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Physics mathematization from a teaching perspective: secondary school teachers' perceptions

Abdelwahab El Azzouzi[1], Ihsane Kouchou[2], Abdelrhani Elachqar[1], Fatiha Kaddari[1]
[1]Computer Science, Signals, Automation, and Cognitivism Laboratory (LISAC), Faculty of Sciences Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, Fez, Morocco
[2]Normal High School (ENS), Cadi Ayyad University, Marrakech, Morocco

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ABSTRACT

The courses of physics and mathematics are usually related. So, it is essential to transfer mathematical knowledge and skills to understand and solve a situation in physics. The main objective of this research is to identify teachers' perceptions of physics mathematization. To highlight our objective, we used an analysis of textbooks and scientific literature to support a questionnaire for 141 physics teachers in the region of Fez, Meknes, Morocco. The teachers emphasized that to understand or solve problematic situations in physics it is important to go through mathematics. Still, the majority of them do not have clear ideas on how to do it. However, in the absence of a unified method, the teachers suggest some work techniques with their students whose contents are purely mathematized to overcome the difficulty of physics mathematization. This research is primarily related to curriculum development, teacher training, and the need to foster a deeper understanding of the relationship between mathematics and physics in the Moroccan educational system.

Corresponding Author:

Abdelwahab El Azzouzi
Computer Science, Signals, Automation, and Cognitivism Laboratory (LISAC)
Faculty of Sciences Dhar El Mahraz, Sidi Mohamed Ben Abdellah University
Fez, Morocco
Email: abdelwahab.elazzouzi@usmba.ac.ma

1. INTRODUCTION

Currently, in science and technology, the evolution of knowledge shows more and more that it is necessary to relativize the representation of totally independent disciplines and opt more for interrelated scientific disciplines. A typical example of this interrelation is the case of physics and mathematics. It has been shown throughout the history of science that mathematics and physics are two deeply intertwined disciplinary fields [1]. Newton [2] in his work emphasized the presence of a deep interaction between physics and mathematics.

The two disciplinary fields are then closely linked and teachers and students must transfer their knowledge and skills in mathematics to understand and solve a situation in physics [3]. However, several researchers say this relationship does not translate into pedagogical reality. Indeed, the physics and mathematics courses contain common concepts and require knowledge and skills to facilitate learning in both disciplines [4], [5]. The example is seen with physics equations that represent a relationship between symbols by mathematically modeling the conceptual knowledge of physics and vice versa physics can give mathematical equations a sense of concreteness for secondary students [6].

On the other hand, Redish and Kuo [7] stated that in the curricula, the objectives of physics courses are distinct from those of mathematics courses. This implies that the educational goals, content, and skills taught in physics and mathematics courses are fundamentally different and serve unique purposes in the curriculum. Also, Tinker [8] presented research findings indicating that 16-19-year-old students in England perceive physics and mathematics as separate and unrelated subjects. Furthermore, it is suggested that these students tend to disregard any connections or relationships between physics and mathematics. This highlights those students in this age group may not recognize the interrelatedness and the potential application of mathematical concepts in the context of physics, or vice versa.

Finally, the relationship between physics and mathematics is one of the most representative forms of interdisciplinarity among scientific disciplines [4], [9], [10]. This means that these two subjects, physics and mathematics, often overlap and interact in a way that combines knowledge and methods from both disciplines to enhance understanding and problem-solving. Therefore, interdisciplinarity is defined according to Reverdy [11] as "a real interaction between learning processes or knowledge from different subjects." In other words, interdisciplinarity involves genuine collaboration and interaction between fields of study that are traditionally distinct. Interdisciplinarity also embodies a complementary approach, combining various methods and teaching strategies within a specific discipline. This can lead to a more comprehensive understanding of a subject.

In general, Kabil [12] stated that no area of physics does not involve mathematical formulas, equations, and manipulations in some form. The involvement of mathematics in physics is an interaction that can range from simple communication of ideas to the total integration of purely mathematical concepts and notions [13]. To understand and solve a situation in physics, teachers as well as students must use their mathematical knowledge and skills [14]–[16]. This state of affairs requires a clear curriculum relationship between physics and mathematics [17], [18].

In the Moroccan educational context, while there is a rising interest among researchers in exploring the phenomenon of mathematization in physics, there appears to be a significant shortfall in the number of teachers and students who effectively engage with this concept. This disparity in research enthusiasm and teachers' involvement serves as the primary motivation for the work undertaken in this study, which seeks to investigate the reasons behind the limited adoption of mathematization in physics by Moroccan students and its implications for their learning experiences. The general question of this research: Is the interdisciplinarity of mathematics and physics taken into consideration in the Moroccan educational system?

Based on the premise that the teacher plays a pivotal role in determining the outcome of teaching and learning endeavors, it seemed prudent to direct our attention toward this factor. This method allows us to simultaneously shed light on the aforementioned overarching question and the specific inquiry central to this study: How the Moroccan teachers perceive the mathematical implications in physics learning? To address the research question, we identified the specific sections of the 2nd baccalaureate physics program that require mathematical knowledge and outlined the nature of this required knowledge. Subsequently, we analyzed the existing scientific literature on physics mathematization, focusing on eight recent articles that highlighted challenges in implementing mathematization, specifically in problem-solving and mathematization practices. We then developed a paper-and-pencil questionnaire consisting of six items, drawing from our analysis of 2nd baccalaureate textbooks and the scientific literature. The questionnaire aimed to provide insights into various aspects of physics teaching and learning, particularly regarding the intersection of mathematics and physics.

2. METHOD

2.1. Textbook analysis

To see the degree of mathematization in 2nd baccalaureate physics programs, we conducted a qualitative analysis of two physics textbooks currently used in high schools and published in 2007: Al Wadhih/l Massar Textbook (SVT option) and Al Wadhih/Al Massar Textbook (PC option). The first point noted from this thorough reading of the two textbooks is that each part calls for skills and/or mathematical concepts, as shown in Table 1. All parts of the physics program involve mathematical knowledge, which confirms the important place of mathematization in the Moroccan 2nd baccalaureate program.

2.2. The scientific literature

The importance of physics mathematization is increasingly challenging educational researchers. In the last two decades, researchers have focused either on the practice of mathematization or on the use of mathematics in physics problem-solving, as shown in Table 2. The literature researches affirm the observation that mathematics and physics are interrelated and that to understand physics phenomena one cannot bypass mathematics.

Table 1. Different parts of physics involve mathematics

Program parts	Mathematical knowledge required	
Nuclear transformation (NT)	Natural exponential function	
	Natural logarithmic function	
Electricity (E)	Differential equations	
Mechanics (M)	Integrals and primitives	
Others	Waves	Chemistry
	Linear function	Derivability
	Affine function	

Table 2. Examples of studies on physics mathematization

Discipline	Articles	Thematic
Physics	[18]–[20]	Problem-solving
	[6], [12], [21]	Mathematization practice
Chemistry	[14]	Problem-solving
	[15]	Mathematization practice

2.3. Questionnaire development

Through the examination of relevant textbooks and an extensive review of the existing literature, we undertook a methodical approach to gather pertinent insights that would address the research inquiries at hand. To systematically organize and elicit responses for our research questions, a structured paper and pencil questionnaire was crafted, encompassing six distinct items. The intricacies of each research question and the specific objectives associated with each item are comprehensively delineated in Table 3 providing a succinct and organized overview of the research framework.

Table 3. Objectives and elaboration of the different research questions

	Question	Question objective
Q1	What part(s) of the course do you think requires more mathematization in the terminal program?	Identify teachers' perceptions of the parts of the physics curriculum in the senior year.
Q2	According to you, the most common problems encountered in the teaching of physics in the terminal are?	Identify teachers' perceptions of the most encountered problems in physics.
Q3	Mathematics and physics are complementary in a lasting and continuous way.	Identify teachers' perceptions of the relationship between physics and mathematics.
Q4	To study a physical phenomenon, one always resorts to the integration of mathematics.	Identify teachers' perceptions of the integration of mathematics into the explanation of physical or chemical phenomena.
Q5	Mathematization is a difficulty in teaching and learning physics.	Identify teachers' perceptions of the difficulty of mathematizing physics in the terminal.
Q6	Do your students find difficulties in mathematizing physics problems?	Identify teachers' perceptions of the types of difficulties associated with physics mathematization.

2.4. Participants

In the current investigation, we conducted an empirical study involving physics teachers in Moroccan high schools, focusing on the assessment of their perceptions concerning physics mathematization. The survey targeted teachers engaged in high secondary education within the Fez-Meknes Region. The selected population comprised 141 physics teachers, representing 17.11% of the total teaching cohort in the region (824 physics teachers), as per data obtained from the Regional Academy for Education and Training of the Fez-Meknes. To ensure a representative sample, the study encompassed a diverse group of teachers within the specified geographical area.

The reliability and validity of the questionnaire, as a research instrument, were meticulously considered. The questionnaire demonstrated high face validity, as its items were expertly designed to align with the specific focus of the study, namely the perceptions of physics teachers regarding the integration of mathematics in their teaching practices. Content validity was ensured through a rigorous review process, involving experts in both physics and education, to guarantee the relevance and appropriateness of the questionnaire items. Furthermore, the instrument's reliability was assessed through a pilot study involving a subset of the target population. Internal consistency was evaluated using statistical measures such as Cronbach's alpha, resulting in a coefficient indicative of the questionnaire's reliability. The respondents, in this case, were not included in the main study, ensuring that the data obtained during the pilot phase did not influence the subsequent analysis.

Additionally, the ethical considerations surrounding the administration of the questionnaire were addressed. The assurance of anonymity was communicated transparently to the participating teachers, emphasizing that their responses would not be linked to the evaluation of their teaching practices. This approach aimed to mitigate potential biases and encourage candid and uninhibited responses, thereby enhancing the overall validity of the data collected. Teachers' willingness to engage with the survey, reflected in the completion time of 10 to 20 minutes, further supports the questionnaire's acceptability and practicality in the research context.

2.5. Data treatments

The results of the collected data were processed by Microsoft Excel. Moreover, we used Cronbach's alpha test to verify the internal consistency and thus guarantee the reliability of the measurement tool, which is the questionnaire. The value obtained is 0.85. It should be noted that this value is higher than the recommended threshold [22]. Indeed, a Cronbach's alpha value between 0.73 and 0.94 indicates the validity of a questionnaire [23]–[25]. Simpson [26] in his famous paradox applies an index that is called Simpson's index. This index represents the dominance or diversity of a sample when the choices of selected participants are combined. Simpson's original formula is:

$$C=\sum(f_{relative})^2$$

Where, f is the relative frequency for each choice.
Also, the scientific literature frequently uses a second index, which is the diversity index, corresponding to the Simpson index [25], [27]. This diversity index is first of all more intuitive to read than the Simpson index. Its formula corresponds to:

$$D=1-\frac{\sum f.(f-1)}{n.(n-1)}$$

Where, f is the frequency of each choice; n the total number of participants (141 teachers).

3. RESULTS AND DISCUSSION

3.1. Question 1

The first question was asked so that teachers could choose one or more answers at the same time. According to Table 4, the three parts: nuclear transformations (NT), electricity (E), and mechanics (M) were chosen by more than 80% of the population surveyed. We can therefore say that more than 4/5 of the teachers in the Fez-Meknes region consider that these three parts of physics require mathematization. It should be noted that the NT part is the one that uses the most mathematics since the percentage of teachers who have chosen it is close to 100%.

Table 4. Percentages of responses given by teachers regarding the parts of the course that require more mathematization

NT	E	M	Other
137	113	131	35
97.16%	80.14%	92.90%	24.82%

To see if other parts of physics are not mentioned in the propositions mentioned in the questionnaire, we added the proposition "others". The percentage of the teachers who filled in this answer modality did not exceed 24%. They mentioned two new themes: waves (13%) and chemical kinetics (11%).

It can be noted that the teachers' answers to question Q1 are in line with the data from the analysis of school textbooks and those reported in the literature, namely that physics depends on mathematics. Thus, for example, in the case of NT, the Experian function and the exponential function are needed to solve problems about nuclear physics phenomena. Bain *et al.* [15] argues that nuclear systems provide interesting opportunities for students and teachers to integrate mathematical knowledge in the context of half-life time calculations. As for part (E), it cannot be understood without passing the differential equations and their solutions. Indeed, the equations of electric dipoles require a mastery of the integral and the primitive, they are mandatory to solve a situation in electricity. This can add difficulty as stated by Leone [28] who stated that electrical circuits are already a conceptual difficulty for high school students, and this relationship with mathematics makes the situation even more difficult (Q5).

The integral and primitive are also essential for solving problems related to motion time equations of a mechanical system (M) like the projectile. In this context, Kim *et al.* [6] showed that the physics equation represents symbols that mathematically model the conceptual knowledge of physics. On the contrary, the analysis of the selected textbooks showed us that linear and affine functions are essential mathematical knowledge for the graphical reading of some topics in physics such as waves. In addition, derivability seems to be important knowledge in the calculation of the speed of chemical reactions. In the same sense, Rodriguez *et al*. [29] concluded that the understanding of problems in chemical kinetics requires two main features associated with mathematical equations (symbolic forms) and graphs (graphic forms).

3.2. Question 2

For question Q2, the surveyed population had the choice to select one or more propositions among the four proposed. These different proposals were deduced from the bibliographic research. Indeed, we based ourselves -among others- on the work of Jensen *et al*. [20]. The data obtained are presented in Table 5.

With this question, we aim to know the nature of the most common problems encountered in physics teaching in the terminal via teachers' perceptions. According to the data obtained, it seems that each of the proposals expresses the opinion of about a quarter of the population of the teachers surveyed. To verify whether or not there is a particular dominance of the different teachers' choices, we used Simpson's index, which expresses dominance or diversity.

The closer this index is to 1 (Cmax), the more homogeneous the choices are; on the other hand, the closer it is to 0 (Cmin), the more diversified the choices are. In the present work, we had 0.2508 as a value of Simpson's index so we can deduce that the choices of question Q2 are diversified. Also, the value of diversity index (D) varies in an opposite way to the value of homogeneity index (C). When D is close to 1, the more diversified the choices are. The closer D is to 0, the more homogeneous the choices are. In this study, we had 0.6836 as an index of diversity which means that the choices in question Q2 are diverse. This finding confirms the results of the homogeneity index [30].

According to the values of the dominance and the diversity index, we can say that there is no teacher consensus. Starting from the fact that the choice of a proposal by a teacher reflects his way of approaching problems in physics, we can stipulate that-even if the majority of the questioned teachers admit that all 2nd baccalaureate topics of physics studied require mathematization, there is no unified and standardized method of dealing with problems in physics among the questioned teachers [31].

Table 5. Percentages of responses given by teachers regarding the most common problems encountered in physics teaching

Problem description	Frequency	Percentage (%)
Problems that require little physics and the work consists mainly of mathematizing the situation.	84	22.95
Problems that require in-depth physics analysis before you can think about mathematizing the situation.	97	26.50
Problems that require mathematics before physics to solve the problem.	89	24.31
Problems that require physics and mathematics to be involved simultaneously rather than separately.	96	26.22

3.3. Question 3

The results of responses by teachers regarding the complementarity of physics and mathematics are shown in Figure 1. Based on these data, it appears that only 14% of the survey population does not agree that physics and mathematics are complementary. On the other hand, more than 3/4 of the teachers (86%) subject to the survey expressed their agreement.

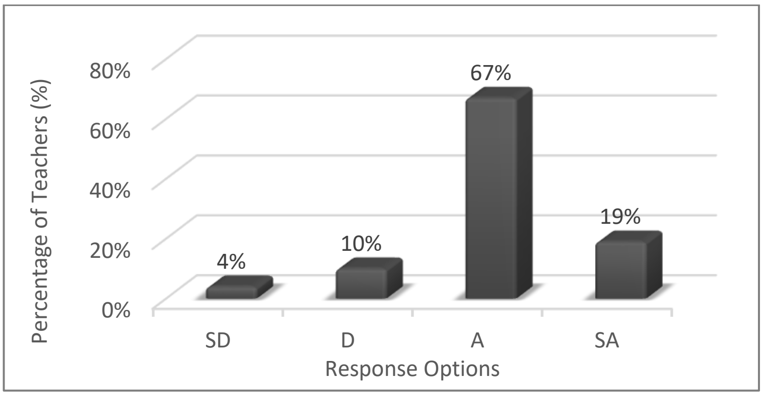

Figure 1. The percentages of responses given by teachers regarding the complementarity of physics and mathematics

3.4. Question 4

The data obtained regarding the responses given by teachers to the integration of mathematics in the interpretation of physics phenomena are illustrated in Figure 2. As in the previous questions, these data are in line with those provided by the literature that physics has deep mathematical implications. Whenever a teacher wants to explain a physical phenomenon to students (Q4) or he/she solves a problem in physics, he/she calls upon mathematics [19], [20].

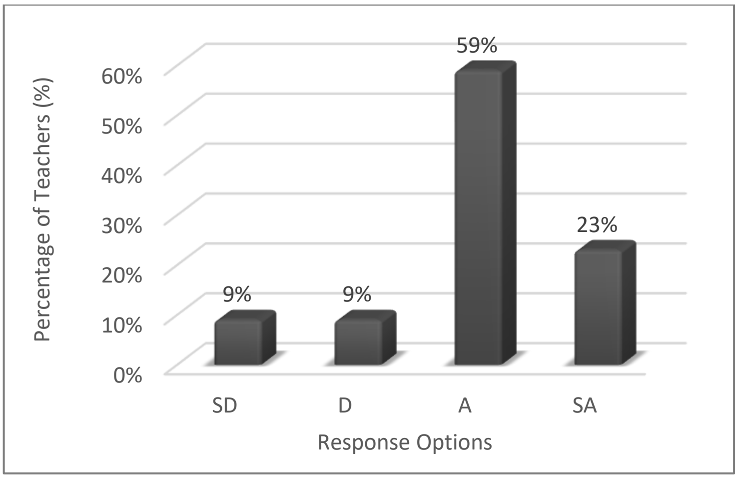

Figure 2. The percentages of responses given by teachers to the integration of mathematics in the interpretation of physics phenomena

3.5. Question 5

The percentages of responses for question (Q5) are presented in Figure 3. The results of question Q5 teachers report difficulty in teaching physics based mainly on mathematics. These data are consistent with the study conducted by Hu and Rebello [32] which shows the complexity of explaining and understanding mathematical equations in physics courses. Indeed, this situation according to Hu and Rebello [32] is difficult to teach the discipline because the interaction between mathematics and physics becomes an unproductive mixture educationally. The data from this question is perfectly consistent with the responses to question Q4 where 18% of the surveyed teachers say they do not need mathematics to understand physics.

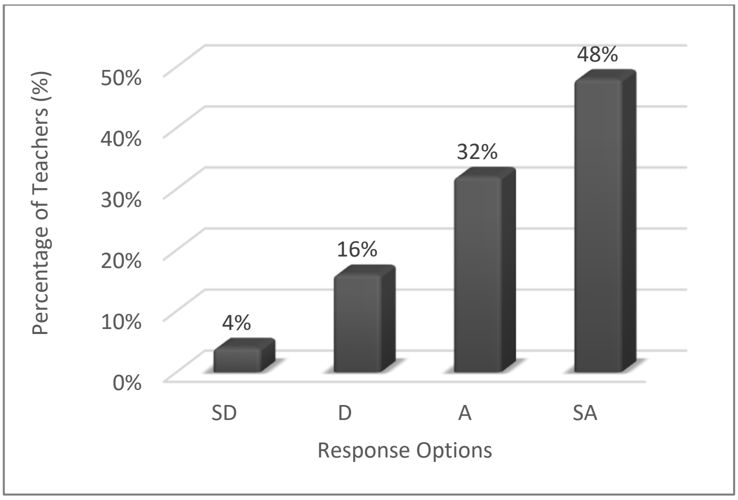

Figure 3. The percentages of teachers’ responses to the difficulty of mathematization in learning physics

3.6. Question 6

Figure 4 is disjunctive and therefore the choice can only be yes or no. According to Figure 4, almost all the teachers seem to affirm that their students find difficulty with physics mathematization. The 92% of the teachers answered "Yes" and only 8% of the surveyed population opted for the answer modality "No". We then asked the teachers who answered "Yes" to specify the causes of the difficulties. Several answers were given:

- Students cannot understand the physical meanings of mathematical symbols and/or formulas;
- Students cannot physically interpret mathematical equations;
- Teachers also cited that their students find difficulties with mathematical processes in solving physical problems.

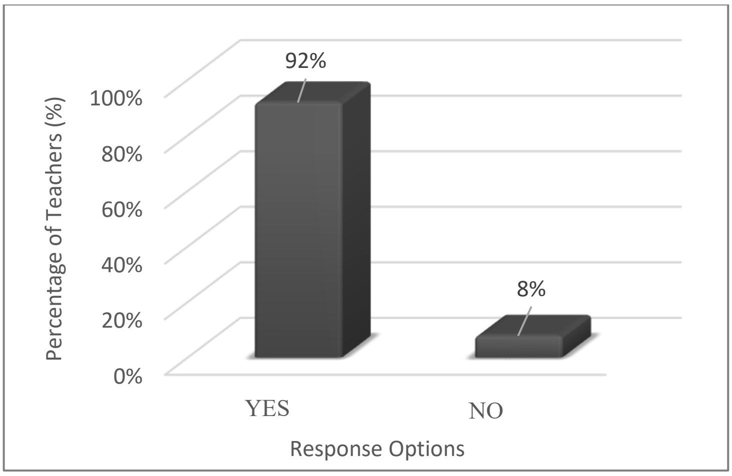

Figure 4. The percentages of teachers' responses to difficulties with students' mathematization of physics

The teachers questioned in this question (Q6) cited some difficulties with physics mathematization. These difficulties are already represented in the scientific literature. Hu and Rebello [32] concluded that many students fail to combine their mathematical knowledge with physics in a productive way, although they have the required mathematical knowledge. In this sense, Redish and Kuo [7] pointed out that teachers are often surprised by their students who may excel in mathematics courses but may find difficulties in mathematizing physics. Also, Kabil [12] pointed out that teachers showed that students fail to adapt formulas, equations, and/or mathematical manipulations to the problematized situation. In this context, Zeidmane [33] showed that the development of skills of a student is essentially related to the good attachment between physician practices and mathematical manipulations [34]. Then, the analysis of the perceptions of the questioned teachers showed us that Moroccan students have difficulty in physics mathematization. This confirms the findings of West *et al*. [13] who showed that many physics teachers in secondary education insist on the difficulties of students in their lack of mathematical knowledge [31], [35].

The survey of physics teachers in Moroccan high schools yielded crucial insights with practical implications for educational policy and practice. Teachers overwhelmingly identified NT, E, and M as areas requiring heightened mathematization, aligning with literature emphasizing the indispensable role of mathematics in these physics' domains. Diverse challenges in physics teaching were identified, reflecting varied approaches among educators. The survey underscored the enduring complementarity of physics and mathematics, emphasizing their continuous interdependence. While teachers recognized the necessity of mathematization, they also acknowledged its instructional complexities, resonating with existing research. These findings collectively inform the need for flexible educational strategies, tailored interventions, and professional development initiatives to enhance the integration of mathematics in physics education in Moroccan high schools.

4. CONCLUSION

The present work focuses on mathematization in physics teaching in the Moroccan curriculum according to an empirical study based on physics teachers' perceptions in the region of Fez-Meknes. In the absence of a unified method, the teachers suggest some techniques and pedagogy of work with their students whose contents are purely mathematized to overcome the difficulty of physics mathematization. This work emphasizes the need for well-structured pedagogical instructions focused on physics mathematization. These instructions aim to provide clear guidance to physics teachers regarding the incorporation of mathematical concepts into their teaching practices. Additionally, this study suggests implementing programs that can stimulate and inspire physics educators to integrate the educational pedagogy of mathematization into their physics courses seamlessly. The ultimate goal is to foster a more effective scientific education that promotes and reinforces physics mathematization among students. In essence, it underscores the importance of providing teachers with the tools and resources necessary to improve the understanding and application of mathematical principles in the context of physics education.

We hope that this research will provide an experimental framework for the foundation of qualified learning and teaching of physics in the Moroccan curriculum. Thus, teachers wish to use interdisciplinary studies in physics. Curriculum designers can also use these topics to prepare interdisciplinary curricular activities. In general, the teachers interviewed think that interdisciplinary studies are useful, but they do not have clear ideas on how to implement them in the Moroccan disciplinary curriculum.

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Abdelwahab El Azzouzi	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ihsane Kouchou	✓	✓	✓	✓		✓	✓	✓		✓	✓			✓
Abdelrhani Elachqar	✓	✓		✓	✓	✓	✓		✓		✓	✓	✓	
Fatiha Kaddari	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓		✓

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

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author [AEA], upon reasonable request. The data include responses to the questionnaire administered to physics teachers. Due to privacy considerations and the potential for identifying individual participants, the dataset is not publicly available.

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BIOGRAPHIES OF AUTHORS

Abdelwahab El Azzouzi is a Ph.D. student, Laboratory of Computer Science, Signals, Automation, and Cognitivism, Dhar El Mahraz Faculty of Sciences, Sidi Mohamed Ben Abdellah University, Fez, Morocco. He is a physics teacher, National Education Ministry, Preschool and Sports. He is also a member of TICE, Pedagogical Innovation, and Science Learning (TIPAS) laboratory at the Faculty of Sciences Dhar El Mahraz, Fez, Morocco; member in the project: "Interest of Young Moroccans in Science and Technology: Realities and Perspectives", as part of the Ibn Khaldoun IK 18-34 program supporting scientific research in the human and social sciences field. He can be contacted at email: bdelwahab.elazzouzi@usmba.ac.ma.

Ihsane Kouchou is a professor assistant in didactic of Sciences at the Normal High School (ENS), Laboratory of Interdisciplinary Research in Didactics, Education, and Training (LIRDEF), Cadi Ayyad University, Marrakech, Morocco, and associate researcher in the Laboratory of Computer Science, Signals, Automation and Cognitivism (LISAC) at Dhar El Mahraz Faculty of Sciences, Sidi Mohammed Ben Abdellah University, Fez, Morocco. She is a member in the project: "Interest of Young Moroccans in Science and Technology: Realities and Perspectives", as part of the Ibn Khaldoun IK 18-34 program supporting scientific research in the human and social sciences field. She interested in didactic of sciences, pedagogical innovation, teacher/student training and learning, neuroscience, and cognitive neuroscience in the educational context. She can be contacted at email: kouchouihsane88@gmail.com.

Abdelrhani Elachqar is a vice president in charge of Academic and Pedagogical Affairs, Sidi Mohamed Ben Abdellah University, Fez, Morocco. He is also a teacher-researcher interested in the didactics of sciences, pedagogical innovation, and digital teaching, Laboratory of Didactics and Pedagogy of the Teaching of Chemistry, Laboratory of Didactics and Pedagogical and Curricular Innovation (LADIPEC); Vice dean in charge of Pedagogical and Student Affairs at the Faculty of Sciences Dhar El Mahraz, a position he held until 2019; Initiator and coordinator of various pedagogical innovation projects (MOOCs, e-learning, virtual lab, and simulation projects); Member and coordinator at USMBA level of several European Tempus and Erasmus+projects. He can be contacted at email: aelachqar@yahoo.fr.

Fatiha Kaddari joined the Department of Chemistry of the Dhar El Mahraz Faculty of Science at the University of Sidi Mohamed Ben Abdellah in Fez, Morocco, in 1988. Her first teaching activities were in the first year of undergraduate studies, which made her aware of the difficulties faced by novice students and was partly responsible for her turning to research in science didactics. This research led to a state doctorate thesis, defended in 2005. Since then, she has broadened her interests through the Laboratoire de Didactique, Innovation Pédagogique et Curriculaire (LADIPEC), which she directed from 2011 to 2017. She is currently in charge of the educational technology team at the Laboratory of Computer Science, Signals, Automation, and Cognitivism. Dhar El Mahraz Faculty of Sciences, Sidi Mohamed Ben Abdellah University, Fez. She can be contacted at email: kaddari@yahoo.fr.