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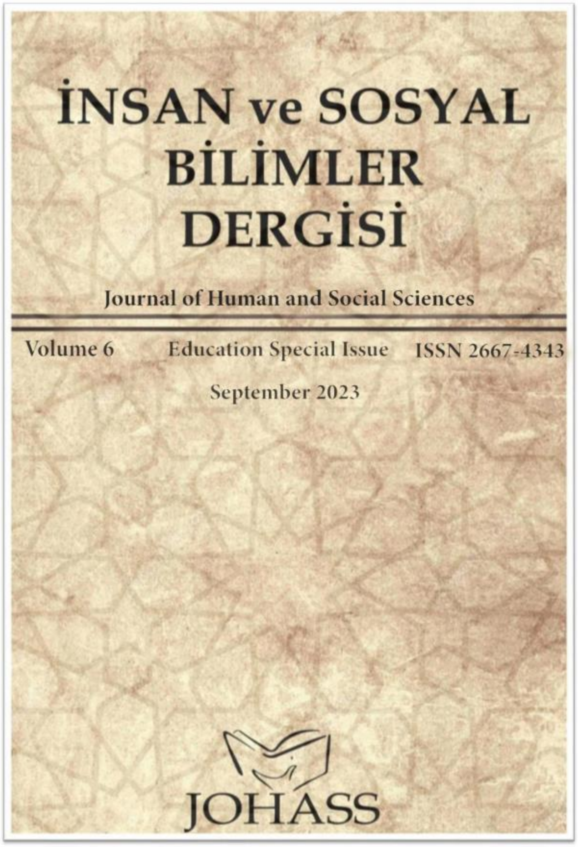

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Analyzing University Entrance Exam Physics Questions using Physics Problems Taxonomy for Cognitive Processes

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Analyzing University Entrance Exam Physics Questions using Physics Problems Taxonomy for Cognitive Processes

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Abstract **Research Article**

University students often find physics challenging due to physical and mathematical obstacles, poor mathematical skills, and inadequate problem-solving abilities. This perception affects their interest and performance in the subject. High school students also struggle with numerical problems and understand curricular topics that lack concrete examples and require mathematical manipulations or visualization. Analyzing physics problems is crucial for guiding curriculum development, contributing to physics education, identifying students' difficulties in understanding and solving problems, and improving the process of physics education at all educational levels. Taxonomies are hierarchical frameworks used in education to classify educational learning goals or objectives according to their complexity. Bloom's Taxonomy, Anderson and Krathwohl's revised taxonomy, Lee Shulman's learning grid, Marzano's New Taxonomy of Educational Objectives (NTEO), and the Taxonomy of Introductory Physics Problems (TIPP) are all essential tools for understanding and improving educational learning outcomes. The study adapted the TIPP taxonomy into Turkish and analyzed 7 physics questions in the 2023 BPT. Results showed 3 questions were at recall, 1 at comprehension, and 3 at analysis, with no question at using knowledge. The study demonstrates that TIPP is a useful taxonomy for teachers to plan, apply, and evaluate knowledge and algorithms in solving physics problems, identifying students' needs. This taxonomy allows educators to create questions that engage students at all cognitive levels, promoting cognitive engagement. Researchers can analyze physics questions in the TYT and AYT in earlier years.

Keywords: Physics problems, basic proficiency test, taxonomy, cognitive processes

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Introduction

University students perceive physics as a difficult course and face a number of obstacles while studying this course (Adianto & Rusli, 2021; Örnek, Robinson, & Haugan, 2007; Snetinova & Koupilova, 2021, Süzük, Çorlu, & Gürel, 2011). Physical challenges include understanding queries and identifying applicable equations, while mathematical challenges include placing data into equations and performing mathematical operations (Balta et al., 2019). Students' lack of understanding of physics concepts, poor mathematical skills, and inadequate problem-solving abilities contribute to these difficulties (Djudin, 2018). Furthermore, students' negative attitudes towards physics and the perception that physics is the most difficult science subject also affect their interest in and performance in physics (Ibrahim, Zakiang, & Damio, 2021). Emotional problems and inadequate preparation are also important factors affecting students' views towards physics (Bray & Williams, 2020). (Harikrishnaprabu & Annapooranam, 2019) Difficulties in solving numerical problems in physics arise from students' inability to define the relevant concepts and recognize the questions asked. Students also have difficulty in understanding the problem and planning a solution (Sartika & Humairah, 2019).

High school students also perceive physics as a difficult subject (Adianto & Rusli, 2021). These difficulties can be classified into several categories. Physical difficulties include difficulties in understanding queries and identifying valid equations (Adianto & Rusli, 2021). Mathematical difficulties consist of problems in substituting data into equations and performing mathematical operations (Balta et al., 2019). Students' inability to solve non-intuitive problems can be attributed to a superficial understanding of problem statements (Mumthas & Abdulla, 2019). In addition, students tend to perform poorly in mathematical problem solving in physics, especially in creating or defining formulas, extracting information from diagrams, applying physics concepts to create schematic diagrams, and applying mathematics to solve physics problems (Harikrishnaprabu & Annapooranam, 2019). In addition, students often struggle to identify relevant concepts and recognize the questions asked in numerical problems (Yuliati & Parno, 2018). Furthermore, students have difficulty identifying coordinate axes, depicting free-body diagrams, representing forces, and determining resultant forces and direction of motion (Supeno, Subiki, & Rohma, 2018). Moreover, students struggle to understand curricular topics that lack concrete examples and require mathematical manipulations or visualization (Reddy & Panacharoensawad, 2017). In addition, they find it difficult to solve problems independently and ask questions in class (Erinosho, 2013). Students think that the most challenging aspect of physics is the course material, followed by their own abilities and instructors (Ekici, 2016). High school physics education often focuses on fragmented and repetitive exercises, leading to incomplete and non-retained understanding of the subject matter (Antonowiski, Alencar, & Rocha, 2017). In general, students struggle to understand physics concepts, apply mathematical skills, and develop problem-solving skills, contributing to the perception that physics is a difficult subject.

The analysis of physics problems is crucial for several reasons. First, understanding the cognitive processes required to solve these problems can guide curriculum development and the construction of assessments (Adianto & Rusli, 2018). Second, analyzing physics problems contributes to the field of physics education by enabling researchers to examine the relationship between cognitive processes and problem solving (Teodorescu et al., 2013). Moreover, by analyzing physics problems, students' difficulties in understanding and solving problems can be identified, which enables the development of effective learning models and strategies (Braun, 1984). On the other hand, it also improves the process of physics education at all educational levels, including primary, secondary and higher education (Burbano, 2013). It enables identifying and analyzing the needs of students and learners in solving problems and tasks in physics (Hanáková & Kluvanec, 2016). In addition, analyzing physics problems helps to develop problem-solving skills that are essential for physicists in the workplace (Ling, Moebs, & Sanny, 2016). In addition, it enables students to acquire problem solving skills in physics, which is crucial for their physics education (Koupilová, Mandková, & Sntinová, 2017). Finally, analyzing physics problems helps to identify the difficulties that students face when completing tasks and enables the discovery of strategies and methods that can help students solve problems correctly (Snetinova & Koupilova, 2012). Analyzing physics problems is crucial for developing problem solving skills (Teodorescu et al., 2013). Curriculum design for introductory physics courses can be guided by an understanding of the specific skills needed to solve physics problems (Adams & Wieman, 2007). Moreover, analyzing physics problem solving skills can help researchers to determine the extent to which various cognitive processes are used during problem solving and the relationship between these processes (Ariani, 2020). By analyzing problems, students can grasp concepts and learn how to apply them effectively (Masitoh et al., 2021). This knowledge enables students to plan and implement problem-solving strategies (Nehru, Kurniawan, & Riantoni, 2020). Through analysis, students can recognize the difficulties they face in understanding problems and developing solutions (Adams & Wieman, 2015). It also identifies incomplete applications of concepts that can hinder problem-solving skills (Yuliati & Parno, 2018).

A taxonomy can be used to analyze and classify physics problems according to the level of knowledge and understanding required for a correct answer (Buick, 2011). In solving physics problems, it is crucial to classify problems according to their underlying principles rather than their context (Mason & Singh, 2016). This strategy can encourage a more in-depth approach to students' learning and lead to higher levels of achievement (Mason & Singh, 2016). By comparing the categorization of problems according to solution similarity, students can learn to recognize the fundamental similarity between problems with different contexts but with the same underlying physics principles (Adams & Wieman, 2015). In addition, the identification of different sub-skills that affect problem solving skills in various contexts supports the use of taxonomies in teaching and assessing problem solving in physics education (Buick, 2011; Mason et al., 2016; Adams et al., 2015). These taxonomies establish a relationship between physics problems, the type of physics knowledge they require, and the cognitive processes they promote in students (Teodorescu, Bennhold, & Feldman, 2008). Taxonomies facilitate the classification of problems by categorizing physics questions according to the level of knowledge and understanding required for a successful response (Buick, 2011). Moreover, the ability to categorize problems based on underlying principles as opposed to contexts is considered a hallmark of problem-solving expertise in physics (Mason & Singh, 2016). Using taxonomies to analyze physics problems can help students recognize the fundamental similarity between problems with different contexts but the same physics principles (Adams & Wieman, 2015).

What is a Taxonomy? What are Txonomies in Education?

In education, a taxonomy is a hierarchical framework used to classify educational learning goals or objectives according to their complexity. Globally, numerous taxonomies have been developed and implemented in educational institutions. The purpose of these taxonomies is to provide a system for classifying students' cognitive abilities and skills in the teaching, learning and assessment processes. Bloom's taxonomy, Anderson's taxonomy, SOLO taxonomy, Shulman's learning grid and Marzano's taxonomy are well-known taxonomies in education (Aripin et al., 2020; Irvine, 2021). These taxonomies differ from each other in the way they address knowledge, cognition, metacognition, higher order thinking skills, affect and underlying learning theories. These taxonomies have had a significant impact on higher education and are used to inform teaching decisions and to understand the potential consequences of educational decisions (Pathak & Palvia, 2021; Rigney & Zhao, 2022). Taxonomies have also been developed for specific domains, such as virtual and augmented reality applications in education, to categorize and clarify communication between researchers, developers and educators (Motejlek & Alpay, 2021).

Bloom's Taxonomy was first published in 1956 and has since been widely used in UK Higher Education (HE). The taxonomy classifies educational objectives into six levels: knowledge, comprehension, application, analysis and synthesis (Newton, Da Silva, & Peters, 2020). Bloom's taxonomy is a popular educational model used to categorize learning objectives into various levels. It consists of cognitive, affective and psychomotor domains. Cognitive domain levels include knowledge, comprehension, application, analysis, synthesis, and evaluation (Velázquez-Iturbide, 2021). It helps to define teaching and learning objectives, learning strategies and assessment. It is a powerful tool that helps educators analyze assessment items and can be used to categorize assessment questions (Laddha et al., 2021). Bloom's taxonomy is used by educational institutions to design course learning outcomes (CLOs) and match assessment items to them in order to improve student learning (Shaikh, Daudpott & Imran, 2021). However, difficulties in using the taxonomy have been reported and some authors have suggested that there are inherent flaws in the classification system (Sahu et al., 2021). To address this issue, researchers have proposed deep learning models such as LSTM-based models to more accurately classify CLOs and assessment items into Bloom's levels (Waheed et al., 2021). In addition, Bloom's taxonomy was used to analyze and improve the comprehension skills of the pre-trained language models, resulting in improved performance on question answering tasks (Sahu et al., 2021).

The taxonomy developed by Anderson and Krathwohl is a revised version of Bloom's Taxonomy. The revised taxonomy classifies thinking skills at six levels: knowledge, comprehension, application, analysis, synthesis, and evaluation (Arlianty et al., 2018). Bloom's (1956) first taxonomy classified thinking skills as lower-order thinking skills (LLSS) and higher-order thinking skills (HLSS) (Tee et al., 2010). Lower order thinking skills (LLSS) and higher order thinking skills (HLSS) are distinguished from each other by the cognitive process dimension. HOTS include analyzing, evaluating and creating, while LOTS include remembering, comprehending and applying. The knowledge dimension focuses on the types and variety of mental activities required to complete a task ((Urgo, Arguello, & Capra, 2019), (Arlianty et al., 2018)). Anderson and Krathwohl's (2001) revised taxonomy made significant changes to the original taxonomy, including the addition of the synthesis level and the reordering of the levels. In addition, the revised taxonomy includes commonly used action verbs to assess each level of thinking skills. Overall, Anderson and Krathwohl's taxonomy extends Bloom's Taxonomy and provides a more comprehensive framework for categorizing and assessing thinking skills in education (Arlianty et al., 2018; Tee et al., 2010).

Anderson and Krathwohl's taxonomy is used in education to analyze and classify reasoning skills in various subjects and learning levels. It provides a framework for understanding and assessing students' cognitive abilities. In the papers presented, Anderson and Krathwohl's taxonomy was used in various ways. In the study by Ariffin et al. (2020), the taxonomy was used to analyze the paradigm of thinking skills used in arithmetic education during the British colonial period. Motejlek and Alpay (2021) used the taxonomy to create a taxonomy of virtual reality and augmented reality applications in education. Arlianty et al. (2018) use the taxonomy to identify students' capacity to answer questions according to their cognitive level. Sahu et al. (2021) use the taxonomy to improve the question answering comprehension capabilities of pre-trained language models. Overall, Anderson and Krathwohl's taxonomy is a useful tool for understanding and improving educational learning outcomes.

Biggs and Collis developed the SOLO taxonomy in 1982 (Ladias, Ladias, & Karvounidis, 2019). This taxonomy is a framework for mapping students' levels of understanding and is used to improve student learning (Graf, 2021). The taxonomy aims to move from the concrete to the abstract and to achieve greater complexity of reasoning (Hook, 2018). It allows students to articulate learning outcomes, understand the learning process and set new learning goals over time (Castro & Fisler, 2017). Education, cognitive psychology and curriculum design were influential in the development of the SOLO taxonomy (Baxter & Durrant, 2017). It includes five levels of achievement: pre-structural, structural, multi-structural, relational, and extended abstract (Li & Goos, 2013). The taxonomy is used to assess students' understanding and knowledge in various disciplines, including correlation graphing (Vrettaros, Vouros, & Drigas, 2007). The assessment tool derived from the SOLO taxonomy is used to identify which aspects of correlation graphing students struggle with and need additional instruction. The SOLO taxonomy is also used to assess knowledge and learning outcomes in visual programming environments such as Scratch. It enables educators to assess the request detection maturity of a student's code and their understanding of tracing requests between processes in a programming environment. In addition, the modeling of diagnostic systems using fuzzy logic is examined, in particular the SOLO taxonomy system, which can be used in numerous diagnostic science disciplines. The intelligent system developed based on this modeling can improve the extraction of results in e-learning and remote diagnostic systems and facilitate the use of diagnostic systems in education (Ladias, Ladias, & Karvounidis, 2019; Li & Goos, 2013; Vrettaros, Vouros, & Drigas, 2007). In education, the SOLO taxonomy is used to assess students' cognitive abilities and improve their understanding of complex concepts. It aims to classify educational learning goals or objectives according to their level of complexity. The taxonomy has been used to assess students' ability to develop algorithm runtime complexity and to improve the engineering education teaching process (Patterson, 2021). It has also been compared and contrasted with other taxonomies commonly used in education such as Bloom's taxonomy and Webb's depth of knowledge to understand its treatment of knowledge, cognition, metacognition, and higher-order thinking skills (Aronshtam, Shrot, & Shmallo, 2021). Using the SOLO taxonomy in teaching can improve student activity, resource selection, conceptual understanding, and the growth of students' cognitive activities (Kaharuddin & Hajeniati, 2020). It can result in better understanding and learning, leading to improved student performance (Ladias, Ladias, & Karvounidis, 2019).

Lee Shulman created the learning grid in 2002 as a tool for interdisciplinary reflection on student learning (Mortier & Yatczak, 2016). In education, Shulman's learning grid is used to understand student learning across disciplines. It provides a visual representation of how students learn in specific courses or programs. The chart is used in interdisciplinary dialogues related to the Science of Teaching and Learning (SoTL) (Mortier & Yatczak, 2016). In the higher education context, the grid has been used to assess and guide students' learning progress in blended teaching methods that combine face-to-face instruction with the use of a Learning Management System (LMS) (Lai & Sanusi, 2013).

The taxonomy created by Marzano in 1998 (Irvine, 2017) is used in education to promote higher-order thinking skills and meaningful, transferable learning (Irvine, 2020; Insani, Pratiwa, & Muhardjito, 2019; Irvine, 2020). The ego provides a framework for the integration of metacognitive and cognitive systems (Dubas & Toledo, 2016). The Marzano taxonomy assists instructors in course design, establishing student learning outcomes, conducting assessments, and providing targeted feedback (Toledo & Dubas, 2016; Irvine, 2021). It is often combined with other models such as problem-based learning and integrated learning to increase the effectiveness of instructional strategies (Asmi, Wonorohardjo, & Widarti, 2019). The aim of Marzano's taxonomy is to move students from concrete to abstract thinking and increase the complexity of their reasoning (Graf, 2021). Furthermore, Marzano's taxonomy is used to design and categorize virtual and augmented reality applications in educational settings, thus facilitating communication between researchers, developers, and educators (Finelli & Rasoulifar, 2014). Taxonomy is also used in interdisciplinary teaching approaches for engineering design education where it helps to map design thinking and improve students' performance in design tasks (Motejlek & Alpay, 2021). In addition, Marzano's taxonomy has been compared to other well-known taxonomies in education, with a focus on addressing knowledge, cognition, metacognition, higher order thinking skills, affect, and learning theories (Irvine, 2020; Insani, Pratiwi, & Muhardjito, 2019; Dubas & Toledo, 2016; Toledo & Dubas, 2016).

In education, Marzano's New Taxonomy of Educational Objectives (NTEO), created in 2006 (Marzano & Kendall, 2006), is used to categorize and assess students' achievements in various knowledge domains. It distinguishes between content and process or lifelong knowledge, which in turn is subdivided into complex thinking, data processing, communication, group collaboration and the development of habits of mind (Cotič, Felda, & Žakelj, 2020). Marzano's taxonomy is used to explicitly teach higher-order thinking skills and promote psychomotor learning through activities such as apprenticeships, internships and school practicums (Rigney & Zhao, 2022). It provides a framework for setting instructional goals, organizing instructional content and activities, and assessing instructional outcomes (Marzano & Kendall, 2006). Taxonomy has been a mainstay in formulating goals and best practices in higher education for decades (Krau, 2011). Marzano's New Taxonomy, which includes different goals and tasks for retrieval, comprehension, analysis, knowledge application, metacognition and self-system (Marzano & Kendall, 2008), is also used as a scale to measure student performance. Aheisibwe, Kobusigye, and Tafadzwa (2002). NTEO is a two-dimensional architecture consisting of three reasoning systems and three knowledge domains. The actions of these systems are determined by the learner's procedural knowledge. The six levels are the self system, metacognitive system, information use, analysis, comprehension and retrieval. Self-system beliefs, attitudes and expectations determine motivation for a new task. Level 5 of the metacognitive system mobilizes the system by defining goals and developing strategies to achieve them. The cognitive system (levels 1-4) is responsible for the effective processing of information (Teodorescu et al., 2013).

According to the related literature, university students generally find physics challenging due to physical and mathematical difficulties. These difficulties are exacerbated by a lack of understanding of physics concepts and poor mathematical and problem-solving skills. Emotional issues and lack of preparation also contribute to students' perspectives on physics. Taxonomic analysis of physics problems seems important for several reasons, including guiding curriculum design, allowing researchers to study the relationship between cognitive processes and problem solving, developing problem solving skills for physicists, and helping students identify difficulties and explore strategies. Furthermore, taxonomic analysis can be used to categorize problems based on knowledge and understanding, which will promote a deeper approach to student learning and higher levels of achievement. In this context, the aim of this study is to analyze the physics questions asked in the Higher Education Institutions Exams Basic Proficiency Test (BPT) with the Physics Problems Cognitive Processes Taxonomy.

Method

Model

In this study, document analysis technique, one of the qualitative research methods, was used. Document analysis involves analyzing written items that contain information for the data targeted for study (Yıldırım & Şimşek, 2013). Document analysis is the process of analyzing the data obtained in a systematic way by reviewing and evaluating electronic and printed materials (Bowen, 2009).

Sample and Population

The sample of the study consists of 7 physics questions in Higher Education Institutions Exams BPT in 2023.

Collection of Data and Analysis

The data were obtained from the Student Selection and Placement Centre (OSYM)'s website (OSYM, 2023a) and analyzed according to the Physics Problems Cognitive Processes Taxonomy adapted from Teodorescu et al.'s (2013) study. The classification of the Basic Proficiency test questions according to the Physics Problems Cognitive Processes Taxonomy was done separately by the researcher and 2 experts. It was seen that the analysis made by the researcher and 2 experts agreed 85.71%. The 3 questions that did not agree were re-decided according to the joint analysis. The Physics Problems Cognitive Processes Taxonomy used for the analysis is explained in detail below.

Taxonomy for Evaluating Physics Problems

Teodorescu et al. (2013) created Taxonomy of Introductory Physics Problems (TIPP) using NTEO. TIPP is an implementation of NTEO that classifies physics problems according to the cognitive processes and knowledge involved. Knowledge domains and cognitive processes are shared by both taxonomies, with the exception of TIPP's emphasis on overcoming obstacles.

There are several differences between TIPP and NTEO. While TIPP is a database of physics problems that provides descriptions and examples of problems involving cognitive processes, NTEO is a framework for creating educational goals, assessments and curriculum design for any subject. Second, while NTEO provides general descriptions of reasoning processes and examples from various disciplines, TIPP extends these descriptions to physics and includes only physics-related problems as examples. While NTEO organizes cognitive processes, TIPP organizes physics-related topics. Finally, while NTEO can be applied in all academic disciplines, TIPP is specific to physics education (Teodorescu et al., 2013).

The TIPP classification of physics problems assumes minimal exposure to certain knowledge, mental processes and cognitive abilities. Students often engage in different processes than those who have never encountered the problem. The focus is on basic processes such as sequencing the tasks required by the problem. Despite the adoption of NTEO's hierarchical process organization, additional research on student behavior is needed to verify the relationship between the cognitive processes activated during physics problem solving. The type of knowledge, including information and mental processes, and the cognitive complexity required to solve the problem are used to classify problems (Teodorescu et al., 2013).

The validity of the TIPP was assessed in three phases with the participation of instructor feedback, problem creators and physics education researchers. Comments focused on the classification algorithm, the definitions presented and the examples given. Participants were asked to answer questions about the algorithm, levels, definitions, necessity, examples and classification of introductory physics problems. Each participant received the taxonomy and had up to three months to evaluate the queries. Without exception, all answered "yes" to every question and found the levels indispensable. A senior researcher in physics education confirmed that students engage in cognitive processes when solving problems. To determine the reliability of the TIPP, Cohen's Kappa coefficient inter-rater reliability agreement coefficient was calculated. Test-retest reliability was determined by calculating Cohen's Kappa coefficient for each rater at two independent times (June 2008 and April 2009). These coefficient values indicate that there is a high level of agreement between raters and that the taxonomy is reliable (Teodorescu et al., 2013).

The Taxonomy of Introductory Physics Problems (TIPP) is a framework for classifying physics problems according to the cognitive processes required to solve them. It consists of levels, sublevels, categories and subcategories based on the taxonomy of educational objectives. TIPP targets physics problem solving knowledge as defined by the Physics Education Research (PER) and uses the cognitive processes defined by PER. It can be extended to metacognitive aspects that monitor, investigate and evaluate thought processes during problem solving activities. TIPP is a theoretical framework with numerous practical applications, compatible with all kinds of teaching approaches. In the past, textbook publishers have categorized physics topics according to their logic, but not according to the complexity of knowledge, mental procedures and cognition required to solve a given problem. TIPP can help textbook authors and developers to replace the vague "easy-medium-hard" distinction for end-of-chapter problems with a more precise representation of the knowledge, mental procedures and cognition required to solve a given problem (Teodorescu et al., 2013).

This taxonomy can be used to assess students' problem solving skills in physics or their cognitive development in specific domains targeted by TIPP. Future research will focus on validation based on students' performance on various problem categories, discussions prompted by the problems, and correlations between problem scores and students' scores on conceptual understanding assessments, attitude assessments, and exams. TIPP also plans to extend the taxonomy to include metacognitive aspects of student thinking, the role of intuition, attitudes, dispositions and epistemological beliefs. TIPP is a theoretical construct with practical applications in solving physics problems. Teodorescu et al. (2013) state that this construct can be used in designing educational objectives and assessing the cognitive processes of students solving physics problems.

Cognitive Processes and their Effects on Physics Knowledge and Mental Procedures

This section describes cognitive processes and their effects on physics knowledge and mental procedures, adapted from the work of Teodorescu et al (2013).

Level 1. Undoing

1-a Recall and recognition: Recalling basic physics knowledge about a problem without having to understand its structure.

Recall and recognition of physics knowledge: The student should be able to identify, list, name, recognize and write physical quantities, units, basic equations, formulas, physics terminology, concepts, symbols and phenomena. They should also be able to express general physical laws and principles, write their corresponding equations and recognize their real-world applications. The purpose of non-mathematical physics problems involving recall or recognition of knowledge is to test students' background knowledge of physics. These problems should not be complex, requiring students to recall the content of the laws and definitions of physics without requiring them to perform calculations.

1-b Execution: Performing a problem-solving procedure without making a significant error but not understanding how it works.

Carrying out physical mental procedures: The learner can calculate various physical quantities, derive their results, draw free-body diagrams, graph and plot physical quantities and solve equations related to physics.

Level 2. Understanding

2-a Integration: Defining the knowledge structure of physics and distinguishing critical problem features from non-critical ones.

Integrating physics knowledge: The learner can identify, separate, extract and select relevant physics knowledge such as domain availability, results and generalizability.

Integration of physics mental procedures: Students can mentally process separating necessary items from non-essential ones, creating and planning problem-solving strategies, and identifying and demonstrating mental procedure steps.

2-b Symbolization: Representing knowledge or mental process to solve physics problems correctly.

Symbolizing physics knowledge: Physical quantities, basic equations, formulas, vocabulary terms, concepts, symbols and phenomena can be represented visually, verbally, mathematically or graphically by the student.

Symbolizing physics mental procedures: The learner can represent, illustrate and map the conceptual procedures involved in solving a problem.

Level 3. Analysis

3-a Matching: Identifying similarities, differences and relationships between the components of a physics problem.

Matching physics knowledge: The learner can compare, organize, distinguish, match, order and reorder the magnitudes of physical quantities, physical phenomena, equations and related expressions, as well as identify similarities and differences. They can also organize, classify and group specific details into meaningful categories and identify similarities and differences between one generalization or principle and other generalizations or principles.

Matching physics mental processes: The learner can compare, organize, differentiate, differentiate, distinguish, match, order, sort, sequence and reorder mental processes. The student can identify similarities and/or differences between two mental processes.

3-b Classification: Organizing physics knowledge into higher and lower categories for problem solving.

Categorizing physics knowledge: The learner can identify, determine, demonstrate and assign lower and higher categories for specific knowledge, including identifying the higher category of a physics principle and inferring its applications and implications.

To be able to classify mental procedures in physics: The learner will be able to define, discuss, evaluate, explain, discuss, evaluate, explain and determine the degree of generality of higher and lower mental procedures in physics problems.

3-c Analyzing errors: Analyzing the logic, reasonableness and accuracy of physics knowledge.

Analyzing errors in knowledge of physics: The learner can identify, demonstrate, discuss, evaluate, check, discuss, explain, illustrate, exemplify and assess the reasonableness of knowledge of specific details, generalizations and principles.

Analyze errors related to physical mental procedures: The learner can recognize errors made during the mental execution of a procedure.

3-d Generalization: Using existing physics knowledge to establish new generalizations or principles.

Generalizing physics knowledge: Students can construct and defend generalizations and principles based on given details, and when exposed to these principles, they can construct them in a more general way.

Generalizing physical mental processes: The student can formulate and defend generalizations about mental processes.

3-e Determination: Using knowledge of physics, discovering new applications and logical consequences.

Identifying physics knowledge: This category of problems requires students to develop generalizations about mental processes that are not widely available in textbooks or PER literature. They can recognize properties that may or may not hold under certain conditions and predict what can or should occur under those conditions.

Identify mental processes in physics: The learner can make inferences about mental processes and their consequences under certain conditions and detail how the use of a particular process helps them make predictions.

Level 4. Knowledge Utilization

4-a Decision-making: Choosing between two or more alternatives.

Decision-making: The learner can make decisions about details, generalizations and principles.

Decision-making about physics mental procedures: The learner makes decisions about mental procedures based on his/her mental procedure abilities and knowledge.

4-b Overcoming obstacles (problem solving): Completing a goal or initiative despite obstacles or limiting circumstances.

Overcoming obstacles related to knowledge of physics: The student solves problems involving lower-order cognitive processes by using knowledge to overcome obstacles presented in the problem, overcoming constraints and developing problem-solving skills.

Overcoming obstacles related to physics mental procedures: The learner overcomes an obstacle using knowledge of a mental procedure.

4-c Experimentation: Generating and testing hypotheses to understand phenomena based on the rules of evidence of statistical hypothesis testing.

Experimentation related to knowledge of physics: Students generate and test hypotheses about physics and make predictions based on known or assumed principles. Design tests and evaluate the validity of principles based on test results.

Conducting experiments related to physics mental procedures: Using knowledge of mental procedures related to physics, the learner generates and tests hypotheses related to mental procedures.

4-d Research: Developing and testing hypotheses about past, present and future events using logical and well-structured arguments as evidence.

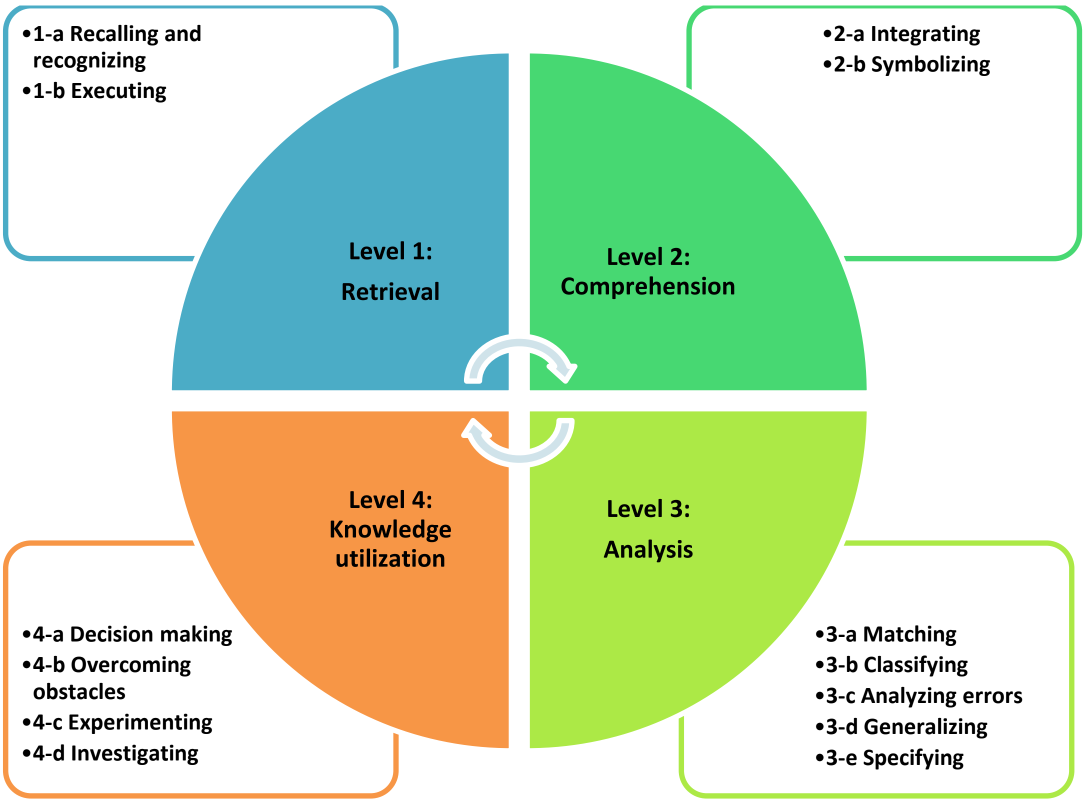
Investigate physics information: The learner uses information literacy to investigate past, present or future events or to conduct information-related research.

Investigate mental procedures related to physics: The learner uses their knowledge of mental procedures to investigate past, present or future events or to investigate mental procedures.

Figure 1 below shows the taxonomy of cognitive processes in physics problems.

Figure 1

Taxonomy of Cognitive Processes in Physics Problems



Findings

Analysis of BPT Physics Questions according to the Taxonomy of Cognitive Processes

In this section, the results of the analysis of the physics questions in the 2023 Higher Education Institutions Exams, Basic Proficiency Test (BPT) for the application of the Physics Questions Cognitive Processes Taxonomy (PS-PST) will be presented.

In BPT, there are 7 questions in Physics from 9th and 10th grade subjects. Table 1 shows the subject distribution of physics questions asked in 2023-BPT according to grade levels.

Table 1

Distribution of 2023 BPT Physics Questions by Grade Level

Subject’s Title	Grade Level	Question Number
Introduction to Physics	9	-
Matter and Properties	9	Question 1
Motion and Force	9	Question 2
Work, Power and Energy	9	Question 3
Heat, Temperature and Expansion	9	Question 4
Electrostatics	9	-
Grade 9 Total Number of Questions		**4**
Electric Current and Circuits	10	Question 5
Magnets and Magnetism	10	-
Pressure	10	-
Lifting Force	10	-
Introduction to Waves and Spring Waves	10	-
Water, Sound and Earthquake Waves	10	-
Enlightenment	10	Question 6
Shadow, Plane Mirrors and Spherical Mirrors	10	Question 7
Refraction of Light and Colors	10	-
Lenses and Optical Instruments	10	-
Grade 10 Total Number of Questions		**3**
Total Number of Questions		**7**

As can be seen in Table 1, while 4 questions were asked at the 9th grade level in 2023, 3 questions were asked at the 10th grade level. "Matter and Properties", "Motion and Force", "Work, Power and Energy" and "Heat, Temperature and Expansion" are the subjects that were asked questions at the 9th grade level. At the 10th grade level, questions were asked on "Electric Current and Circuits", " Enlightenment" and " Shadow, Plane Mirrors and Spherical Mirrors".

A detailed explanation and analysis of each question according to TIPP is shown below.

Analysis of Question 1

Question 1 is a question about matter and its properties. Atmospheric measurements are planned to be made with a balloon high above the ground on a newly discovered planet. The mass-volume graph of gases A, B, C and D on this planet at constant temperature and pressure is given. The atmosphere of this planet can be composed of A, B, C or D gases and the balloon can be filled with these gases. It is asked in which of the following situations the balloon can take off from the ground and make atmospheric measurement: filling the atmosphere with A gas and the balloon with a mixture of B and D gases, filling the atmosphere with B gas and the balloon with A gas, and filling the atmosphere with a mixture of C and D gases and the balloon with C gas. The weights of the balloon and the measuring devices on the balloon are neglected.

In the solution of this problem, the basic points that the student should know about the subject will be as follows:

1. Know that the mass of a substance is calculated by dividing its mass by its volume.

2. Know that the mass of a mixture will have a value between the masses of the substances that make up the mixture.

3. Know that the gas or gases filling the balloon must be smaller than the mass of the gases and gases that make up the atmosphere in order for the balloon to be able to lift off the ground.

4. Using the given mass-volume graph, rank the masses of gases A, B, C and D and mixtures of gases B and D and C and D in order of magnitude for each situation asked in the question.

In this first question on matter and its properties, students are expected to recognize the concept of mass and calculate the mass from the mass-volume graph. After calculating the mass, they are expected to make comparisons for different situations. In this framework, according to TIPP, this question requires matching (3-a) at the analysis level.

Analysis of Question 2

Question 2 is a question about motion and force. It is observed that the magnitude of the total displacement of an automobile moving on a highway for 30 seconds is equal to the total distance traveled during this period. Accordingly, it is asked which of the following statements are absolutely true: the car moves at a constant speed for 30 seconds, it travels in the same direction continuously or it moves on a linear path.

In the solution of this problem, the basic points that the student should know about the subject will be as follows:

1. The concept of displacement is equal to the vectorial difference between the final position of an object and its initial position.

2. The path taken is calculated by multiplying the average speed of the object by the total elapsed time.

3. Students should be able to evaluate the equality of displacement and path taken and decide whether the situations given in the question are correct or not.

In the second question from the subject of motion and force, students are expected to know the concepts of displacement and "path taken" and the difference between them. They are expected to decide whether the given situations are correct by using the knowledge that the displacement and the path taken are equal. In this context, it is a question that requires matching (3-a) at the analysis level according to TIPP.

Analysis of Question 3

Question 3 is a question about work, power and energy. It is also a question that seems to be related to the subject of illumination. The average illuminance of 750 candela on the surface of a desk in a room can be provided by any one of 75 watt incandescent filament, 13 watt LED or 40 watt fluorescent bulbs alone. Accordingly, it is desired to compare the electrical energy consumed by incandescent filament, LED and fluorescent bulbs when these bulbs are operated for equal time.

In the solution of this problem, the basic points that the student should know about the subject will be as follows:

1. Know that the mass of a substance is calculated by dividing its mass by its volume.
2. Know that the mass of a mixture will have a value between the masses of the substances that make up the mixture.
3. Know that the gas or gases filling the balloon must be smaller than the mass of the gases and gases that make up the atmosphere in order for the balloon to be able to lift off the ground.

4. Using the given mass-volume graph, rank the masses of gases A, B, C and D and mixtures of gases B and D and C and D in order of magnitude for each situation asked in the question.

In the third question from the topic of work, power and energy, students are expected to remember the formula between electrical energy and electrical power and solve the equation by substituting the given values. In this context, according to TIPP, it is a question that requires executive processing (1-b) at the recall level.

Analysis of Question 4

Question 4 is a question about heat, temperature and expansion. Energy transfer between substances in thermal interaction can be realized by conduction, convection or radiation. Accordingly, the fact that the heat given by the Sun to space can reach the outermost layer of the Earth's atmosphere without the need for a material medium can be given as an example of heat transfer by conduction, radiation or convection.

In the solution of this problem, the basic points that the student should know about the subject will be as follows:

1. Know that energy transfer by conduction and convection is the transfer of energy between particles of matter.
2. Know that energy transfer by radiation is by means of radiation, i.e. electromagnetic waves, and therefore can also take place in a vacuum (an environment where there is no matter).

In the fourth question from the heat and temperature topic, students are expected to remember the properties of heat conduction pathways. In this framework, according to TIPP, the fourth question is evaluated as a question at the recall and recognition level (1-a).

Analysis of Question 5

Question 5 is a question on electric current and circuits. A student constructed an electrical circuit by connecting a battery with neglected internal resistance, a switch and identical K, L, M, N, P and R bulbs. In the first observation, the student touches the tip of the switch to point 1 and observes the brightness of the bulbs. In the second observation, he touches the tip of the switch to point number 2 and observes the brightness of the bulbs. Accordingly, the student is asked which light bulbs' brightness will remain the same for both observations.

In the solution of this problem, the basic points that the student should know about the subject will be as follows:

1. Know that the brightness of lamps depends on their power.
2. Know that electrical power is directly proportional to the resistance of the lamp and the square of the current flowing through the lamp.
3. Draw the circuit when the switch is placed in different positions in the circuit.
4. Know how to calculate the equivalent resistance of a circuit.
5. Know what a short circuit is.
6. Calculate the power of a battery in an electrical circuit.
7. Calculate the power to be allocated to the lamps in an electrical circuit.

In the fifth question on electric current and circuits, students are expected to analyze the circuit and make comparisons. In this context, according to TIPP, this question requires matching (3-a) at the analysis level.

Analysis of Question 6

Question 6 is a question about illumination. A point source of luminous intensity I is placed at the center of a transparent spherical lampshade and suspended from the ceiling by a chain. The intensity of illumination of a point K perpendicular to the lampshade at a distance of K units is E and the total luminous flux passing through the lampshade surface is Φ. In this arrangement, respectively; 1. operation: Remove the transparent spherical lampshade and install another transparent lampshade of smaller radius made of the same material, 2: Painting the entire surface of the new lampshade to be translucent, and 3: Shortening the chain of the lampshade. According to the changes in the intensity of light (I), intensity of illumination (E) and luminous flux (Φ) as a result of the operations performed, the total luminous flux (Φ) passing through the lampshade surface increases at the end of the 1st operation, the intensity of light (I) of the point source decreases at the end of the 1st operation, the intensity of light (I) of the point source decreases at the end of the 2nd operation. The intensity of illumination (E) of point K decreases at the end of the 1st process, the intensity of illumination (I) of the point source increases at the end of the 2nd process, or the intensity of illumination (E) of point K does not change at the end of the 3rd process.

In the solution of this problem, the basic points that the student should know about the subject will be as follows:

1. Know the definition of luminous flux, remember that it does not depend on the radius.
2. Know the definition of luminous intensity, remembering that it depends on the number of light particles emitted per unit time from the source.
3. Know the definition of the intensity of illumination, remember that it is directly proportional to the luminous flux falling on the surface.
4. Know the definition of the intensity of illumination and remember that it is inversely proportional to the square of the perpendicular distance from the light source.

The sixth question, which comes from the topic of enlightenment, expects students to know the basic concepts of luminous flux, luminous intensity and intensity of illumination and to recognize the general properties of these concepts. They are also asked to make calculations related to each concept. In this context, it is a question that requires integration at the comprehension level (2-a) according to TIPP.

Analysis of Question 7

Question 7 is a question about shadows, plane and spherical mirrors. In order to measure the distance between the Moon and the Earth, an astronaut on the Moon wants to place a system on the lunar surface that allows LASER beams sent from the Earth to reflect back on itself. For this purpose, he prepares different setups by using several plane mirrors as well as hollow and bump mirrors with focal point F and center M and places them on the lunar surface. Accordingly, it is asked which systems the astronaut placed on the lunar surface could be.

In the solution of this problem, the basic points that the student should know about the subject will be as follows:

1. Know the rules of reflection in plane mirrors.
2. Know the rules of reflection in spherical mirrors.
3. Apply the rules of reflection in systems using different mirrors.

In the seventh question about plane and spherical mirrors, students are expected to apply the reflection of light in different mirrors. In this context, according to TIPP, this question is evaluated as a question requiring executive processing (1-b) at the retrieval level.

The results of the analysis detailed above are shown together in Table 2.

Table 2

Analysis of 2023 BPT Physics Questions according to TIPP

Question Number	TIPP Level
1	3-a (Analysis-Matching)
2	3-a (Analysis-Matching)
3	1-b (Retrieval- Executing)
4	1-a (Retrieval- Recalling and recognizing)
5	3-a (Analysis-Matching)
6	2-a (Comprehension-Integrating)
7	1-b (Retrieval- Executing)

According to Table 2, 3 of the questions were evaluated as a question at level 1, 1 at level 2 and 3 at level 3. At the 4th level, there were no questions. The question with the lowest level is the 4th question from the subject of heat, temperature and expansion, which is considered to be at level 1-a. In level 1-a questions, students can express basic laws and principles of physics, identify, determine, list, name, recognize and write physical quantities, units, equations, formulas and phrases, ideas, symbols and phenomena. They can also formulate equations and understand how they are applied in the real world. There are 3 questions with the highest level and all of them are at level 3-a. In these questions, students are expected to compare physical quantities, physical phenomena, equations and expressions, organize, distinguish, sort, find similarities or differences and categorize certain details into meaningful groups. Table 3 below shows the distribution, percentages and frequencies of the questions according to the levels.

Table 3

The Distribution of 2023 BPT Physics Questions according to TIPP

Level	Category	Question Number	Frequency	Percentage
1	Retrieval	3, 4, 7	3	42.85
2	Comprehension	6	1	14.30
3	Analysis	1, 2, 5	3	42.85
4	Knowledge Utilization	-	-	-

As can be seen in Table 3, 42.85 percent of the TYT physics questions were at the recall level, 42.85 percent at the analysis level and 14.30 percent at the comprehension level. No questions were asked at the level of knowledge utilization.

Discussion and Results

In this study, the TIPP taxonomy developed by Teodorescu et al. (2013) using NTEO was adapted into Turkish and 7 physics questions asked in the 2023 BPT were analyzed using this taxonomy. According to the results obtained, it was determined that 3 of the 7 questions were at the recall (recall-recognition) level, 1 at the comprehension level and 3 at the analysis level. It was determined that no question was asked at the level of using knowledge.

In the related literature, Qaddafi, Ikbal & Sari, (2022) and Tunnisa, Syamsu & Werdhiana, (2015) used Taxonomy of Introductory Physics Problems (TIPP) in their studies. Qaddafi et al. (2022) analyzed the structure of the cognitive system in the national high school physics exams in 2019 using the Taxonomy of Introductory Physics Problems (TIPP) framework. The findings show that the analyzed questions were designed according to the TIPP principles with the categories of remembering, understanding, analyzing, and using knowledge. The distribution of questions across categories was uneven, with fewer questions in the categories of remembering and understanding than in analyzing and using knowledge. These findings are consistent with this study in terms of the unbalanced distribution of questions across categories.

Tunnisa et al. (2015) used the TIPP to analyze and describe the problem solving skills of students studying physics. Their study revealed that pre-service physics teachers' problem solving skills in particle dynamics were classified as low. One of the factors influencing this is that most of the students only know the equations and their expressions without understanding the concepts behind Newton's laws. Also, students showed low interest in solving problems related to the applications of Newton's laws, which affected their problem solving skills. In the 2023 TYT Science (Physics, Chemistry, Biology) test, the average success rate was 2.91 out of 20 questions (OSYM, 2023b). In this study, although 42.85 percent of the questions were first level, the success rate (2.91/20) was around 14.55 percent. This shows that students in high schools are not able to acquire even the first level in science courses. Considering that the physics test success rate may be even lower, it suggests that students may be at the lower levels of the first level in physics courses in high schools.

The results obtained from this study are generally in line with the related literature. The results of the study show that TIPP can be a good taxonomy that can enable teachers to plan the review, application and evaluation of knowledge and algorithms in solving physics problems. Discussions with related literature emphasize the importance of choosing the appropriate taxonomy for teaching purposes and show that analyzing physics problems can help to identify and understand students' needs.

Recommendations

In this study, physics questions asked in the basic proficiency test (TYT) of higher education entrance exams were analyzed according to TIPP. According to the results obtained, more questions are asked at the first level (retrieval) and third level (analysis). Based on the findings acquired, a greater number of questions are posed at the primary stage of retrieval and the matching stage of analysis. In this context, physics teachers should allow students to express the basic laws and principles of physics in various ways and help them comprehend how these laws and principles are implemented in the real world. Additionally, students should possess the capability to discern physical quantities and occurrences, and to distinguish similarities and disparities when they encounter unfamiliar situations. Classes on the subject of physics should be organized in this particular situation, granting pupils the opportunity to grasp the principles and regulations of physics and gaining knowledge on how to implement them in different situations. Once again, based on the discoveries of this examination, it is recommended that physics educators appropriately configure their appraisal and evaluation procedures. As an illustration, Angraeni et al. (2020) devised a Fluids Assessment (FAss) grounded on the Taxonomy of Introductory Physics Problems (TIPP) for dynamic fluid material. An analysis of validity employing the Rasch Model demonstrated that 17 out of 34 items were deemed valid, and the reliability was classified as "good" with a coefficient of 0.90. The FAss exhibited a relatively moderate level of difficulty, a good power differential, and functioning distractors. The majority of students achieved mastery in all levels of the TIPP, except for levels 3a, 4d, and 4c, which were associated with matching, investigating, and experimenting.

Furthermore, researchers have the capacity to scrutinize previous years' questions on physics in the TYT in accordance with this taxonomy, thereby examining how they have evolved throughout the years. Likewise, apart from the TYT questions, physics questions posed in the Field Proficiency Tests (AYT) can also be investigated utilizing this taxonomy, enabling the making of diverse comparisons.

Lastly, educators have the opportunity to devise physics questions employing this taxonomy, facilitating students to engage in cognitive processes not solely at the lower levels, but also at the upper levels.

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