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ANALYZING STUDENT LEARNING DIFFICULTIES, AND PROBLEM-SOLVING IN FIRST YEAR ELECTRICITY COURSES, CASE OF MOROCCAN UNIVERSITY

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Abstract

This study investigated academic challenges among 490 first-year Moroccan university students, focusing on their competency in solving electricity problems and the associated difficulties in applying mathematical concepts. Using a Conceptual Survey of Electricity and Magnetism-inspired performance tests, reliability was ensured through difficulty and discrimination indices, with a survey gathering qualitative insights. Over 35% scored below 4/10 in overall academic achievement, emphasizing the robust relationships between mathematics, electricity, and overall success. Specific hurdles have emerged in applying mathematical concepts to electricity problem solving. Multiple Correspondence Analysis revealed complex links between challenges in mathematics, physics, and the French language, influencing students' grasp of electricity concepts. The study concludes that gender minimally affects electricity module success, underscoring the need to address mathematical barriers to enhanced academic achievement.

Keywords: Electricity, Student Performance, Learning Difficulties, Problem Solving, Scientific Programs, Gender, Moroccan University.

1. INTRODUCTION

Learning about electricity is not only complex but also a decisive subject at all school and university levels. Several studies have shown that upon entering university, students face many difficulties in learning the concepts of electricity and re-investigating them in problem-solving situations [1, 2]. These difficulties have been attributed to several factors, including the abstraction and complexity of scientific concepts, mathematical shortcomings, and physicists' use of mathematical prerequisites. Indeed, a good background in mathematics helps students build an understanding of the abstract concepts of electricity [1]. In other words, if a student has good marks on math exams, he will obtain better results on physics exams, and vice versa.

The absence of necessary language skills creates difficulties that prevent the understanding and solving of problems containing formalisms and concepts of physics in general, and electricity in particular [3, 4, 5, 6]. These skills play an important role in physics at university level. In Morocco, science courses are taught in French, which contributes to student failure when faced with problems arising from scientific modules [7, 8].

The non-performance of practical work, owing to the lack of equipment and necessary materials, influences the understanding of scientific concepts, which reduces the success rate of electricity at certain university institutions [9,10]. Practice in teaching physics helps students acquire new knowledge and monitor and challenge prior knowledge, which highlights abstract and complex concepts using modeling phenomena [11,12]. Studies have demonstrated both the relationship between experiments and students' performance in science and the impact of the quality of materials available for practical work. Indeed, many students are not interested in the various contents of physics courses taught without practical work [13].

The objective of this study is to analyze student learning difficulties and problem-solving in first-year electricity courses through a test and a survey. The students were enrolled in one of four first-year scientific bachelor’s programs: Physical Matter Sciences (SMP), Chemistry Matter Sciences (SMC), Mathematical and Computer Sciences (SMI), and Mathematical Sciences and Applications (SMA). The test aims to analyze the performance of students in solving problems in electricity, while the survey is designed to deepen the analysis of performance and identify the major factors that cause difficulties for students in electricity, thus preventing them from achieving better results in electricity courses.

The problem of this study is related to the effect of certain factors on the performance or failure of students in electricity, such as sex (M/F), the repetition of one year or more in the exams of this subject, the knowledge and mathematical prerequisites, and mastery of the French language as the teaching language of scientific courses in Moroccan universities. These factors are further discussed in the conceptual framework. The methodology section describes the target population, hardware used, and software that helped us examine and interpret the data collected via an appropriate questionnaire on the difficulties faced by the students in solving electricity problems related to the chosen factors.

2. PROBLEMATIC

To examine students’ performance on exams or tests, many researchers have assessed their responses when solving problems, considering correct responses as an indicator of performance, and incorrect responses as an indicator of failure [14,15,16]. This makes it possible to discern learning difficulties that prevent students from finding an adequate solution to a problem. Several factors can significantly affect student performance. Indeed, [17] and [18] found that the performance of university physics students was influenced by their gender. Other studies [3, 4, 5] have revealed that mastery of language skills positively affects students’ performance in studying physics at universities. Students’ performance on this subject has also been studied in relation to the performance of experiments in the context of practical work [10,12] and in relation to skills in graphical representations [19,20,21,22].

Several studies have shown that positive results obtained by electrical students at the university level are closely correlated with their mathematics performance [1, 16, 23]. Positive and significant correlations were observed between the scores achieved by students in physics and their knowledge of algebra [24]. Students’ knowledge of vector notions in mathematics has been studied [1, 20, 25], as has their knowledge of integrals and differential equations [26,27] and their knowledge of graphical representations in physical science [20,28].

This study focuses on two variables that affect the performance of Moroccan students in their first year of university when solving electricity problems: socio-pedagogical and cognitive variables. Socio-pedagogical variables include gender and number of years a student has repeated an electrical exam. The cognitive variables concern concept complexity and the transfer of acquired physical knowledge in other electricity courses, language difficulties, knowledge of graphical representations, and the realization of practical experiments in electricity.

The data were collected from a group of 490 students who answered a test designed to study their performance in solving electricity problems in connection with the mathematical knowledge of the students, and a survey with a questionnaire designed to illustrate Student Learning Difficulties in electricity.

The main goal of this study was to examine the effects of the considered variables on the performance of university students in solving electricity problems, which were divided into pedagogical and didactic sub-questions concerning the performance or

difficulties of students in electricity, in relation to the effects of:

The mastery of the French language on the achievements of students in electricity,

Acquisition of knowledge in mathematics and the ability of students to apply and transfer it in the context of electricity.

The realization of the experiments of practical works on the learning of concepts in electricity,

The use of graphical knowledge in electricity in connection with the skills of students in using graphic representations acquired in a mathematical context.

Success in solving electricity problems according to sex and number of years to repeat the exam for this subject.

Analysis of the empirically collected data was performed using multiple correspondence analysis (MCA) [29], which makes it possible to identify the direct links between the different variables considered in the problem.

3. THEORETICAL FRAMEWORKS

3.1 Student performance in physics and mathematics by gender

Several studies have revealed differences between the performance of boys and girls in problem solving in physical sciences and mathematics at the secondary and university levels [17,18], unlike other studies [11,15,30] that did not find a significant gender difference in problem solving in these science subjects.

Some studies have attributed gender gaps in physical science problem-solving performance to affective factors. They found that girls had significantly lower self-efficiency than boys [15]. According to [31], boys place a high value on self-efficacy in physical science, whereas girls are more demotivated in physical science, which lowers the success rate in physics among girls at the university level. Other affective factors can influence performance in physical science, such as interest, positive or negative attitudes toward the discipline to be learned, and anxiety. Girls show high levels of anxiety and less interest in solving physical science problems, which are considered difficult for them compared to boys [15, 17, 18, 31, 32]. However, some findings go in the opposite way, revealing that girls are more likely to have a better understanding of physics lessons than boys [33].

3.2 Language of teaching and student achievement in science, physics, and mathematics

The relationship between language learning performance and gender has been widely studied [18,34,35], showing that girls perform better than boys at different levels of learning in terms of their ability to read, write, and master the language.

In mathematics, the results of male students were better than those of female students [36]. According to some surveys, girls have low algebra scores [37]. However, girls tended to excel more in numerical activities [38]. At the university level, boys find it advantageous to learn mathematical concepts that require greater abstraction [36,38]. Some researchers have shown that boys perform slightly better than girls in solving mathematical problems [34,36], whereas others have reported that the gender gap is not significant [39].

Boys perform considerably in physical science at the secondary and university levels [15, 36, 39]. At university, boys perform well on physical examinations, and the difference between sexes is often considerable [36,40]. Other studies [28, 41, 42] have indicated that the performance gap between boys and girls is insignificant in physical science. According to some studies, girls obtain higher scores than boys in the physical sciences [43, 44].

In electricity, girls perform better on university exams than boys [45]. Contrary results obtained at university and high school levels [18, 28, 46, 47] show that the grades of boys are higher than those of girls. According to other studies, the results of electrical students are not moderated by gender, whether in high school [42] or at the university level [28,40].

Some studies have highlighted the relationship between the language of teaching (mother or second language) and student performance [3, 5]. Many students with weak knowledge of the second language of teaching (French) find it difficult to learn science subjects, such as physics [4, 48]. In high school, learners encounter several difficulties, including reading physical science textbooks [6, 49, 50]. However, the acquisition of the physics discipline does not seem to be affected by language, according to [47] , who studied the effect of the language of teaching on the results of students in the problem-solving of electricity.

In Morocco, university students in science courses encounter difficulties in learning courses taught in a second language (French) [7]. [8] showed that 80% of Moroccan university students in scientific and technical fields do not master the French language, which weakens their understanding of science. This finding is alarming for both students and teachers.

3.3 Influence of mathematics on students' performance in physics.

Physical science subjects use a variety of abstract concepts and formulas, making it difficult for students to learn, especially when physical concepts are intertwined with mathematical knowledge. Indeed, success in physics is positively linked to knowledge acquired in mathematics [51, 52, 53]. It has been shown that students' lack of mathematical skills is one of the factors that lead to poor skills in acquiring physical concepts [22, 54] , knowing that some essential mathematical concepts to understand physics lessons are taught as a reminder of physics lessons [55]. If these concepts are not understood correctly, it will be difficult for learners to learn physics. Some learners' difficulties in physics lessons are due to their ignorance of the role of mathematical formalisms in understanding abstract physical concepts [54], and their ability to solve problems in physics lessons is closely related to their mathematical skills [15, 56] .

The difficulties, success, and failure of students in electricity, whether in high school or university, are highlighted by various studies [52, 53, 55, 57, 58, 59] that linked students' failures in physics problem-solving to the mathematical knowledge needed to acquire physics course concepts [60]. The inability of students to apply mathematical knowledge acquired in physics problem-solving situations has also been studied [22,55, 57, 61].

However, some studies have shown that good achievement in mathematics does not ensure good performance in solving physics problems [22, 55, 62]. As Pepper et al [1], The mastery of mathematics alone is not sufficient to solve a problem in physics. It is necessary for students to have a good understanding of the problem to be solved in physics, a good application of problem concepts to mathematical formulas, a good treatment and resolution of these formulas, and a good interpretation of the solution to the concepts of the course of physics. This is performed before evaluating the final result to indicate whether it is adequate with the problem posed initially. Some high school or university learners perform poorly on physics subject exams despite having good math skills [22, 55]. These learners seem unable to mobilize their mathematical knowledge in specific situations in the context of the physics course.

3.4 Factors affecting learning Physics and Electricity courses

Symbols, variables, quantities, equations, parameters, signs, constants, and units are used differently in mathematics and physics, causing difficulties for students when moving from mathematical situations to physical contexts. Indeed, a lack of mastery in the conversion of units and a lack of knowledge of the dimensionality of symbolic forms of quantities can aggravate this problem [63,64]. Mathematical symbols are another source of difficulty encountered by students in their learning of physical concepts in problem solving [25,65]. Therefore, many students have difficulty attributing positive or negative signs to physical quantities. [15] reported that

students found solving problems containing symbols more difficult than solving a number of problems. [64] finds that learners are unable to extract symbols from problems posed in physics to develop mathematical formulas. Similarly, [66] showed that students confuse variables and constants expressed literally or numerically, which further complicates their understanding of physical equations.

Some researchers [64,67] have found differences between mathematical equations containing an unknown representing numerical constants and physical equations representing the values, units, and meanings of physical quantities, which should be considered by students in physics problem-solving. Other difficulties contribute to the weakening of students' results in physics, such as the inability to interpret physical quantities [21, 22, 64].

Graphical representations (tables, algebraic, geometric graphs, etc.) play an important role in learning physical and mathematical sciences [19, 25]. The application of these representations contributes to success in learning the physical sciences [53, 68]. To solve a problem involving such a concept, students should place themselves between different modes of representation of this concept [69]. The application of multimodal representations, as required skills, supports the construction of an adequate understanding of a scientific concept by students [20], whereas with a single representation, they cannot build an overall idea of the concept studied [64,69,70].

Several studies have reported that students with difficulty learning physical sciences, especially the representation of data in problem solving [15, 21,22,28], showed difficulties in understanding, reading, extracting information, interpreting, and making sense of graphs in the physical sciences. In solving problems in the physical sciences or mathematics, learners make errors in the graphical representation of data due to misunderstanding of concepts such as slope and physical area and their interpretation, point-interval confusion, variable confusion, interval/point confusion, or even area-slope-height confusion [19,21,22,68].

Several studies have focused on students' difficulties in assimilating electricity courses at universities, considering their mathematical skills [16, 28, 71]. This shows that complex concepts of electricity cannot be acquired without mathematical skills [16, 24].

Some students who succeeded in solving mathematical problems using graphs failed to solve similar physical science problems [21,22] . Therefore, students' problem-solving performance is affected by the context (mathematics or physics) in which graphs are presented [19, 68, 72], because students change their strategies from one context to another. [73] observed that learners with graphical knowledge in a mathematical context cannot apply it in the physical sciences. This shows the non-transferability of graphical knowledge strategies from mathematical to physical science contexts [21,22]. According to [56], mathematical, analytical, geometric, algebraic, graphic, and calculation knowledge help learners to solve problems in physical sciences; contrary to [72], which showed difficulties of students in transferring their mathematical and graphical skills into physical science situations.

Moreover, according to some authors, the mathematics effect on physics learning at universities or high schools seems to be non-significant [16,74]. Indeed, the results of first-year university physics students were not influenced by the mathematical knowledge acquired in high school. The misunderstanding of physical concepts is not always due to mathematical shortcomings [21, 22, 54, 55]. Generally, [16] show that mathematical and physical prerequisites acquired in high school are not determining factors in the learning of physical sciences in university careers.

Physical science experiments, especially in electricity, are crucial for students to understand and demonstrate laws and concepts; they help to demonstrate certain abstract theoretical knowledge and allow learners to avoid certain misconceptions, which further increases the performance of students engaged in empirical experiments [12]. However, learners do not realize the fundamental role of experiments in the physical sciences or experimentation, which is an essential component [11]. The lack of practical work does not allow students to build a deep understanding of physical science, which affects their attitudes and abilities to solve physical problems [10, 75]. In some Moroccan universities [12], increasingly overloaded practical work sessions do not allow planned experiments to be carried out while respecting the time devoted to the practical work sessions. Sometimes, students try to understand theoretical and physical knowledge without resorting to practical work.

4. METHODOLOGY

4.1 Target population

The initial target population consisted of 561 students enrolled in the first year of mathematics studies (SMA/SMI) and physical sciences (SMP/SMC) at various Moroccan universities. The final sample, how fully the test was completed, and the survey questionnaire contained 490 students, with 251 (51.22 %) males and 239 (48.78 %) females. The sociodemographic characteristics of the students, including age, field of study, and home university, are presented in Table 1.

Table 1: Sociodemographic variables related to student's number and percentage in the studied sample

Variables	Terms	Students number	Percentage (%)
Sex	F	239	48.78
	M	251	51.22
Age	17	17	3.47
	18	86	17.55
	19	160	32.65
	20	90	18.37
	21	57	11.63
	22	34	6.94
	23	23	4.69
	Over 23 years	23	4.69
Section	SMA	52	10.61
	SMC	70	14.29
	SMI	71	14.49
	SMP	297	60.61
University	CASABLANA	127	25.92
	FES	72	14.69
	KENITRA	148	30.20
	MEKNES	74	15.10
	RABAT	69	14.08
Repeating the 1st year	No	324	66.12
	Yes	166	33.88
BAC Type	Biology	30	6.12
	Mathematical	115	23.47
	Other	48	9.80
	Physical	297	60.61
Favorite subject	Mathematics and Electricity	210	42.86
	Mathematics	126	25.71
	Electricity	154	31.43

The students' ages ranged from 17 to 27 years, with an average age of 20. The majority of students (83.67%) were between the ages of 18 and 22 years. In terms of field of study, 60.61% of students were enrolled in SMP, 14.29 % in SMC, 14.49 % in SMI, and 10.61% in SMA. It should be noted that the participants who responded to the test and survey questionnaires were primarily from Ibn Tofail University in Kenitra (30.2%), Hassan II University in Casablanca (25. 92%), Moulay Ismaïl University (15.1 %), Sidi Mohamed Ben Abdellah University in Fez (14.69 %), and Mohammed V University in Rabat (14.08 %).

4.2 Test for performance analysis

Several tests have been used to study students' learning in physics, such as the CSEM (Conceptual Survey of Electricity and Magnetism) multiple-choice test, which is used to explore the difficulties faced by students in electricity and magnetism [76,77,78,79,80]. We were inspired by this work to build a test to measure the performance of electricity students in relation to mathematical knowledge.

The participants provided consent to complete this written test. Beforehand, they were informed that their answers would be confidential and would be used only for research purposes. They were provided with the necessary information and explanations to complete the test. In addition, participants had the possibility of not answering the questions if they did not think they had the right solution. No time limit was fixed, but the majority reserved a time of 30 minutes to one hour to give the answer.

4.3 Test development and validation

Before administering the test to the students, we conducted individual interviews with three professors who had taught the electricity module at the university for several years to assess the content and quality of the test and its items. The results of the individuals' interviews led us to reduce the number of items, then reformulate some of them, and finally revise the content of the remaining items to facilitate its understanding and acceptability by our sample of students [81].

The final test consisted of 10 multiple-choice questions on electricity: Q3, Q4, Q6, Q8, and Q10 concerned the direct application of basic mathematical acquisitions, which required the mobilization of mathematical skills about the affine function (Q3), solving system of equations (Q4), algebraic calculation (Q6), graphical calculation (Q8), and solving differential equations (Q10). Questions Q1, Q2, Q5, Q7, and Q9 concerned the definitions of certain fundamental laws of electricity taught in physics classes. They require skills in electricity, namely, the application of Coulomb's laws (Q1), Ohm's laws (Q2), Pouillet's law (Q5), Laplace's laws (Q7), and the establishment of the differential equation RLC (Q9). For the assessment, the students were given a score of 1 for each correct answer and 0 for an incorrect answer.

Many indices are commonly used to measure the validity and reliability of a test [77, 78, 80, 82]. For example, the Kuder-Richardson reliability index, difficulty index, discrimination index, and point biserial index. In this study, we used difficulty and discrimination indices.

The difficulty index of a single item on a test is the ratio of the number of correct answers to the item to the total number of students who have attempted to answer the same question [80]. The values that the discrimination index can take are -1 to 1, and require it to be equal to or more than 0.3 [80] . The acceptable margin is in the [0.3 - 0.9] interval [77,78]. The Question Discrimination Index examines the discriminative strength of each question [80]. Most questions should have higher discrimination indices to ensure that the test can discriminate between stronger and weaker students [80]. It is usually calculated by subtracting the number of students in the bottom 27% of the total score range who correctly solved the item and by calculating the ratio between the result of this difference and half of the sum of these two categories of students [82].

4.4 Performance measurement and analysis

The overall performance considered in terms of marks was calculated from each student's achievement of questions asking for prior mathematics knowledge (the score obtained for questions Q3, Q4, Q6, Q8, and Q10) and their achievement of questions that did not need mathematics knowledge (score obtained in Q1, Q2, Q5, Q7, and Q9). We called the score requiring prior knowledge of mathematics "performance in mathematics," and that which did not require mathematical knowledge, "without mathematics." Performance in terms of marks was statistically analyzed using SPSS version 25 software for (M) electrical problems requiring mathematical knowledge (grade/5) and (E) electrical problems not requiring mathematical knowledge (mark/5). The overall performance (G) is associated with a "mark/10'.

4.5 Difficulty analysis (Survey)

To deepen the students' performance analysis and study the causes of difficulties encountered by students in the subject of physics, particularly in electricity, we developed another questionnaire containing questions on students' opinions on their difficulties in physics and their attitude towards mathematics. Indeed, we asked students to give their opinions in writing regarding physics subjects through the questionnaire we developed by inspiring from certain research [83, 84], which allowed us to adapt similar questions to the learning of electricity in the Moroccan context. Table 2 shows the number of items in the difficulties questionnaire, its objectives, and the nature of the students' responses. This makes it possible to study certain correlations between students' difficulties in solving physics problems and their prior knowledge of mathematics.

Table 2: Categorization of items in terms of object, questionnaire difficulties, and responses types

Item	Object	Wording	Type of response
Q11	**Math Difficulties**	D in math	Very Low / Low / Medium/ High / Very High
Q12	**Difficulties related to differences between mathematics and physics symbols**	D symbols differences	Very Easy/Easy / Moderate / Difficult /Very Difficult
Q13	**Degree of complexity of study of electricity subject**	D level in Electricity	
Q14	**Degree of complexity of study of mechanics subject**	D level in Mechanic	
Q15	**Degree of complexity of study of Mathematics**	D level in Mathematics	
Q16	**Degree of complexity of study of French language**	D level in French language	
Q17	**Difficulties in understanding mathematical concepts and their application in physics**	Type math difficulties	Math apps / math-concepts
Q18	**Factors helping in physics performance: use of mathematical formula; mastering French language; doing practical work and experiments in physics; understanding physical concepts.**	Type difficulty	French language / Mathematical formula /Physical concepts /Physical experiments

4.5 Data analysis by MCA method

The following methodology describes the data and variables illustrated in the problem section. The collected data were processed by the multiple correspondence analysis (MCA) method [29], which allows the identification of the direct links that exist between the different qualitative variables and the difficulties of the students in the electricity module [1] . Data analysis using MCA was performed using the statistical package SPSS [85]

5. RESULTS AND DISCUSSIONS

5.1 Performance analysis (Test results)

Performance Test Validation

To validate the performance test, we evaluated its reliability by calculating the values of two reliability indices: the difficulty index and discrimination index.

The average value of the difficulty index of the studied items was calculated as 0.478, which is within the desired criteria range for standardized tests [80] . The average value of the discrimination index of the same items was 0.215, which was close to the required margin of the criteria set by [80] .

Normality tests were employed to assess the equality of variances among the test items and to determine whether the sample conforms to a normal distribution. In our study, we opted for The Kolmogorov-Smirnov and Shapiro-Wilk tests because of the large size of our population. The results of the performance test data, as evaluated using the Kolmogorov-Smirnov and Shapiro-Wilk tests (Table 3), remained statistically significant at $\alpha \geq 0.05$. Thus, our performance test data exhibited overall homogeneity and adhered to a normal distribution [86].

Table 3: Shapiro-Wilk and Kolmogorov-Smirnov test of normality

Performance	Shapiro-Wilk	dof	Sig.	Kolmogorov-Smirnov	dof	Sig.
M	0.985	490	0.000	0.041	490	0.049
E	0.998	490	0.947	0.024	490	0.200*
G	0.994	490	0.070	0.029	490	0.200*

* This is the lower bound of the true meaning.

M: Performance in electrical problems requiring mathematical knowledge.

E: Performance in electrical problems not requiring mathematical knowledge.

G: Overall performance

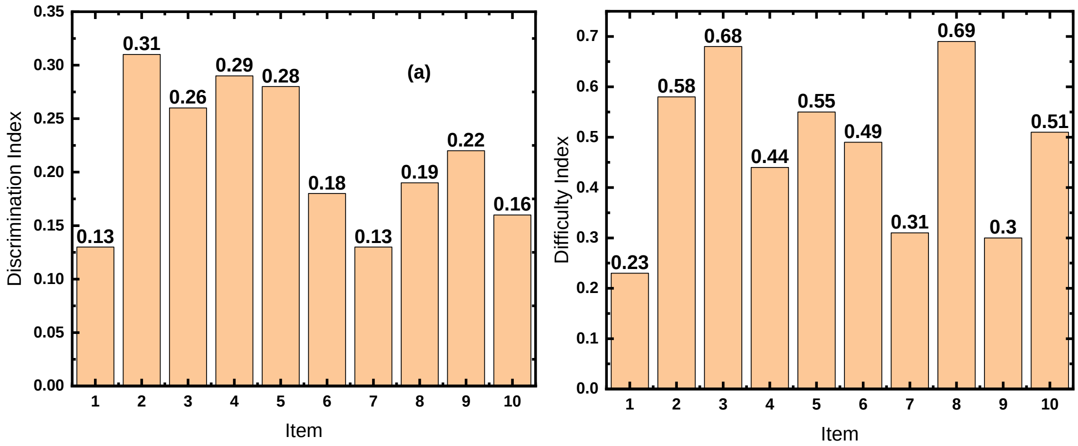

Fig 1: Difficulty (a) and discrimination (b) index values for each performance test item

Analysis of answers requiring mathematical tools

The distribution of incorrect responses to Q1–Q10, which involved electricity and the required mathematical tools, is presented in Table 4. It is striking to observe that more than 40% of students encountered difficulties in answering each question correctly, except for Q3, which studied affine functions, and Q8, which focused on graphic calculation. The rates of incorrect responses to the two questions decreased to 34.08% and 33.47%, respectively. This can be attributed to students' familiarity with this type of question during previous levels of learning.

Furthermore, it is to highlight that students encountered challenges in solving electricity-related problems, particularly those requiring mathematical knowledge and a deep grasp of electricity laws. These findings align with those of several studies on learners' problem-solving difficulties [1, 20, 71].

Table 4: Failure rate of students in solving the problem questions used for the performance test

Question	Objective of the question	Failure rate (%)
Q1	Coulomb's law	78.78
Q2	Ohms law	43.67
Q3	affine function	34.08
Q4	solving system equations	58.16
Q5	Pouiellet's law	46.94
Q6	Algebraic calculation	52.86
Q7	Laplace's law	70.61
Q8	Graphic calculation	33.47
Q9	Establishing the RLC differential equation	72.24
Q10	Solving RLC differential equation	50.82

When it came to solving a system of equations for electricity (Q4), it was observed that 58.16% of students were unable to do so. To solve the RLC differential equations (question Q10), nearly half of the students (50.82%) struggled to apply their algebraic knowledge in a physical context. It is also worrisome that over one out of three students (33.47%) had difficulty using the graphical knowledge required for graphical calculations (question Q8). Despite being exposed to the concept of differential equations, students' performance remained below satisfactory, with correct answers not exceeding 27.76% for question Q9, which aimed to establish differential equations in the electricity context. Similarly, only 49.18% of the students were able to find solutions to this type of equation (question Q10).

The high rates obtained for incorrect answers (Q1, Q2, Q4, Q5, Q6, Q7, Q9, and Q10) revealed that students had difficulty with electricity when they used mathematical tools (algebraic and graphic knowledge, concept of the differential equation, etc.). These difficulties may result in a lack of acquired resources in mathematics as the main cause of students' inability to apply mathematical knowledge outside the mathematical context. This is consistent with previous studies [61, 64] that consider the transfer of mathematical skills to learning situations in the electricity context crucial for the rigorous learning of concepts and formalisms of electricity. As found in several studies, a lack of algebraic knowledge affects the appropriate learning of electrical formulas [53, 55, 87]. Some students do not correctly apply graph knowledge to solve electricity problems [20, 28]. Solving differential equations in electricity and mobilizing knowledge of integrals seem to be skills that students lack in the problem-solving of electricity [16, 63, 71].

However, we found some incorrect answers related to electricity items that "did not require mathematical knowledge," with the highest failure rates observed for Coulomb's law (78.78%) and Laplace's law (70.61%) for Q1 and Q7 items, respectively. The decrease in the correct response rate for the two electricity laws can be attributed to the students' unfamiliarity with this type of problem. Furthermore, questions concerning Ohm's law (Q2) and Pouillet's law (Q5) yielded high rates of incorrect responses (43.67% and 46.94 %, respectively). These results indicate that students lack a thorough understanding of these concepts (electricity laws and principles), possibly due to gaps or inadequate knowledge they had regarding these concepts [88].

Table 5: Students' performance in terms of obtained marks in math (M), electricity (E), and general (G)

Score	M		E		G	
	n	%	n	%	n	%
0	7	1.43	13	2.65	-	-
1	24	4.90	109	22.24	13	2.65
2	147	30.00	247	50.41	4	0.82
3	204	41.63	108	22.04	116	23.67
4	102	20.82	13	2.65	39	7.96
5	6	1.22	-	-	205	41.84
6	-	-	-	-	5	1.02
7	-	-	-	-	101	20.61
8	-	-	-	-	3	0.61
9	-	-	-	-	4	0.82
Total	490	100	490	100	490	100

M: Performance (score/5) in electrical problems requiring mathematical knowledge.

E: Performance (score/5) in electrical problems that do not require mathematical knowledge.

G: General performance (Score /10)

The students' performance in solving mathematics and electricity problems was analyzed (Table 5, Figure 2). For electricity problems that required mathematical knowledge, Figure 2 M) shows that 382 students (77.96%) achieved scores equal to

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or inferior to 3/5, with 102 students (20.82%) scoring 4/5, and only one student achieved a perfect score (5/5), representing 1.22% of the participants. For the performance in solving electricity problems not requiring mathematical skills (Figure 2 E, Table 5), the results showed that 369 students (75.31%) scored 2/5 or lower, while 108 students (22.04%) scored between 3/5 and 4/5. Only 13 students achieved a score of 4/5, being 2.65% of the participants. Considering the overall students' performance in solving electricity problems, whether requiring mathematical skills or not (Figure 2 G, Table 5), we found that more than 35.1% of students did not exceed a score of 4/10, while four students (0.82%) reached the maximum score of 9/10. Table 6 summarizes the Pearson correlation results for students' performance (M, E,

and G). There is a strong and significant relationship between performance in mathematics and overall performance (0.93) and between performance in electricity and overall performance (0.901). However, the correlation between performance in mathematics and electricity is average (0.679). As a result, one can state that students with difficulties in mathematics perform relatively less well in solving electrical problems, and vice versa.

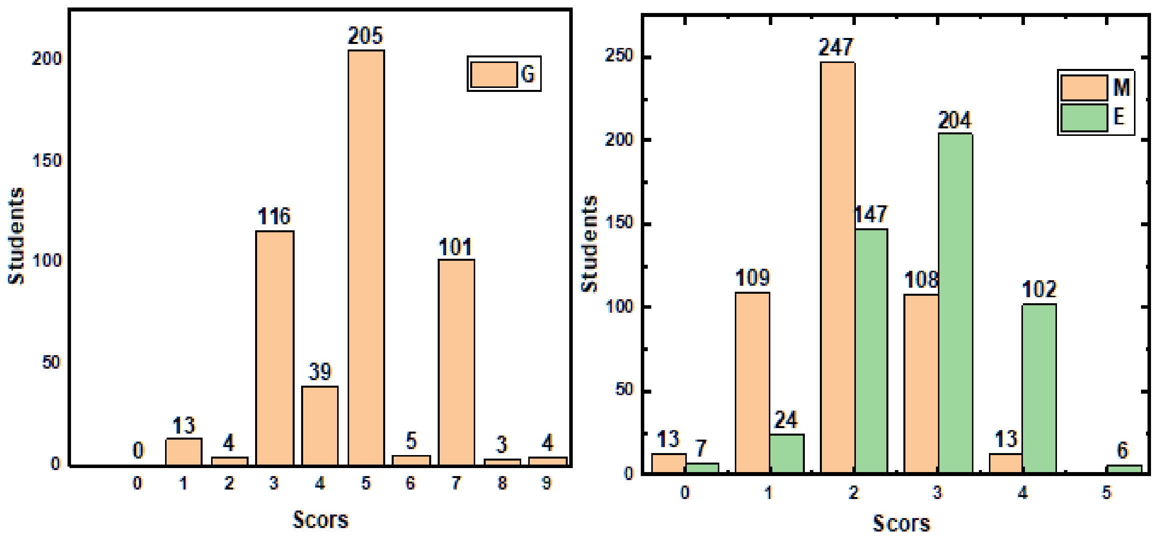

Fig 2: Students' performance in terms of obtained marks in math (M), electricity (E), and general (G)

The results obtained from this first test are confirmed by some research [23], which found positive and significant correlations between performance in mathematics and academic performance in electricity. Other research has shown that prior mathematical knowledge has no influence on students' acquisition in solving electricity problems at universities [16].

The results given in Table 6 reveal that a large proportion of students did not solve the problem questions of the performance test (Questionnaire 1) in electricity correctly. To gain more insights into the difficulties encountered by students, we used another test (Questionnaire 2) intended for the students to give explanations, which could help us understand some possible reasons that lead to the weak performance of students in electricity.

Table 6: Pearson correlations between the different performances denoted M, E, and G

	M	E	G
M	1	0,679**	0.930**
E	0.679**	1	0.901**
G	0.930**	0.901**	1

** The correlation is significant at the 0.01 level (two-sided).

M: Performance in electrical problems requiring mathematical knowledge.

E: Performance in electricity problems that do not require mathematical knowledge.

G: Overall performance.

5.2 Difficulty Analysis (Survey Results)

Analysis of student's difficulties responses

Table 7 presents the results obtained in terms of the number and percentage of students who had difficulties in relation to the various studied variables, as shown in the first column of this table. As shown, 33.47% of the students had difficulties in mathematics, as indicated by the very high and high response terms; 76.94% did not understand mathematical concepts, and 22.86% confused mathematics and physics symbols. We noted that 23.06% of the respondents were not able to reinvest and apply their mathematical learning in other physical situations, and 27.55% of the students declared that they were not able to handle mathematical formulas correctly. Thus, most students encounter mathematical difficulties in problem solving and confuse concepts, symbols, and mathematical formulas. They were unable to apply or transfer mathematical knowledge to situations within the context of electricity.

Indeed, it has been confirmed that students have difficulty understanding and mobilizing mathematical concepts and formalisms [19, 21, 22, 60], which leads them to misunderstand the concepts of electricity.

Concerning the answers related to the different physical options, we observed that 15.31% of the students declared that electricity was one of the most difficult subjects to learn. Regarding the difficulties encountered, 54.08% of the respondents mentioned that the assimilation of concepts affects the learning of electricity; 11.63% of the students evoke mastery of the French language as a serious difficulty, while 6.73% of the students refer to the execution of practical work. The results relating to the difficulties due to the complexity of electricity concepts are supported by certain studies [89], which found that the concepts and the modulated formalisms of the electrical phenomena are difficult to understand because of their abstraction. In addition, conducting scientific experiments contributes to the attenuation of the abstraction and complexity of concepts [12,72], whereas the lack of practical work prevents the understanding of these concepts.

The language of instruction can further help students to rigorously understand and solve problems in physics [3,4,5]. However, it does not seem to have a remarkable and significant effect on the performance of students in problem solving related to electricity concepts [47]. This is relatively in agreement with the results obtained by this study concerning the effect of the French language on appropriation of electricity, since only 11.63% have difficulties due to the teaching language.

Table 7: Results concerning the variables related to the students' difficulties (The answers were given in terms of the number of students and in terms of the percentage)

Wording	Terms	Students number	Percentage (%)
D in math	Very Low	71	14.49
	Low	71	14.49
	Medium	184	37.55
	High	81	16.53
	Very High	83	16.94
D in symbols differences	Very Easy	37	7.55
	Easy	39	7.96
	Moderate	302	61.63
	Difficult	66	13.47
	Very Difficult	46	9.39
D level in Electricity	Very Easy	33	6.73
	Easy	47	9.59
	Moderate	335	68.37
	Difficult	31	6.33
	Very Difficult	44	8.98
D level in Mechanic	Very Easy	27	5.51
	Easy	51	10.41
	Moderate	323	65.92
	Difficult	39	7.96
	Very Difficult	50	10.20
D level in French language	Very Easy	37	7.55
	Easy	45	9.18
	Moderate	304	62.04
	Difficult	52	10.61
	Very Difficult	52	10.61
D level in Mathematics	Very Easy	53	10.82
	Easy	126	25.71
	Moderate	204	41.63
	Difficult	17	3.47
	Very Difficult	90	18.37
Math difficulties type	math applications	113	23.06
	math-concepts	377	76.94
Type Difficulties	Electric concepts	265	54.08
	French language	57	11.63
	Mathematical formulas	135	27.55

Analysis of difficulties responses by MCA method

After performing MCA (Table 8), we retained a three-dimensional model that represents 67.33% of the total data inertia. Cronbach's alpha coefficient was 0.65, considered moderately acceptable from 0.6, to reflect the internal consistency and reliability of the MCA analysis made in this study. Approximately 25.02% of the variability was explained by dimension 1, 21.75% by dimension 2, and 20.56%. On average, 22.44% of the global variance was explained by our ACM model.

Figures (3B), (3D), and (3F) demonstrate a strong relationship between factors influencing performance in physics and the difficulties encountered by students, particularly in electricity (yellow circle) and physics in general (green circle). This observation also applies to the continuations of Figures (3A), (3 B), and (3C) (in red, pink, and brown), where it can be observed that students who struggle with manipulating mathematical formulas and physics concepts (electricity) find the study of physics modules very challenging, especially the electricity and mechanics modules.

Table 8: Proper values and percentages of inertia of the selected 3-dimensional model

Summary of models				
Dimension	Cronbach's Alpha	Represented Variance		
		Total (proper value)	Inertia	% of variance
1	0.700	2.752	0.250	25.020
2	0.640	2.392	0.217	21.750
3	0.614	2.261	0.206	20.558
Total		7.406	0.673	
Medium	0.654a	2.469	0.224	22.443

Cronbach's alpha was based on the proper average value.

Figures (3D) and (3F) demonstrate a significant correlation between the factors that contribute to difficulties in mathematics and the challenges faced by students, particularly in electricity (brown circles) and physics. The black and orange circles indicate the connection between difficulties in mathematics and challenges in the mechanics module of physics, whereas the yellow and purple circles highlight the relationship between difficulties in mathematics and challenges in physics modules. This observation also applies to the subsequent Figures (3A), (3 B), and (3C) (in red, pink, and dark blue), where it becomes apparent that students who struggle to manipulate mathematical formulas and concepts, as well as physics concepts (electricity), encounter particular challenges in studying physics modules, especially those related to electricity and mechanics.

On the other hand, students with deep mastery of the French language seem to find it easier to learn physics, especially electricity. However, those who encounter difficulties in physics, particularly electricity, seem to do so because of their less deep mastery of French. It is possible that gaps in language skills affect students' understanding of concepts and mathematical formulas used in these fields. In addition, it appears that male students grasp mathematical concepts more easily than girls, while the latter obtain insufficient results in electricity due to the difficulty in assimilating the scientific concepts taught in physics modules, particularly in electricity (figures (A), (C), and (E)).

By analyzing figures (3A), (3 B), and (3C), we can distinguish five distinct categories. The first category pertains to students who find physics modules difficult to study. The second category consists of those who perceive themselves to be very challenging to learn. The third category included students who considered physics to be moderately difficult to grasp. The fourth category comprises students who find physics concepts easy to understand. The fifth category included students who found physics concepts easy to study. Consequently, this indicates that the level of difficulty in studying electricity does not significantly differ from other physics modules (represented by yellow and purple circles in figures (3 B), (3D), and (3F)).

The results obtained by the MCA allow us to retain that mastery of mathematical knowledge, particularly formulas and concepts, is necessary for students to learn more about the concepts of physics in general and electricity in particular. In this sense, [24] showed that students with strong math skills are also able to achieve high scores on electrical exams, while the grades of electrical students are low due to their poor math achievement, regardless of gender. We also see that success with electricity is only weakly affected by the language of teaching (French, in the Moroccan context). This finding is supported by [47].

Another important result that can be drawn from the MCA concerns the negligible and non-significant effect of gender on the success and performance of students in the electricity module, which is supported by some studies [18, 28, 47]. However, the results obtained on gender in this study seem to contradict the results of [45] , who found that boys perform worse than girls on electrical exams, and other results [18,90], who found that boys perform better than girls on electricity.

6. CONCLUSION

This study aimed to analyze the factors that affect students' performance in learning electricity, particularly when using a problem-solving tool. Two types of factor effects were studied. The first category concerns students' identity (gender and repetition). The second concerns students' performance in other subjects: French as the teaching language of electricity, mathematics knowledge (concepts, formulas, symbols, algebraic, and graphics), and physics knowledge (concepts, graphs, symbols, and practical work).

The analysis of data obtained from the test and the survey was carried out using SPSS 25 software to carry out descriptive statistics and MCA methods on the electricity students' achievements in different Moroccan universities. The participating students were enrolled in the SMPC and SMAI streams in their first university year.

Hence, the analysis allows us to draw the following conclusions:

- Student test scores realized in electricity are not affected by different studied factors, which is consistent with some works but not with most research, as detailed in the theoretical part of this study.
- Realizing high performance in electricity does not require students to have a high level of mastery of French as a language for teaching electricity. Students need a language skills base, which could be used as a support to understand electrical concepts in solving electrical problems.
- A Positive and significant effect of mathematics performance on success in solving electricity problems was confirmed. Thus, learning electricity concepts at the university level cannot be accomplished in the absence of knowledge of mathematical concepts and formalisms.
- Mathematical knowledge (concepts, formulas, graphs, etc.) makes electricity learning easier for students. Generally, students with deep mathematical acquisitions achieve high scores in electricity; while Students with math deficiencies encounter difficulties to understand electricity
- The realization of practical work seems to help students better understand concepts related to electrical phenomena.

Finally, this study attempts to explore and analyze the performance of Moroccan students in relation to several factors. The large sample size (490 students) chosen

for this study from diverse universities provides more representative results, which appear to be generally consistent with the literature.

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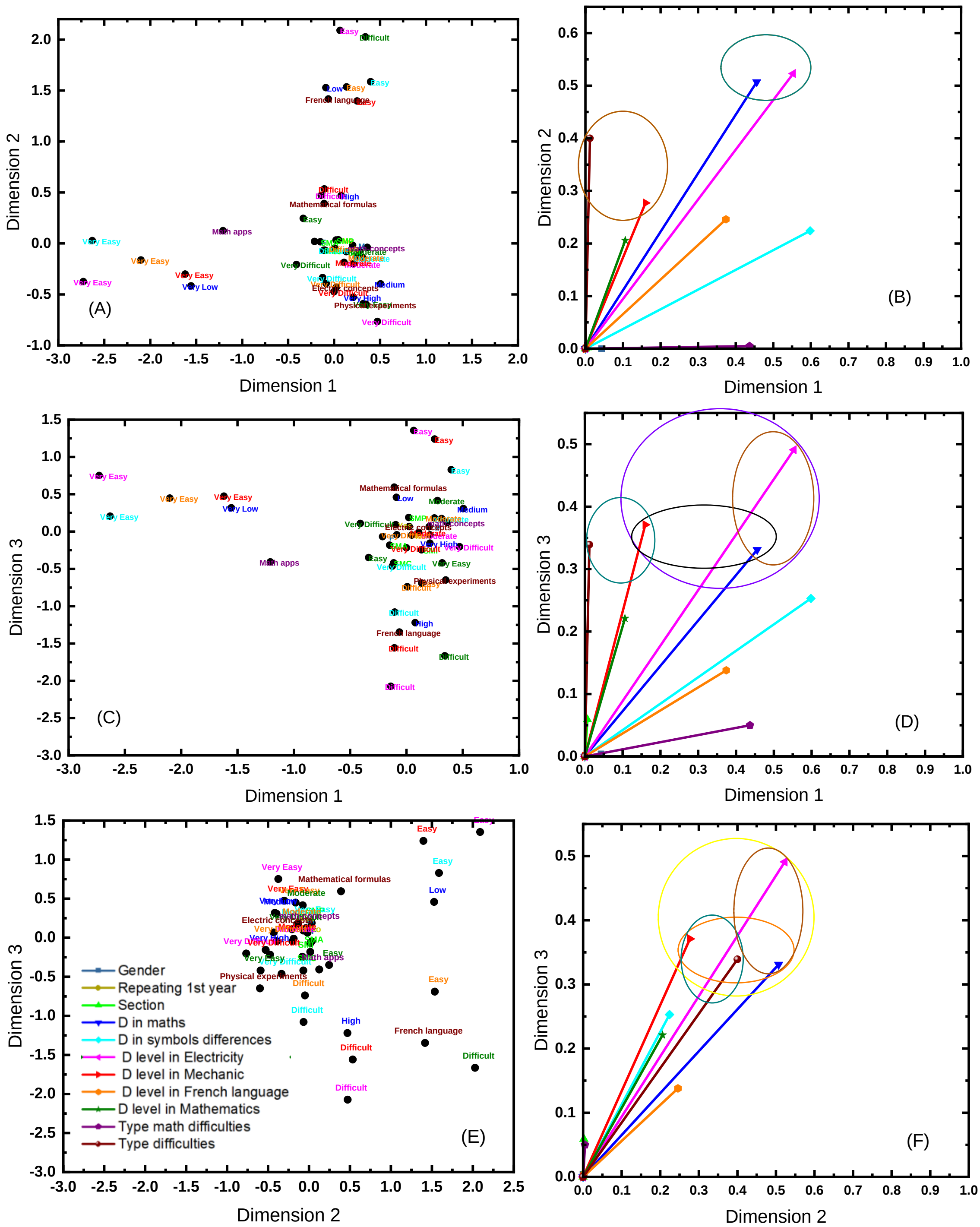

Fig 3: Diagrams of different MCA dimensions (A), (C), (E): projection of variables; (B), (D), (F): Projection of the factors

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Conflicts of Interest

The authors declare no conflicts of interest.

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