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An analysis of the secondary school electricity curriculum via the taxonomy of introductory physics problems

Ahmed Lazaar[1], Chaimae Chafi[2], Jamila Riyahi[1], Mohamed Chergui[3]
[1]Natural Resources and Sustainable Development Laboratory, Science Faculty, Ibn Tofail University, Kénitra, Morroco
[2]High Normal School (ENS), Mohamed V University, Rabat, Morocco
[3]Research Team in Mathematics Teaching and Learning, Regional Center of Training and Education Professions, Kenitra, Morocco

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ABSTRACT

One of the factors responsible for difficulties in learning electricity is the lack of relevance in the choice of cognitive activities engaged in teaching activities. Given this situation, we sought to explore cognitive aspects in the secondary school electricity curriculum and its implementation in textbooks. The study uses a mixed-methods approach to examine some cognitive aspects of the official framework texts and their implementation in the activities of final-year secondary school physical science textbooks. The corpus analyzed consists of 36 activities proposed in two officially accredited textbooks, totaling 258 questions covering the various topics in the electricity program. The taxonomy of introductory physics problems, designed for physics problems, is used as a data collection tool. The official texts and each question in textbooks activities are examined using a grid to identify the cognitive levels involved. After quantitative and qualitative data processing, the study revealed that all the cognitive levels of this taxonomy are recommended in the formal electricity curriculum, with a clear advantage for the two cognitive levels: comprehension and analysis. This choice of cognitive levels is relatively respected in the conceptualization activities proposed in the textbooks, with a strong preference for comprehension and analysis. The dependency between the cognitive levels involved in the activities and the topics on electricity has also been confirmed statistically. This dependence is justified by the fact that the degree of involvement of certain cognitive sub-levels of restitution and analysis varies significantly from chapter to chapter. We have also noted that the utilization of knowledge and certain sub-levels of analysis of knowledge are almost neglected.

Corresponding Author:

Ahmed Lazaar
Natural Resources and Sustainable Development Laboratory, Science Faculty, Ibn Tofail University
University Campus, Kenitra, Morocco
Email: ahmed.lazaar@uit.ac.ma

1. INTRODUCTION

Electricity is essential to all human activity, and it is therefore important to enable learners to acquire not only the knowledge that relates to it, but also the skills needed to understand and explain physical and other phenomena, and in particular the appropriate use of this tool. Thus, electricity as educational knowledge is one of the fundamental concepts integrated into physics curricula at all grades. However, it is also one of the concepts for which misconceptions are very frequent and more persistent, as indicated by several authors [1], [2]. Student misconceptions include the existence of static current in open-circuit wires [3], the substantial nature of electric potential [4], zero current implies zero voltage [5], current is the cause, and voltage is the consequence [6].

The authors [7], [8] observed that learners often have difficulty understanding the nature of electric current, perceived as a continuous flow of electric charges requiring a closed circuit. They also consider that current attenuates in a circuit, where it is used by other components and by the unused terminal of the battery. Electrical components are also often seen as electrical sinks that transform current into energy. Another form of misconception among learners is the relationship between voltage and current, and the role of power supplies in circuits. Indeed, the authors [9], [10] noted that students confuse electromotive force, voltage and electric potential difference. In addition, they perceive voltage as the result of current rather than its source, and power supplies as sources of constant current. They also believe that voltage is only present in closed circuits. Gilbert and Watts [11] noted that students often have difficulty understanding resistance and its role in a circuit. They interpret resistance as a mathematical link between voltage and current, and may naively believe that it consumes electrical charge.

To overcome these difficulties, it is necessary to develop effective teaching strategies to help students overcome these difficulties and make physical science knowledge more accessible. In particular, planning differentiated instruction, defining relevant objectives, diagnosing students' difficulties and designing appropriate learning activities will be major challenges. To this end, Cox and Unks [12] stress the need for teachers to analyze questions addressed to learners in order to target all cognitive functions and ensure that they are strongly related to those the teacher wishes to develop. They then suggest the use of cognitive taxonomies as a model to help students engage their learning in complex tasks and situations at school and in life. Several other authors [13]–[15] have pointed out the importance of developing students' cognitive abilities. This involves designing learning activities that target them with well-designed questions. In this respect, Azar [16] asserts that the development of students' creativity and critical thinking is strongly linked to the quality of the questions they are asked. Beatty *et al*. [17] also highlight that, to be used effectively in physics teaching, the question needs to have a pedagogical objective that targets content, process and metacognition.

These attitudes are aligned with the work of Bloom [18], who developed a taxonomy to assess the requirements of course objectives and in part to explore examination requirements, and became widely used, especially as it was subsequently modified by Anderson and Krathwohl [19] to better meet the specific needs of various disciplines. Speaking of discipline specifics, we would like to point out that experimental activity is an essential component of physical science teaching. Indeed, Girwidz *et al*. [20] argue that experiments in physics education help students to observe, test hypotheses, understand complex concepts, comprehend technical devices and test predictions, theories and models, thereby generating interest and enhancing understanding. Ozkal *et al*. [21] confirm that experiments in physics promote the apprehension of science and technology, as well as in-depth analysis of the role of new scientific knowledge in human society. It is therefore natural to see taxonomies being developed to address the specificities of this field of science. For example, focusing on student actions and learning outcomes, Doyle [22] identified four types of tasks: memory tasks, procedural tasks, comprehension tasks and opinion tasks. According to Dickie [23] and Doyle's [22] work is relevant to physics exam questions, as it adds procedural complexity to cognitive ones. Procedural tasks involve the application of standardized formulas or algorithms, while comprehension tasks involve recognizing transformed information and drawing conclusions.

For Süzük [24], the taxonomic analysis of physics problems is crucial for certificative assessments to guide program design. After examining how different cognitive processes are used to solve problems in a basic skills test using a taxonomy of cognitive processes in physics problems, he deduced that none of the questions targeted the use of knowledge. Tikkanen and Aksela [25] analyzed 257 questions from 28 French higher education exams between 1996 and 2009 to determine the types of cognitive skills and knowledge measured by these tests using a qualitative approach and content analysis based on Bloom's revised taxonomy. The results showed that the majority of chemistry questions requiring higher cognitive skills involved analysis, while those dealing with lower cognitive skills were evenly split between comprehension and application. Most questions required procedural knowledge and some conceptual knowledge. Qaddafi *et al*. [26] reported that many students taking the national physics exam in Indonesia found the questions difficult. To understand how the questions were designed and to describe the cognitive system of this exam, they used the taxonomy of introductory physics problems (TIPP). They observed that the questions were distributed across all levels of the TIPP, with the utilization and analysis of knowledge being the most frequent. The most engaging process was overcoming obstacles, but symbolism and decision-making were not included in the test questions.

Several studies have shown that the use of higher cognitive levels is not common practice. For example, Gates and Pugh [27] conducted a study to determine the extent to which examinations match the skills required by employers, such as synthesis and creation, in British higher education. The study used Bloom's taxonomy to classify exam questions and identify the cognitive levels students need to succeed. The results showed that electromagnetism and thermodynamics questions tested memory and application more than other cognitive domains, with evaluation and creation being tested less. The study suggests that formulating questions using a variety of measurable verbs may be more effective in encouraging high-level metacognitive skills in formal exams.

On the other side, using Bloom's revised taxonomy, Upahi *et al*. [28] analyzed 328 questions from West African Examination Council exams from 2010 to 2014 to determine the types of cognitive skills and knowledge dimensions measured by chemistry exams. Results showed that questions focused more on lower-order cognitive skills than higher-order cognitive skills, with question frequency generally divided into conceptual, factual and procedural categories. Johnson *et al*. [29] conducted a study to determine the cognitive levels of learning objectives in the recently revised physics, chemistry and biology programs in Queensland. The study analyzed the objectives of the three programs using Marzano and Kendall's [30] taxonomy of educational objectives, with a list of verbs defining each cognitive level. The analysis revealed that most subjects focus on the restitution or comprehension of physics, and less on the utilization or analysis of knowledge. The chemistry questions, on the other hand, showed a more even distribution of cognitive levels.

From this review of literature, it emerges that the transposition of electricity concepts into the various teaching grades is hampered by difficulties revealed in students' conceptualization processes. In addition, a lack of interest or even a negligence in appropriately selecting the types of cognitive activities involved in teaching physics can only have a negative impact on the quality of learning. Given this situation, we consider it of the greatest importance to examine the conditions under which electricity is taught in Moroccan secondary schools. Our exploration will be of a cognitive scope. Consequently, it aims to answer the following research questions: i) What place do official guidelines for teaching electricity assign to students' cognitive activity? ii) What cognitive levels are involved in textbook activities? and iii) Do the types of cognitive levels involved in textbook activities depend on the topics covered in the electricity course?

The main aim of this study is to find out whether the design of the electricity curriculum and its implementation in textbooks contribute to good cognitive development that promotes the acquisition of skills related to this indispensable area of physics. Consequently, the added value of this research is to make available to all pedagogical actors a detailed description of the cognitive aspect in the teaching of electricity, and consequently provide practicing teachers with the ability to make appropriate choices of teaching and learning processes in this important field of physics.

2. THEORETICAL BACKGROUND

In this section, we limit ourselves to presenting a synthesis of some taxonomies related to physics problem-solving, which will be useful in the remainder of our work for developing the methodological framework and elaborating a framework for discussing the results that will flow from the data collection. Motivated by the idea of classifying a physics question on the basis of a taxonomy, and having found that the one defined by Bloom did not perfectly meet the mental requirements of physics questions, several researchers have proposed the development of appropriate taxonomies. We begin with the taxonomy for coding the cognitive demands of physics assessment items, developed by Dickie [23] on the basis of Bloom's taxonomy. In this taxonomy, the degree of thinking required by assessment items is classified into four hierarchical levels. The first level corresponds to memory, which involves recalling information as it has been learned, such as memorizing terminology and specific facts associated with a field of study. The second level involves performing a series of routine steps to solve a problem. The third level concerns solving a problem, but requires choosing the rule or formula to apply based on the information provided in the problem. The final level consists of recognizing transformed information and drawing conclusions from the information previously encountered. Dickie [23] considers that by adopting these levels, the cognitive requirements of problems are divided into four levels: memory, mechanical application, those requiring limited understanding, and those requiring understanding of principles.

In the same line of thinking, Marzano and Kendall [30] have developed another taxonomy of educational goals, which has been used and tested in a wide variety of contexts and with a wide variety of audiences. This new taxonomy has one dimension relating to the three knowledge domains and a second relating to the three systems of thought. The three knowledge domains include information, sometimes called declarative knowledge, procedural knowledge and the psychomotor domain [30]. As for the three systems of thought, according to Marzano and Kendall [31], they relate to the cognitive, the metacognitive and the self-system, and are classified according to the following levels:

- Level 1: recuperation, involving the recognition, recall and execution of basic information and procedures. These objectives correspond to Bloom's "knowledge" level.
- Level 2: comprehension, which involves identifying and symbolizing the essential characteristics of knowledge. This level is similar to Bloom's taxonomy, but excluding the symbolization processes.

- Level 3: analysis, which concerns thoughtful extensions of knowledge. This level is sometimes referred to as the higher order, as it involves five types of analysis process: comparison, classification, error analysis, generalization and specification.
- Level 4: utilization of knowledge, i.e., the execution of specific tasks, often integrated into authentic tasks. This new level includes decision-making, problem-solving, experimentation and investigation, which are closely related to synthesis in Bloom's taxonomy.
- Level 5: metacognition involves setting and monitoring goals. The new taxonomy identifies four types of metacognitive process: objective specification, process control, clarity control and precision control. This level cannot be compared with any other in Bloom's taxonomy.
- Level 6: the self-system concerns the involvement of attitudes, beliefs and behaviors controlling motivation, rarely addressed explicitly. This new level has no clear equivalent in Bloom's taxonomy.

In seeking an appropriate classification for physics problems, Teodorescu *et al*. [32] developed the TIPP, which relates physics problems to the cognitive processes required to solve them. The aim is to provide a system for evaluating the individual processes involved in solving physics problems. In fact, Teodorescu *et al*. [32] consider that the fundamental idea in the design of this taxonomy is to seek to categorize physics problems according to the cognitive processes and knowledge domains they involve. According to these authors, the taxonomy developed by Marzano and Kendall [30] integrates problem-solving into the list of cognitive processes, it also includes cognitive processes identified by physics education research as relevant to physics problem-solving, and it makes a clear distinction between knowledge and cognitive processes. They therefore chose Marzano and Kendall's [30] taxonomy as the basis for developing TIPP, limiting themselves to the first four levels of the cognitive system. The levels of TIPP and the related sublevels are summarized in Table 1.

According to Toledo and Dubas [33], the TIPP taxonomy offers an operational framework for distinguishing lower-order from higher-order thinking. It consists of cognitive levels that are differentiated according to the degree of cognitive control or intentionality of the thinking processes required to accomplish a task. On the other hand, it enables a more precise classification of thinking skills by focusing on the targeted or engaged process.

Table 1. Description of TIPP taxonomic levels

Taxonomic levels	Taxonomic sublevels	Description
Retrieval	R1: Recall and recognition	Identify the fundamental physical knowledge associated with a problem
	R2: Execution	Perform a procedure or task required to solve the problem without making significant errors
Comprehension	C1: Integration	Identify the fundamental structure of physics knowledge and distinguish between critical and non-critical aspects
	C2: Symbolization	Develop an accurate symbolic representation of the information or method required to solve a problem
Analysis	A1: Matching	Reveal similarities, disparities and links between the elements of a problem
	A2: Classification	Classification Determine the types of categories into which the knowledge related to a physics problem can be classified
	A3: Error analysis	Highlight the logic, reasonableness and accuracy of physical knowledge
	A4: Generalization	Construct new generalizations or principles from available physical knowledge
	A5: Specification	Exploit existing physical knowledge to create new applications or logical consequences
Utilization of knowledge	U1: Decision-making	Make a choice between different options
	U2: Overcoming obstacles	Achieving a goal or carrying out a task in the presence of obstacles or limitations
	U3: Experiment	Generate and test hypotheses to understand phenomena, based on rules of evidence
	U4: Investigate	Create and evaluate hypotheses about past, present and future events, using well-established, logical arguments as effective evidence

3. METHOD

3.1. Research design

Given the exploratory nature of this study, a methodological protocol is established in accordance with this type of research. A mixed-methods research design would be ideal. This model combines qualitative and quantitative methods to explore the cognitive aspects of the secondary school electricity curriculum and its implementation in textbooks. In this study, we limit our analysis to the Moroccan school curriculum. We focus on the electricity program in the final year of secondary school for the physical sciences and mathematical sciences (17-18 years old). We examine the electricity teaching program, starting with the official framework texts, then examining its implementation through textbooks approved by the Ministry of National Education. So, let us start with an institutional framing of the concept.

3.2. Institutional framework

First of all, let us note that the notion of electricity is present in teaching programs as early as elementary school. The middle school electricity program [34] is characterized by a shift from general observation to scientific observation and the application of experimental methods. This approach consolidates the knowledge acquired in elementary school. Concepts such as electric current, electric voltage, resistance, direct and alternating current, electric power and energy are introduced using an experimental approach to help students grasp these concepts in a concrete way. In this grade, students are also put in the position of conducting a quantitative study to verify physical laws such as knot laws, voltage additivity and Ohm's law, thus reinforcing and consolidating the various experimental steps.

In secondary school, the physics program is in line with the pedagogical and didactic continuity of the secondary school program [34]. Thus, the concepts of electric current and voltage, the characteristics of a few passive/active dipoles, the transistor, energy exchange in an electric circuit and electric power will be covered in the first two years of secondary school. In the final year of secondary school, the electricity program takes up 32% of the time allocated to physics. The course consists of four chapters, the first three covering RC, RL, and RLC circuits, and the last covering applications. The RC circuit consists of a resistor and a capacitor, the RL circuit consists of a resistor and an inductor, and the RLC circuit combines a resistor, a capacitor, and an inductor [34]. According to the framework text [35], this program aims to enable students in science streams to acquire fundamental skills by engaging a set of cognitive processes coded P1 to P14, as described in Table 2.

Table 2. Cognitive processes targeted in the teaching of electricity in the final year of secondary school

Abilities	Cognitive processes involved
Knowledge and abilities	P1: Know and use: symbols, conventions, units, order of magnitude, definitions, laws, principles, formulas
	P2: Describe and explain a phenomenon
	P3: Predict the evolution of a physical phenomenon or chemical system
Application of an experimental solution	P4: Propose an experiment protocol
	P5: Draw a diagram of an experiment
	P6: Distinguish between the different parts of an experimental set-up and determine the function of each part
	P7: Use experimental data, analyze them and deduce conclusions
	P8: Anticipate possible risks in experimental situations and use appropriate safety equipment
Problem solving	P9: Mobilize the necessary resources
	P10: Organize the stages of resolution
	P11: Use mathematical tools
	P12: Construct or prove a logical deduction
	P13: Describe and analyze scientific data or results
	P14: Make a critical judgement

3.3. Analysis corpus

For the first question, which aims to explore the place given by official prescriptions to cognitive activity among students in the teaching of electricity, we will analyze the institutional requirements in the light of the theoretical study carried out earlier in this work. The aim is to identify the cognitive levels required to carry out the activities supposed to be practiced by learners, as stipulated in the official texts [34]. For the second question, we will analyze the activities proposed in school textbooks. The analysis of textbooks is justified by their main role in implementing program prescriptions. The activities analyzed are selected from physics textbooks for physical science and mathematical science classes, accredited by the national Ministry of Education with their respective accreditation numbers 12CB21307 and 04CB21108.

In both manuals, each chapter is organized as the following: i) the first part is devoted to preparatory activities, either experimental or documentary, for the introduction of new learning; ii) the second part is devoted to the presentation of the main contents targeted by the program; and iii) the last part proposes a number of practical activities designed to consolidate and invest the new learning. Table 3 shows the distribution of activities and questions in the four chapters of electricity.

3.4. Data collection and processing

Considering that the TIPP taxonomy is designed specifically for physics problems, and that it is made up of a sufficient number of levels and sublevels likely to cover all the problems of this discipline, in particular the "experiment" and "investigate" sublevels which are essential in learning physics, we have chosen to use it as a data collection tool. Hence, each question in the chosen corpus will be examined on the basis of the grid in Table 1, which provides descriptions for identifying the levels or sub-levels implied in official texts or textbook activities. To make this operation more operational, the cognitive level required in each instruction of the 36 activities in our corpus will be identified via the indicators specified in Table 4. Afterwards, the numbers for each cognitive sub-level will be counted for statistical processing using SPSS and EXCEL software.

Table 3. Distribution of activities and questions by electricity chapter

Textbooks analyzed	RC dipole		RL dipole		RLC series circuit		Applications	
	Na	Nq	Na	Nq	Na	Nq	Na	Nq
Textbook 1	2	17	3	16	5	33	4	26
Textbook 2	5	32	4	39	6	48	7	47

Note: Na: Number of activities, Nq: Number of questions

Table 4. Grid of indicators of mental procedures to be implemented

Taxonomic sublevels	Indicators
R1	Restitute laws of physics, definitions of various physical quantities and characteristic properties without going on to their implementation
R2	Carry out procedures for solving physics problems
C1	Define a strategy or simplify one that contains too many unnecessary steps, or complete a given incomplete strategy. Identify relevant information to solve the problem
C2	Represent, illustrate and map the constituent elements of a problem
A1	Compare quantities, physical phenomena and statements, identifying similarities and differences
A2	Classify physical information according to different criteria
A3	Identify errors or missing elements in execution or presentation to find the answer
A4	Generalize results, statements and equations
A5	Generate new applications or logical consequences from available physical knowledge; make predictions
U1	Make decisions about details, principles and generalizations
U2	Mobilize a mental procedure to overcome an obstacle
U3	Generate and test hypotheses
U4	Investing a mental procedure to conduct a scientific investigation

4. RESULTS AND DISCUSSION

In this section, we present the results obtained in the empirical phase of this research. The information gathered is based on a quantitative study supported by a varied statistical analysis. We then turn to a discussion of the results obtained, based on a qualitative analysis supported by the literature review we carried out. This discussion is intended to provide greater comprehensibility.

4.1. Results

4.1.1. Analysis of official prescriptions

The purpose of this subsection is to present the results of the analysis of the official requirements for teaching electricity in the final year of secondary school. The results of the classification of each cognitive process in Table 2, using the indicators in Table 4, revealed that for level R1, only one process (P1) involves knowledge recall. This means that the curriculum does not focus enough on memorization activities. For sub-levels C1 and C2, several processes (P4, P5, P9, P10, P11) are linked to this, showing that the curriculum places significant emphasis on explaining and interpreting knowledge. This indicates that students should be encouraged to understand and make sense of concepts rather than passively memorize them. Several processes (P6, P7, P8, P12) are classified as sub-levels A3, A4 and A5, meaning that students are encouraged to use their knowledge in new situations. As for processes P13 and P14, the required sub-levels are U1 and U2. This suggests that the curriculum aims to get students to transfer and generalize their knowledge, applying it to complex contexts and developing their critical thinking skills. The distribution of cognitive levels in the electricity program can be seen in Figure 1.

4.1.2. Univariate statistics

Concerning the distribution of questions in textbooks according to cognitive level, we have found that there were 56 questions for the retrieval level, which generally involves the recall of factual information, 90 questions for the comprehension level, while those dealing with the analysis and utilization of knowledge were 108 and 4 respectively. A priori, we can say that the questions suggest that the learning activities are designed to target a range of cognitive levels, from recall of information to application of knowledge in practical scenarios, but this requires more rigor in the analysis. On the other side, it is very clear that the distribution of levels required in electricity activities is not evenly distributed between cognitive levels. However, this preliminary result is also insufficient for a precise description of the cognitive dimension in the manual's exercises. It is therefore necessary to present more significant results. We begin by presenting the distribution by cognitive sub-levels. The quantitative results, showing the classification of activity questions according to the various cognitive sub-levels, are given in Figure 2.

These results give rise to the following preliminary remarks: The questions presented in the electricity activities are more focused on analysis. However, it should also be noted that some of its sub-levels are not covered by the activities. The fourth cognitive level, which concerns the utilization of knowledge, is almost entirely excluded from the cognitive objectives of the activities analyzed. The absence of sub-levels A3, U1 and U2 raises the question of the intentionality of this choice in both manuals. Indeed, error analysis on the student's side implies that he or she has to make a choice, and is a necessary step in overcoming potential obstacles.

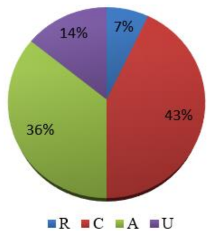

Figure 1. Distribution of cognitive levels in the electricity program

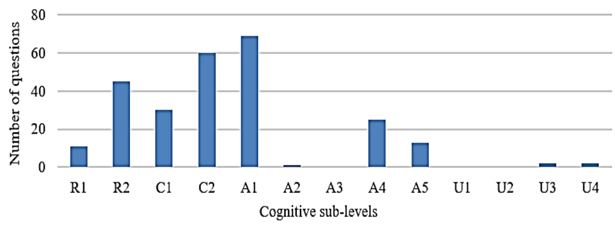

Figure 2. Distribution of questions by cognitive sub-levels

4.1.3. A cross-study

In order to take into account, the content of the activities related to the electricity course in our study, it is also relevant to carry out a cross-study involving both the courses on which the activities focus and the cognitive levels required to carry out these activities. Table 5 shows the joint numbers. For a better understanding of the quantitative results obtained, we present a graphical illustration of these data in Figure 3.

We observe a clear variation in cognitive sublevels depending on the chapters covered in the electricity course. A natural question then arises, are the two variables independent? In other words, is the diversity in the use of cognitive sublevels in different electricity chapters statistically significant? To answer this question, let us test the hypothesis of independence using the non-parametric chi-square test.

Table 5. Contingency table chapters*cognitive sub-levels

Chapters	Cognitive sublevels									
	A1	A2	A4	A5	C1	C2	R1	R2	U3	U4
RC	12	0	1	2	10	7	0	16	1	0
RL	16	0	1	4	6	19	2	6	1	0
RLC	27	0	7	1	5	18	5	18	0	0
Applications	14	1	16	6	9	16	4	5	0	2

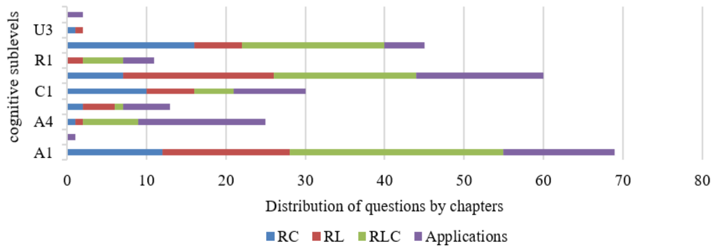

Figure 3. Histogram of stacked cognitive sublevels

4.1.4. Independency test

The main idea of the chi-square test [36] is to check whether the numbers observed in the sample differ significantly from those expected. The differences between the two numbers are therefore examined. A fundamental standard for the reliability of the chi-square test is that the expected numbers for each category must be sufficiently large. In general, it is recommended that at least 80% of the expected numbers should be greater than or equal to 5, and that none should be less than 1. To verify this criterion, we ran the chi-squared test, deleting the A2, U3 and U4 sublevels, which have relatively small numbers. The results of this operation, performed with SPSS software, are shown in Table 6. Since the expected numbers are within the above-mentioned norm, we use the chi-square test. The values obtained are displayed in Table 7. Due to the level of significance is less than 0.05, we can reject the hypothesis that there is significant statistical dependence between the two variables in our study.

Table 6. Distribution of observed and expected counts

Chapters			Application	RC	RL	RLC
Cognitive levels	A	Count	36	15	21	35
		Expected count	29.6	20.3	22.8	34.3
	C	Count	25	17	25	23
		Expected count	24.9	17.1	19.2	28.8
	R	Count	9	16	8	23
		Expected count	15.5	10.6	12.0	17.9
Total		Count	70	70	48	54
		Expected count	70.0	70.0	48.0	54.0

Table 7. Chi-square test results

Statistical parameters	Value	df	Asymptotic significance (2-sided)
Pearson chi-square	14.032	6	.029
Likelihood Ratio	14.194	6	.028
N of Valid Cases	253		

4.2. Discussion

At first sight, Figure 1 shows that all cognitive levels are recommended in the official specifications for teaching electricity in the secondary school classes covered by this study. Comprehension and analysis are more in demand than the other two cognitive levels. However, it should be noted that the two sub-levels of comprehension are engaged, while the first two of analysis are not. The same applies to the utilization of knowledge, where the last two cognitive sub-levels are not involved. This configuration of cognitive levels in the official texts framing physics teaching is relatively preserved in the development of conceptualization activities. This can be seen in Figure 2. Indeed, the predominance of comprehension and analysis persists. Having activities more focused on knowledge analysis brings to mind the conclusion of Tikkanen and Aksela [25] where it was established that the majority of questions in a chemistry bachelor's exam require analysis. On the other hand, the retrieval of electrical knowledge is involved to a greater extent than its utilization. The number of questions requiring the mobilization of the latter level is quite small (1.5%) compared to the other levels. This result is consistent with Süzük's [24] conclusion concerning the problems of a skills test in which this cognitive level was not targeted at all. Theoretically, this choice has a negative effect on metacognitive development, as deduced by Pugh and Gates [27].

In short, there is conformity between official prescriptions and their implementation in textbooks, but also some disparities. To statistically confirm or refute this relationship and measure its degree, we used the correlation coefficient. The calculation, based on the numbers corresponding to each cognitive level summarized in Tables 6 and 7, gave the value R=0.738 for Pearson's correlation coefficient. It follows that the cognitive levels recommended and those applied in the conceptualization activities are positively and strongly correlated.

In terms of cognitive sub-levels, knowledge retrieval represents around 22% of the required levels. It should also be pointed out that this level is only required when dealing with laws of physics or definitions of physical quantities. These are often closed questions dealing with factual knowledge, such as physical quantities and their units, basic equations, formulas and symbols. For example, students are asked to recall the definition of a physical quantity before calculating it, or to determine graphically the time constant τ of an RC circuit. On the other hand, it is important to note that questions relating to the last two sub-levels of knowledge retrieval and comprehension significantly exceed those relating to the first sub-levels of these two categories. More explicitly, activities in the field of electricity require the implementation of procedures specific to physics problem-solving, and a change in the register of semiotic representations, such as the illustration of physical objects or making schemas. For example, students are asked to plot the variation of electrical voltage across a capacitor or a coil with respect to time, check that the variation of current i(t) can be modelled by an exponential function, and interpret the decrease in electrical energy stored in a capacitor using natural language. In this respect, it is worth noting that the task of changing registers of representations of a problem's data or of the resources needed to solve it is a very important one for the learner's cognitive functioning, as confirmed by several authors such as Duval [37]. The role of this choice and its impact on the development of students' communications skills in physics is a research question that we consider relevant to investigate in future work.

Regarding knowledge analysis, the sub-levels (A2 and A3) that involve classifying information according to different criteria, and identifying errors or missing elements in order to find the answer, are almost entirely unexploited in conceptualization activities. The ability to identify errors and the status of the data involved in a problem is necessary in the modeling process, as it enables self-control and self-regulation, as stated by the authors in study of [38]. Comparing quantities, physical phenomena or statements by identifying similarities and differences is the sub-level most required in the activities, with a percentage of around 64%. Next come sub-levels A4 and A5. Examples of questions involving level A4 include proposing an expression for the electric voltage across the coil by experimentally studying its behavior in the case of direct or variable current, and formulating rules based on experimental results. For sub-level A5, students are asked to predict the name of an electronic circuit based on its role in a circuit, to give the relationship between electric current and voltage in the case of a periodic variable current, specifying the meaning of each term in the expression.

For the utilization of knowledge, only questions requiring the generation or testing of hypotheses, or the investment of a mental procedure to carry out a scientific investigation, were proposed. The two cognitive sub-levels represent 1.5% of the total number of questions in the corpus examined. These questions concern the proposal of an experimental protocol, investigating other applications involving an electronic component, or physics-related information such as overmodulation or the principle of amplitude-modulated voltage envelope detection. Here, it is also interesting to note that the absence of questions aimed at developing decision-making on details, or the mobilization of mental procedures to overcome an obstacle, is in line with not targeting sub-levels A2 and A3. Testing the impact of this cognitive choice on the development of students' physics skills is a second interesting question for subsequent study.

The electricity curriculum is structured into four chapters. It was therefore natural to ask whether these chapters were dependent on the levels involved in the conceptualization activities. In other words, whether or not the types of cognitive levels involved in the activities depend on the chapter in question. To answer this question, we opted for the chi-square test of independency. For this purpose, we chose to exclude all the cognitive sublevels of the knowledge utilization level and the A2 and A3 sublevels to avoid any source of bias in the test results, as their sizes are not significant. The test confirmed this dependency on the three levels of the TIPP taxonomy. Several factors may explain this dependency. Firstly, the scores for the R2 sub-level of the first cognitive level related to retrieval, as in Table 5 vary substantially in relation to the chapter under consideration. More precisely, this sub-level is more strongly involved in the two chapters on RC and RLC circuits than in the two others. It is also worth mentioning that in the RL circuit chapter, knowledge retrieval is the least focused. For knowledge comprehension, sub-level C1 is targeted much less than sub-level C2 for the two chapters on RL and RLC circuits and for applications, in contrast to RC circuitry. When it comes to knowledge analysis, the difference in involvement of the cognitive sublevels is most marked for A1 and A4, while sublevel A5 is under-engaged in all chapters.

5. CONCLUSION

Teaching electrical concepts in secondary schools faces difficulties related to students' conceptualization processes and the inefficiency of cognitive activities. This has led to questions about the conditions under which electricity is taught. Most cognitive studies in physics education focus on assessing learning. This work aims to examine the curriculum and its implementation in textbooks, determine the place of students' cognitive activity in official educational guidelines, and identify the cognitive levels involved in textbook activities. The taxonomy of introductory physics problems, designed specifically for this scientific field, is used as a tool to examine official texts and electricity conceptualization activities in textbooks. This new contribution to the research topic aims to improve the quality of learning in secondary schools.

The study revealed that all cognitive levels are recommended in the official curriculum for teaching electricity in the final year of secondary school. Comprehension and analysis are more solicited than the other cognitive levels. This cognitivist choice is relatively respected in the conceptualization activities proposed in the textbooks, with a strong predominance of comprehension and analysis. This correlation between the cognitive levels recommended and those involved in the textbook activities has been confirmed statistically. We also noted that knowledge retrieval was more important than knowledge use. Knowledge retrieval focuses mainly on the laws of physics and definitions of physical quantities. This includes factual questions on units, equations and symbols. It was also revealed that questions on the last sub-levels of knowledge retrieval and comprehension are more frequent. For analysis, the comparison of physical quantities and phenomena, identifying similarities and differences, is the most prevalent sub-level in activities targeting this cognitive level. The dependency between chapters and cognitive levels involved in conceptualization activities has been confirmed for the first three levels of the TIPP taxonomy. Factors contributing to this dependency include, for example, the contribution of sub-levels R2, C2, A1 and A4, which vary according to chapters.

Finally, it is worth noting that this study leads to several innovative perspectives that can be considered to solve problems related to the teaching of electricity. These include models of cognitive engagement that could be developed using adaptive learning systems to match cognitive activities to individual student needs, specific cognitive scaffolding by developing subject-specific pedagogical frameworks to link cognitive levels to the conceptual requirements of each electrical subject, and teacher training to enhance their skills in designing activities targeting under-represented cognitive levels and monitoring student engagement and adjusting lesson plans accordingly. It is also important to state that completing this work has led us to formulate two significant new research questions that open up promising avenues for further investigation. Firstly, we are prompted to explore the role and importance of engaging students in symbolization activities as part of physics teaching practices, particularly with regard to how these activities can influence and enhance physics communication. Second, our results raise the question of how fostering the development of cognitive sublevels A2 and A3 can contribute to enhancing students' physics competencies. These emerging questions reflect the broader educational implications of our study and suggest directions for deepening our understanding of learning processes in the discipline.

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Ahmed Lazaar	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				
Chaimae Chafi	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Jamila Riyahi	✓	✓		✓	✓					✓	✓	✓	✓	
Mohamed Chergui	✓	✓		✓	✓					✓		✓	✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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BIOGRAPHIES OF AUTHORS

Ahmed Lazaar is a secondary school physics and chemistry educational supervisor at the Tangier-Tetouan-Al Hoceima Regional Academy of Education and Training. He received a Master's degree in Chemistry from the Faculty of Sciences, Ibn Tofail, Kenitra, Morocco. Currently, he is a PhD student in Physics Didactics and Experimental Sciences at the same faculty. His research focuses on teaching and learning physics. He is interested in the cognitive activities involved in teaching and learning physics in middle and secondary schools. He has presented several papers at national and international conferences in this field. He can be contacted at email: ahmed.lazaar@uit.ac.ma.

Chaimae Chafi received her PhD in Mathematics Didactics, and Experimental Sciences the Faculty of Sciences, Ibn Tofail, Kenitra, Morocco in 2024. She has been teaching vacation courses in mathematics didactics at the same faculty of science since 2021. She received a Master's degree in Teaching and Training Professions from the Faculty of Sciences, Ibn Tofail, Kenitra, Morocco in 2018. Her research focuses on the assessment of mathematical learning in all its forms. In her research, special emphasis is devoted to cognitive and metacognitive aspects. She works as a teacher of mathematics didactics at High Normal School (ENS), Mohammed V University, Rabat, Morocco. She can be contacted at email: chaimae.chafi@ens.um5.ac.ma.

Jamila Riyahi is a distinguished university professor at Ibn Tofail University Kenitra, Morocco. She is a member of the Natural Resources and Sustainable Development Laboratory affiliated to the Faculty of Sciences at Ibn Tofail University Kenitra, Morocco. She received her PhD from the University Ibn Tofail at Kenitra. She conducts research on life and earth sciences and their instruction. These studies have been published in more than 30 refereed articles. She has directed many theses. She can be contacted at email: jamila.riyahi@uit.ac.ma.

Mohamed Chergui received his PhD from the Faculty of Sciences, Moulay Ismail, Meknés, Morocco in 2009 in applied functional analysis. He is currently full professor at Regional Center of Training and Education Professions (CRMEF) in Kenitra, Morocco. His researches are focused on Mathematics and Didactics. He is also the director of the Laboratory for Research in Teaching, Learning, Mathematics and Computer Science (LaREAMI). He is an author of more then 35 refereed scientific articles. He can be contacted at email: chergui_m@yahoo.fr.