The next three tasks required ChatGPT to formulate assignments in which the learners demonstrate HOTS, namely synthesis, analysis and evaluation – „Write me assignments on this database that train analysis/synthesis/assessment skills” (Fig. 2). Part of the assignments are structured in Table 1.

Table 1. Sample assignments created by ChatGPT

Bloom's level	Sample assignments
Analysis	<p>Assignment 1: Course Enrollment Analysis</p> <ul style="list-style-type: none"> • Write a query to list all students enrolled in the "Algorithms" course (code: 'CS101'). • Write a query to count the number of students enrolled in each course and return the course name and student count. • Find students who are enrolled in more than one course and list their names along with the courses they are enrolled in. <p>Assignment 2: Department Analysis</p> <ul style="list-style-type: none"> • Write a query to list all courses offered by the 'Computer Science' department. • Find all professors working in the 'Mathematics' department and list their names and titles. • Calculate the number of professors and courses in each department and return the department name along with the counts. <p>Assignment 3: Professor and Teaching Analysis</p> <ul style="list-style-type: none"> • Write a query to list all courses taught by 'Dr. Smith'. • Find professors who are teaching more than one course and list their names along with the courses they teach. • Calculate the total number of credits taught by each professor and return their name and credit sum.
Synthesis	<p>Assignment 1: Cross-Relationship Analysis</p> <ul style="list-style-type: none"> • Write a query to find all students enrolled in the same courses as 'Alice' and exclude 'Alice' from the results. <p>Assignment 2: Multi-Step Queries</p> <ul style="list-style-type: none"> • Write a query to find professors teaching students of age 20, and return the professors' names and the courses they teach. <p>Assignment 3: Data Transformation and Aggregation</p> <ul style="list-style-type: none"> • Write a query to calculate the average age of students enrolled in courses in each department. <p>Assignment 4: Advanced Relationship and Path Analysis</p> <ul style="list-style-type: none"> • Identify professors who teach a course in a department but do not have a "WORKS_IN" relationship with that department. <p>Assignment 5: Synthesizing New Data Structures</p> <ul style="list-style-type: none"> • Assuming that students who have enrolled in courses with a total of 12 or more credits have graduated, write a query to add a new label

	"Graduated" to those students.
Evaluation	<p>Assignment 1: Course Effectiveness Assessment</p> <ul style="list-style-type: none"> Write a query to find the three courses with the lowest enrollment and list them by the number of enrolled students. <p>Assignment 2: Student Performance Assessment</p> <ul style="list-style-type: none"> Assuming that students' grades are stored as properties, write a query to identify the top 5 students by their average grades. <p>Assignment 3: Department Efficiency Assessment</p> <ul style="list-style-type: none"> Calculate the ratio of professors to courses within each department, assessing the efficiency of staffing. <p>Assignment 4: Network and Relationship Assessment</p> <ul style="list-style-type: none"> Assuming that collaboration between students is represented by a COLLABORATES_WITH relationship, write a query to find students with the most collaboration links, assessing their network strength. <p>Assignment 5: Education Pathway Assessment</p> <ul style="list-style-type: none"> Assuming that graduated students have a Graduated label, write a query to list the courses most commonly taken by graduated students, which could be used to assess the relevance of those courses in successful education pathways.

The first group of tasks – the **analysis tasks**, is aimed at breaking down the information into separate components and studying the structures or relationships between parts. They require:

- Exploring the database by studying its basic components.
- Investigating details or characteristics of a particular object/connection or group of objects/connections.
- Searching for dependencies between different objects.

For example, the task *"Write a query to list all courses offered by the 'Computer Science' department."* with a sample solution:

```
MATCH (c:Course)-[:PART_OF]->(d:Department { name: 'Computer
Science' })
RETURN c.name as Course_Name;
```

This task requires the following analytical skills from the students:

1. Understanding the Structure: The student needs to understand the structure of the graph database – how nodes are organized (e.g. students, courses, faculties) and what relationships exist between them (e.g. "PART_OF", "WORKS_IN", „ENROLLED_IN“).

2. Identification of relations: Based on the assignment, the student must identify the relationship between faculties and the courses they offer. This would mean looking for a relationship such as "PART_OF" between courses and faculties.

3. Information Filtering: The student should use filtering criteria to extract only the courses related to "Computer Science" faculty. This requires the ability to apply conditions in the query.

4. Data Search and Selection: In addition to the structure and relationships, the student should know how to select specific data (in this case, the names of the courses) to be returned from the query.

In general, this task requires the student's skills to analyze a graph structure, to identify objects and interpret the connections and attributes in it, and to apply criteria for searching and selecting information.

The second group of tasks – the **synthesis tasks** is aimed at combining information about different objects and exploring the connections between them in order to acquire new knowledge. By their nature, they require:

- Building new structures or models that incorporate different objects.
- Combining various parts or concepts to form new knowledge or interactions.
- Applying knowledge about different objects to solve a given problem.

Let's consider the task „*Calculate the number of professors and courses in each department and return the department name along with the counts.*“ with a sample solution:

```
MATCH (d:Department)-[:PART_OF]-(c:Course)
WITH d, count(c) as Course_Count
MATCH (d)-[:WORKS_IN]-(p:Professor)
RETURN d.name as Department_Name, count(p) as Professor_Count,
Course_Count;
```

This task requires the following synthesis skills:

1. Combining different information elements: The student should combine information from different parts of the graph database (professors, courses, departments) into one unified structure or query.

2. Using aggregation: The student should know how to apply aggregation functions in CQL to compute overall values (such as count) for different elements.

3. Structuring the result: The result should be structured in such a way as to provide the name of the department and the corresponding count of professors and courses. This requires the ability to combine and format data into a specific format or structure.

4. Query planning and optimization: Especially with complex queries or large databases, the student should be able to plan and optimize the query so that it is efficient and does not overload the system.

5. Integration of knowledge: The student combines their knowledge of CQL with the knowledge of the graph database structure and the semantics of the

information to solve the problem.

Synthesis skills are related to the ability to combine and integrate various elements of knowledge into a new and coherent whole product or solution. In this task, students need to combine information from different parts of the database, apply aggregation functions, and provide the result in a clear and structured format.

The third group of tasks – the **evaluation tasks**, requires judgment skills about the value, significance, efficiency or quality of certain information, data or results. In general, they include:

- Comparing results, methods, or approaches to determine which is most preferable or effective.
- Determining the truthfulness, adequacy, or reliability of certain information of method.
- Applying criteria or standards for evaluation.

From this group, let's consider the task „Assuming that students' grades are stored as properties, write a query to identify the top 5 students by their average grades.“ with a sample solution:

```
MATCH (s:Student)-[e:ENROLLED_IN]->(c:Course)
RETURN s.name as Student_Name, avg(e.grade) as Average_Grade
ORDER BY Average_Grade DESC
LIMIT 5;
```

This task requires the following evaluation skills:

1. Defining criteria: When completing the query, the student needs to define the evaluation criteria – in this case, the average grade of the student. This requires an understanding of how average values are calculated and how they are used for ranking.

2. Using aggregation functions: The student needs to use aggregation functions in CQL to calculate average values. This requires the ability to assess which tool or function is most suitable in a given context.

3. Evaluation of Results: After the query has been executed, the student should review and evaluate the results. This includes assessing whether the results seem reasonable and if the approach used to calculate the averages is correct.

4. Assessing reliability: It's possible that students might need to evaluate whether the results are relevant or if there are potential anomalies in the data that could affect the ranking.

5. Assessing result completeness: Especially in databases where there might be a large volume of data or many students with identical average grades, it's important to evaluate whether the result provides a complete and accurate view of the top 5 students.

These evaluation skills relate to the process of determining the value, relevance, or quality of information. In this assignment, students use evaluation criteria (average grade) to identify and rank students.

Undoubtedly, ChatGPT has generated diverse and relevant questions in accordance with the specific queries made to it.

5. Conclusion

Forming and training higher-order thinking skills is important for the personal and professional growth of every individual. Learning resources and activities should be planned and designed in a way that stimulates creative and innovative thinking. The conducted experiment showed that ChatGPT can be used successfully to generate assignments aimed at forming and evaluating specific cognitive skills – for synthesis, analysis, and evaluation.

Using ChatGPT to create educational materials has numerous advantages. It is easily assessable, has a free version, and can quickly produce educational materials and resources that support the learning process. It uses information from many sources, making it “knowledgeable” on many topics. However, there are also some risks that need to be considered.

Although ChatGPT is trained on vast amounts of data, in some cases it may provide inaccurate or outdated information. Sometimes it may not “understand” the context of a particular question and may construct an incorrect answer. It is possible for it to create material that does not reflect the cultural, social, or ethical standards of an educational institution or community. Because of this, educational materials should be reviewed and corrected by experts in the respective field before use. When used reasonably and critically, ChatGPT can be a valuable tool for educators. It is important to apply it in combination with other methods and to maintain an active and conscious approach to education.

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REFERENCES

Amria, A., Ewais, A. & Hodrob, R. (2018) A Framework for Automatic Exam Generation based on Intended Learning Outcomes. *Proceedings of the 10th International Conference on Computer Supported Education (CSEDU 2018)*. pp. 474-480.

- Anderson, L. & Krathwohl, D. R. (Eds.) (2001) *A taxonomy for learning, teaching and assessing: A revision of Bloom's Taxonomy of educational objectives*, New York, Addison Wesley Longman.
- Barak, M. & Dori, Y. (2009) Enhancing Higher Order Thinking Skills Among Inservice Science Teachers Via Embedded Assessment. *Journal of Science Teacher Education*. 20, 459–474. doi: 10.1007/s10972-009-9141-z.
- Biggs, J. B. & Collis, K. (1982) *Evaluating the Quality of Learning. The SOLO taxonomy*. Academic Press, New York.
- Bloom, B., Engelhart, M., Furst, E. et. al. (1956) *Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain*. David McKay Company, New York.
- Brookhart, C. (2010) *How to Assess Higher-Order Thinking Skills in Your Classroom*, publ. ASCD.
- Chandio, M., Zafar, N. & Solangi, G. (2021) Bloom's Taxonomy: Reforming Pedagogy through Assessment. *Journal of Education and Educational Development*. 8(1), 109-140. doi: 10.22555/joeed.v8i1.308.
- ChatGPT, <https://chat.openai.com/> [Accessed 21th August 2023].
- Filho, A., Tomazzi, E., Paza, R., Perego, R. & Raabe, A. (2018) Bloom's Taxonomy-Based Approach for Assisting Formulation and Automatic Short Answer Grading. *VII Congresso Brasileiro de Informática na Educação (CBIE 2018)*. doi: 10.5753/cbie.sbie.2018.238.
- Fink, D. L. (2003) *A self directed guide to designing course for significant learning*. San Francisco: Jossey - Bass.
- Hess, K. (2013) *A Guide for Using Webb's Depth of Knowledge with Common Core State Standards*, Common Core Institute, <http://aimc.alpineschools.org/wp-content/uploads/sites/6/2014/06/Webs-Depth-of-Knowledge-Flip-Chart1.pdf>. [Accessed 21th August 2023].
- Kusuma, S. & Alhamri, R. (2018) Generating Indonesian Question Automatically Based on Bloom's Taxonomy Using Template Based Method. *KINETIK*. 3(2), 145-152.
- Na, S. J., Ji, Y. G. & Lee, D. H. (2021) Application of Bloom's taxonomy to formative assessment in real-time online classes in Korea. *Korean journal of medical education*. 33(3), 191-201. doi: 10.3946/kjme.2021.199.
- Neo4j Graph Platform. <https://neo4j.com/>. [Accessed 21th August 2023].
- Partnership for 21st Century Learning (2019) *Framework for 21st Century Learning*, http://static.battelleforkids.org/documents/p21/P21_Framework_Brief.pdf. [Accessed 21th August 2023].

Timakova, Y. & Bakon, K. (2018) Bloom's Taxonomy-Based Examination Question Paper Generation System. *International Journal of Information System and Engineering*. 6(2).

Totkov, G., Raykova, Zh. & Atanasova, M. (2017) Cognitive-didactic model when generating testing items on the topic of "Mechanical oscillation. *Pedagogy*, 89(7).

Ullah, Z., Lajis, A., Jamjoom, M., Altalhi, A. & Saleem, F. (2020) Bloom's taxonomy: A beneficial tool for learning and assessing students' competency levels in computer programming using empirical analysis. *Computer applications in engineering education*. 28(6), 1628-1640. doi: 10.1002/cae.22339.

Zhang, J., Wong, C., Giacaman, N. & Luxton-Reilly, A. (2021) Automated Classification of Computing Education Questions using Bloom's Taxonomy. In *Proceedings of the 23rd Australasian Computing Education Conference (ACE '21)*. Association for Computing Machinery, New York, NY, USA. pp. 58–65. doi: 10.1145/3441636.3442305.