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Analysis of obstacles in teaching and learning nuclear physics: towards a digital approach in secondary education

Aziz Taoussi[1], Ahmida Chikhaoui[1], Khalid El Khattabi[1], Hassan Yakkou[2]
[1]Laboratory of Interdisciplinary Physics, and Informatics, Sciences, Engineering Sciences and Teaching Professions, Ecole Normale Supérieure of Fez, Sidi Mohamed Ben Abdellah University, Fez, Morocco
[2]Engineering Sciences, Multidisciplinary Faculty of Taza, University Sidi Mohamed Ben Abdellah, Taza, Morocco

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ABSTRACT

The study explores the specific obstacles encountered in the teaching and learning of nuclear physics within qualifying secondary schools in Morocco, particularly in the Fez-Meknes delegation. We identified a lack of specific research on this topic, despite a growing interest in improving science teaching. Using questionnaires administered to 100 teachers and 200 students, we found that the absence of laboratory experiments due to the dangers associated with nuclear physics is a major obstacle. Difficulties in understanding concepts such as radioactive decay, nuclear fusion, and fission were also noted. To overcome these challenges, we propose the development of digital teaching resources adapted to the Moroccan curriculum, including simulations and interactive tutorials. These resources are viewed positively by teachers and students alike, as they facilitate understanding of concepts, increase engagement and enable self-paced learning, promoting autonomy in learning and the development of creativity in students. For successful integration, it is essential to provide adequate training and ongoing support for teachers. The results offer concrete avenues for improving the quality of teaching in physical sciences and learning in a digital environment motivates students in Morocco.

Corresponding Author:

Aziz Taoussi
Laboratory of Interdisciplinary Physics, and Informatics, Sciences, Engineering Sciences and Teaching Professions, Ecole Normale Supérieure of Fez, Sidi Mohamed Ben Abdellah University
Fez, Morocco
Email: aziz.taoussi@usmba.ac.ma

1. INTRODUCTION

This research focuses on the use of a specific type of information and communication technology (ICT), digital resources for learning physics, a type of learning that teachers and learners find several difficulties [1]. Thus, it covers two domains [2], namely the ICT domain and the physics teaching domain, in a teaching-learning context [3]. The aim of learning the physical sciences is to awaken students' scientific spirit, to give them a taste for explanation, and to enable them to develop their own initiative in research. To achieve these objectives, specialists in the teaching of this subject are constantly devising and developing the most effective ways of explaining the phenomena involved. Indeed, the renewal and use of improved and modernized teaching aids promotes the development of the learner's analytical and critical faculties, enabling them to acquire the skills needed to reason effectively [4]. Starting from the importance of recognizing the difficulties facing the teaching of nuclear physics, as it is one of the most important scientific subjects, this study came to identify these difficulties and suggested appropriate solutions in the form of digital teaching resources [5]. Also, we will try to answer the following question: can we really identify the most complex concepts related to nuclear transformations in teaching and learning, and propose solutions in the form of adapted digital resources, specifically for qualifying secondary education in Morocco?

The present study seeks to identify the challenges in teaching nuclear physics within the qualifying secondary cycle for science streams in Morocco, as perceived by physics and chemistry teachers. Specifically, it addresses the question of how to design and implement a digital teaching resource tailored to the teaching of nuclear transformations in secondary physical sciences, taking into account the identified difficulties. The study will explore several specific questions:

i) What challenges do students face in learning nuclear transformations in their final year of science?
ii) What difficulties and obstacles do teachers encounter when teaching nuclear transformations in Moroccan secondary schools?
iii) What are the teachers' needs for digital teaching resources to address these challenges?
iv) How does the implementation of such resources impact learners' performance in understanding nuclear physics concepts?

For a number of years, national and international research into the didactics of physics and chemistry has been aimed at identifying the difficulties encountered by learners, understanding the origin of these difficulties, and seeking solutions to overcome and resolve them [6], [7]. The aim of learning physical sciences is to awaken students' scientific spirit, to give them a taste for explanation, to enable them to flourish and develop their initiative in research. The integration of a digital teaching resource (a tutorial) in physical sciences that is interactive and adapted to the learner. It has a positive impact on pedagogy and enables learners to maximize their knowledge [8].

Nasser *et al.* study [9] aimed to identify learning difficulties in physical sciences among qualifying secondary school pupils. Where the researcher noted that he can use ICT to complete experiments and simplify the real systems being studied [9]. According to Pullicino and Bonello [10], the lack of experimental equipment in high school laboratories means that integrating digital technology into teaching seems to be a solution for both learner and teacher. Unfortunately, the availability of digital resources for science, nuclear physics in particular, at national level is far from rich [11]. Despite the efforts of the Ministry of National Education, Preschool and Sports in this area. This research provides an opportunity to identify the difficulties of teaching and learning nuclear physics in Moroccan secondary qualifying classes [12]. One of the solutions to this problem is the design of a digital teaching resource to understand and improve the teaching of nuclear physics, using it as a didactic tool in qualifying secondary schools, especially in the 2nd year of the baccalaureate for science courses [13].

Various studies reviewed reveal major difficulties in learning physics, mainly attributed to inadequate teaching methods, mathematical shortcomings and a lack of student engagement. Ramadhani and Tanjung [14] points out that teacher-centered teaching and a lack of educational resources limit the analytical and problem-solving abilities of secondary school students, recommending a collaborative, student-centered approach. Wahyudi *et al.* [15] identified internal (insufficient preparation, reluctance to ask questions) and external (lack of multimedia and books) barriers among university students, advocating interactive methods to improve performance. Wulandari *et al.* [16] highlights high school students' difficulties with complex mechanical concepts due to insufficient numeracy skills, suggesting detailed explanations and varied exercises. Qotrunnada [17], after analyzing 40 studies, recommends active approaches such as problem- or project-based learning, as well as the use of numerical simulations to overcome obstacles linked to abstraction and formulas in physics. Finally, Wangchuk *et al.* [18] notes that 59.6% of students find physics difficult because of its abstraction and mathematical demands, proposing practical strategies and enriched resources to make the discipline more accessible and motivating. These works converge towards the need for an active and contextualized pedagogy to meet the specific needs of learners. An analysis of previous research on the subject reveals that most of it focuses on identifying learning difficulties in the physical sciences in secondary school students. These studies have been useful in defining the appropriate methodology, formulating the problem and choosing the type of statistical treatment for the current study. This research differs from previous ones in that it is one of the first to focus on teaching and learning difficulties in nuclear physics among qualifying secondary school pupils in Morocco.

2. RESEARCH METHOD

2.1. Sample presentation

To answer these research questions, we carried out this study on a sample of 200 students in the 2nd year of the baccalaureate, from all scientific streams (physical sciences, mathematical sciences, and life and earth sciences), as well as 100 physics-chemistry teachers with over ten years' experience. Participants come from ten qualifying secondary schools in the Fez delegation, part of the Fez-Meknes academy in Morocco. Students were selected by stratified random sampling to ensure balanced representation of different academic backgrounds, while teachers were chosen purposively, based on their specialization in physics-chemistry and significant professional experience, emphasizing their central role in teaching physical sciences. The sample size of 200 students allows for adequate representation of the various streams, and facilitates the identification of difficulties specific to the teaching of nuclear physics. Likewise, the 100 experienced teachers provide valuable insights into teaching practices and challenges encountered in the classroom. Data will be collected via questionnaires sent to learners and teachers to assess their perceptions, the difficulties encountered in nuclear physics, and the impact of digital resources in teaching.

The sample size was determined according to the objectives of the study, the statistical analyses, and the need to ensure reliable representativeness. For this research, we selected 200 students in the final year of secondary school. This choice was guided by the recommendations of Kang *et al.* [19], who emphasizes that a minimum sample size of 30 to 50 is necessary for robust analyses, but that a larger sample size significantly improves statistical power and the generalizability of results. This approach is also based on the work of Pavlov *et al*. [20] who recommends the use of precise sample size calculations to avoid interpretation bias associated with samples that are too small or too large. The chosen sample size allows for the detection of significant differences between groups, while taking into account the variability of the data. Students were selected by stratified random sampling to ensure a balanced representation of scientific disciplines (physical sciences, mathematical sciences, life and earth sciences). In addition, 100 teachers specializing in physics and chemistry and with over 10 years' experience were included, chosen on the basis of their pedagogical expertise. These numbers guarantee a rich and relevant collection of data, enabling us to respond effectively to the objectives of the study and to achieve statistically reliable and pedagogically significant results.

2.2. Presentation of survey questionnaires

This survey was formulated on the basis of several references. The questions were selected according to specific criteria obtained from a previous survey of teachers, educational inspectors, and learners. This survey was carried out in the form of two separate questionnaires, one for teachers and the other for students. In the light of readers' comments and suggestions, both questionnaires were rectified. These measures were deemed sufficient to guarantee the reliability of both questionnaires.

The first questionnaire was drawn up and put online via Google Forms for teachers. It includes general information, learning difficulties in nuclear physics, objectives to be achieved, integration of digital resources in teaching, and solutions to difficulties in nuclear physics. The second questionnaire was created and published online using Google Forms specifically for students, with closed and open-ended questions focusing on the following points: general information, learning difficulties in nuclear physics, the integration of digital resources into teaching, and solutions to difficulties in nuclear physics. The test questionnaires are structured around the following objectives, as presented in Table 1.

Table 1. Presentation of the questionnaire for teachers and students

Questionnaire	Objectives
Teacher questionnaire	General information: working hours/number of hours taught/number of students in class/computer skills/academic level/working environment.
	Learning difficulties in nuclear physics: sufficient or insufficient hourly volume/teaching difficulties/causes/solutions/effects on students' grades/and on success/percentage of students able to solve test exercises/students facing obstacles.
	Degree of attainment of concepts: know the degree to which the student has acquired the main concepts of the following lessons: "radioactive decay" and "nuclei - mass and energy".
	Integrating digital resources into teaching: impact of digital teaching resources on student motivation in the "nuclear transformations" unit.
	Solutions to difficulties in nuclear physics: solutions to difficulties in teaching/learning nuclear physics.
Student questionnaire	General information: gender/age/sector.
	Learning difficulties in nuclear physics: understanding or not understanding the concepts in the lesson/presence of learning difficulties for the concepts in the lesson "radioactive decay"/presence of learning difficulties for the concepts in the lesson "nuclei, masses, energy".
	Integrating digital resources into teaching: the impact of digital teaching resources on improving learning/addressing difficulties in acquiring concepts/and for academic remediation.
	Solutions to difficulties in nuclear physics: solutions to overcome teaching/learning in nuclear physics.

3. RESULTS AND DISCUSSION

To increase the number of responses, both questionnaires were distributed anonymously. There were 100 questionnaires sent to teachers and 200 of which were sent to students. Responses from teachers and students were analyzed using IBM SPSS version 21, and the graphs presented using Microsoft 365 (Office). The percentages presented in the graphs are expressed as a proportion of the number of people surveyed. The sample is made up of 100 teachers and 200 qualifying secondary school students of both genders, working in private and public schools in the Fez-Meknes regional education and training academy.

3.1. Results

3.1.1. Questionnaire validity and reliability

To guarantee the validity of the instrument, it was presented to experts in the physical sciences (four educational inspectors of physical sciences in the Fez-Meknes academy and two researchers in science didactics), for their opinions. The questionnaire was also presented to eight physics and chemistry teachers working in eight different qualifying high schools for their opinion on the questionnaire and the appropriateness of the linguistic formulation, and modifications were made to the instrument in the light of their comments. The pre-test on a sample of 30 participants showed a calculated Cronbach's alpha coefficient of 0.85, indicating good internal consistency [21]. The results are shown in Table 2.

Table 2. Validity and reliability of the research questionnaire

Reliability aspect	Result
Consistency of similar answers	90% of teachers who find teaching difficult also say it affects their grades
Temporal stability (pre-test)	85% of responses remained the same after re-administration of the questionnaire one month later
Sample diversity	Sample of 30 teachers from urban (60%) and rural (40%) areas, with varying levels of experience
Clear, simple questions	The teachers understood the questions without asking for clarification
Response scale structure	Responses on a scale of 1 to 3 were consistent, particularly in terms of conceptual understanding
Well-structured open answers	Open-ended responses were categorized, with a new category created: "lack of infrastructure".
Statistical reliability (Cronbach's alpha)	Cronbach's alpha coefficient of 0.85 for questions on teaching difficulties, showing good internal consistency

3.1.2. Analysis and interpretation

a. Guided teacher questionnaire

- General information

Analysis of the results in Figure 1 shows that 45.88% of teachers have over 20 years' experience, while a third have between 10 and 20 years' experience. In terms of workload, 45.88% teach less than 21 hours a week and 54.12% exactly 21 hours, showing a balanced distribution. The majority (60%) have classes of 30 to 40 students, and 25.88% have between 20 and 30 students. In terms of computer skills, 45.88% have an advanced level, while 37.65% are beginners. In terms of qualifications, almost half have a bachelor's degree, over a third a master's and 14.12% a doctorate. Finally, 55.29% of teachers work in urban areas, compared with 44.71% in rural areas, underlining the diversity of career paths [22].

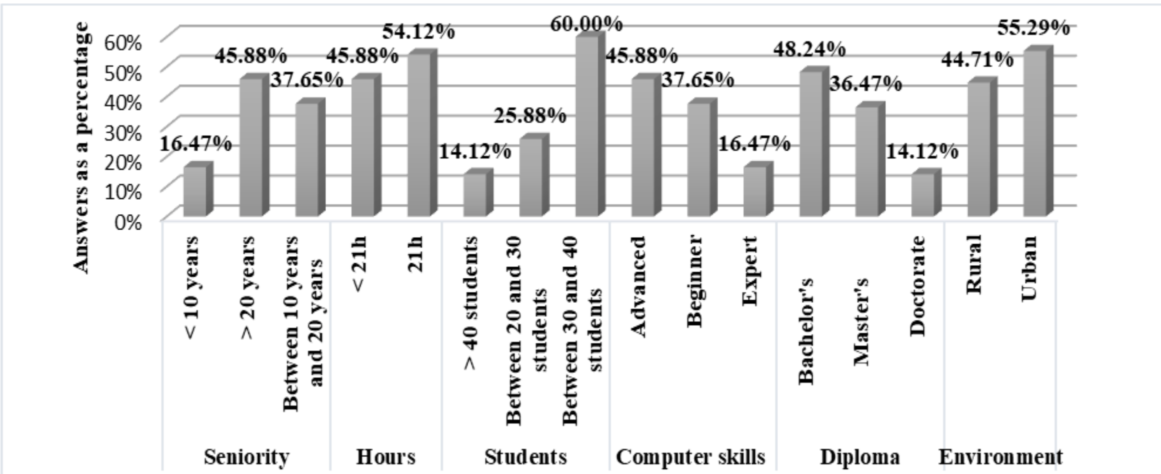


Figure 1. General information

- Learning difficulties in nuclear physics

The results in Figure 2 show that the majority of participants find that the time allocated to the "nuclear transformations" unit is insufficient, and that teachers encounter difficulties in teaching this subject. These obstacles have a negative impact on students' results in continuous testing. As far as these exercises are concerned, between 25% and 50% of students manage to solve them, while a minority manage between 75% and 100%. Most participants also point to a lack of effort on the part of students to overcome difficulties, calling into question their commitment to learning nuclear physics [11].

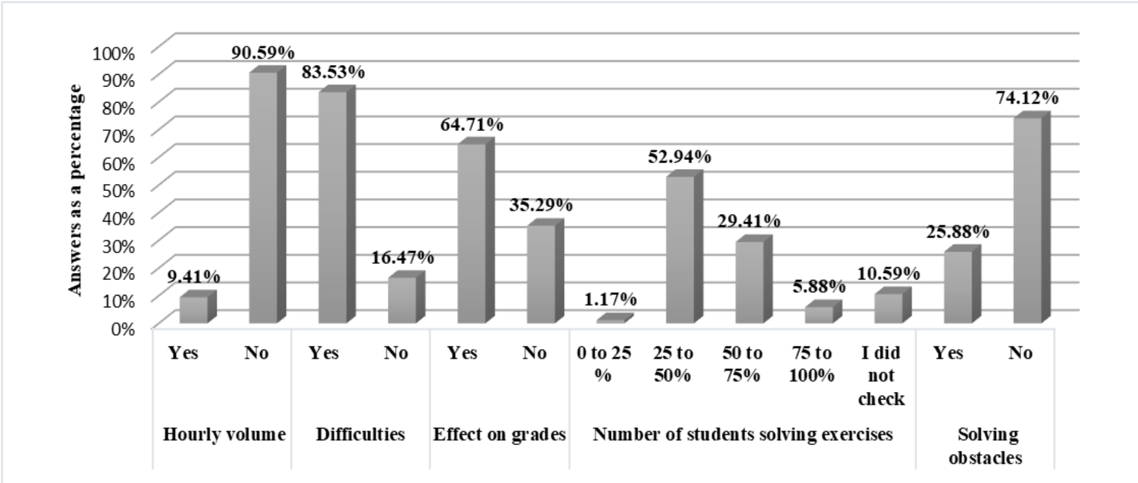


Figure 2. Learning difficulties in nuclear physics

- Degree of understanding of the concept - radioactive decay

The analysis in Figure 3 reveals an overall satisfactory understanding of the composition of the nucleus, with many participants having an intermediate level and some displaying maximum comprehension. However, understanding of the nuclide was slightly less good. Significant difficulties were noted in concepts such as isotopy, the radioactive nucleus, the (N, Z) diagram, radioactivity, and the law of radioactive decay, where a significant number of participants indicated minimal understanding. These shortcomings underline the need to improve teaching. It is crucial to implement varied teaching approaches and adapted resources to help learners overcome their difficulties and deepen their understanding of nuclear physics concepts [23].

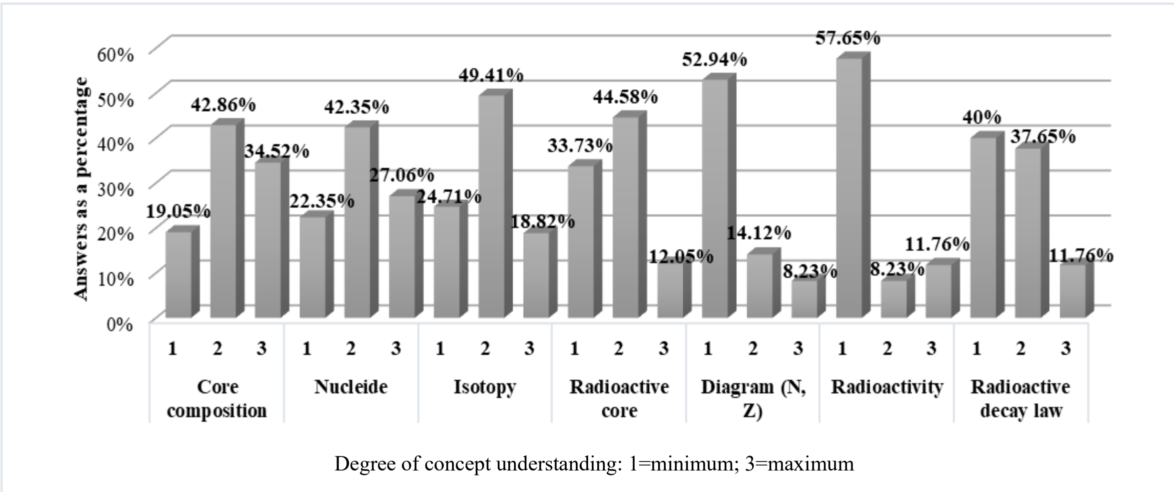
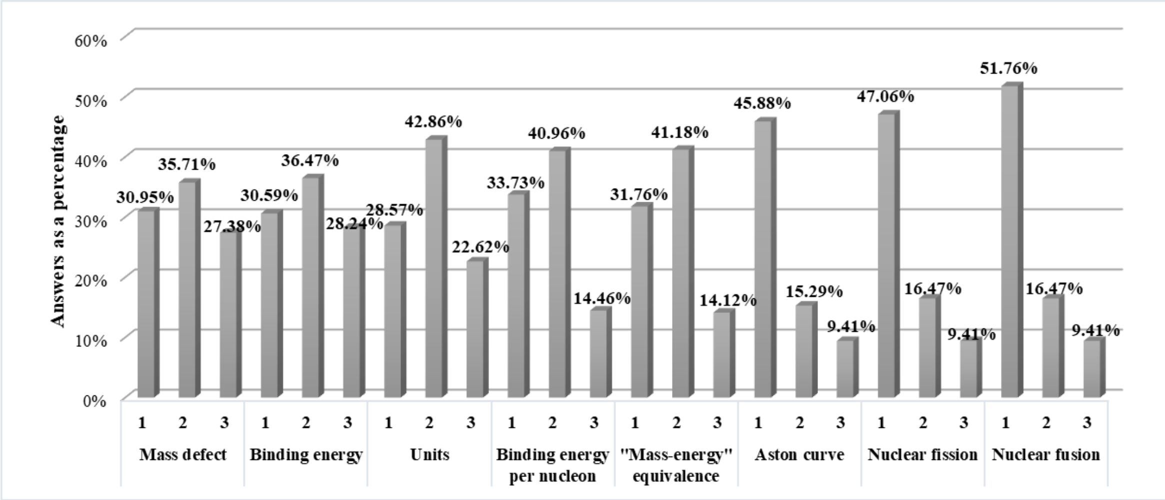


Figure 3. Degree of understanding of the concept - radioactive decay

- Degree of understanding of the concept - cores - mass and energy

The results in Figure 4 reveal variations in participants' understanding of different nuclear physics concepts. For the notions of mass defect and binding energy, participants showed levels of understanding split between minimum, intermediate, and maximum comprehension. Similarly, participants showed varying degrees of understanding for units, binding energy per nucleon and "mass-energy" equivalence. In contrast, relatively low understanding was observed for specific concepts such as the Aston curve, nuclear fission, and nuclear fusion, with a majority of participants showing minimal understanding. These results underline the need to improve participants' understanding in various areas of nuclear physics, focusing on less well-understood concepts. Targeted pedagogical approaches and adapted digital resources can be implemented to fill these identified gaps in understanding [22], [24].



Degree of concept understanding: 1=minimum; 3=maximum

Figure 4. Degree of conceptual understanding - cores - mass and energy

- **Integrating digital resources into teaching**

The results in Figure 5 show that 58.82% of participants use digital resources for teaching nuclear physics, while 41.18% do not. Among those who do not use them, the reasons given were mainly the lack of relevance of the resources (64.71%), followed by lack of training (14.12%) and time and cost constraints (21.18%). With regard to the use of resources during learning sessions, participants reported using simulations (34.12%), animations (38.82%) and digital resources in general (27.06%). A large majority of participants (89.41%) reported that the integration of digital resources had a positive impact on the motivation of 2nd year Baccalaureate students [25], while only 10.59% said they did not see this impact. In terms of solutions to difficulties in nuclear physics, the use of digital resources was identified as a solution by 50.59% of participants. Other approaches included the use of models and images (14.12%), the use of innovative teaching techniques (31.76%) and the use of technology (3.52%).

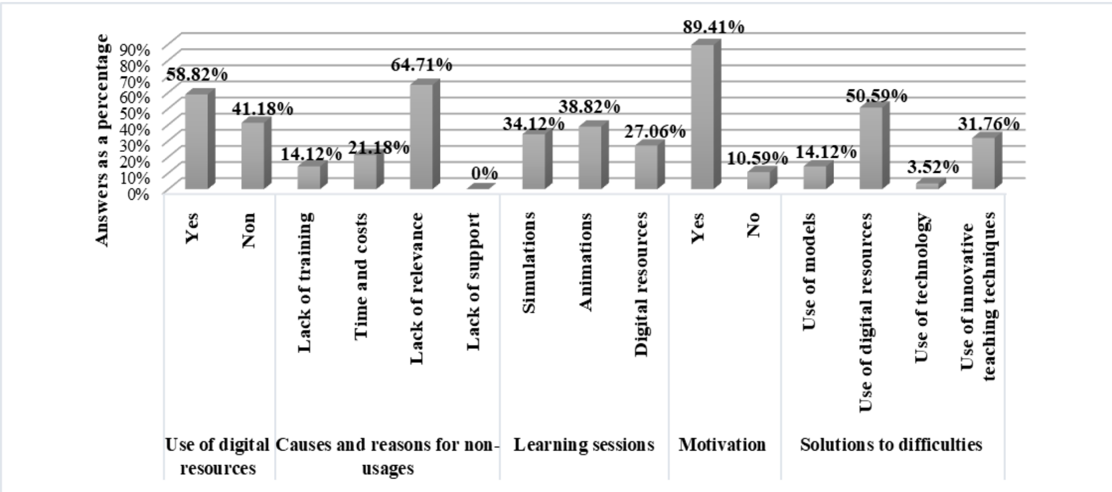


Figure 5. Integrating digital resources into teaching

b. Guided student questionnaire

- General information

The results in Figure 6 show that among the participants, 49% are male, while 51% are female. In terms of age, the majority of participants were 17 (56.5%), followed by those aged 16 (25.5%) and 18 (18%). In terms of field of study, 37.5% of participants are in the 2nd year of the baccalaureate in physical sciences, 33% are in life and earth sciences, 16% are in mathematical sciences A, and 13.5% are in mathematical sciences B.

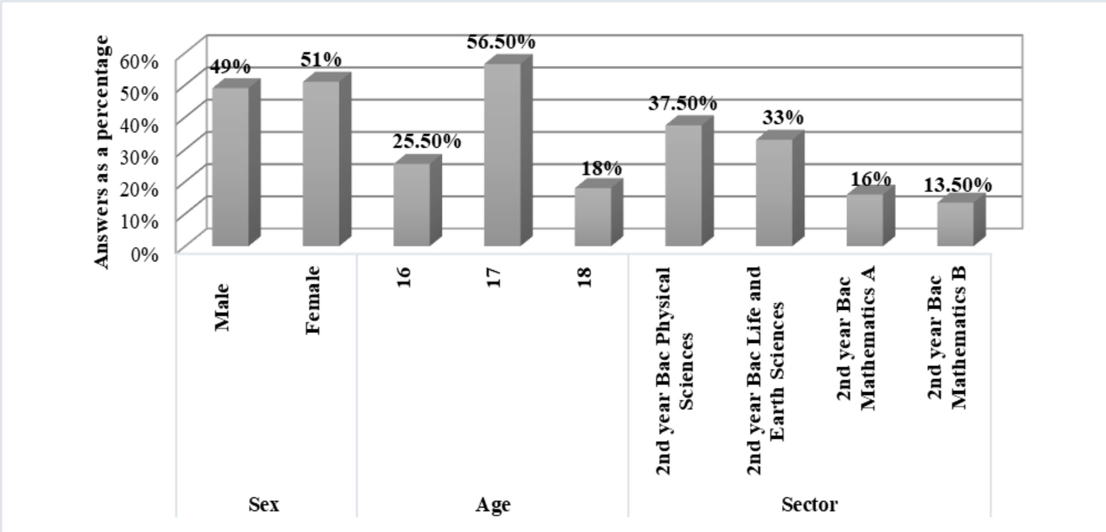


Figure 6. General information

- Learning difficulties in nuclear physics

The survey shows that 81% of participants enjoy nuclear physics, but 56.5% find it complicated. The majority (68.5%) find it difficult to understand the lectures, particularly those on radioactive decay and mass/energy relationships. The most difficult concepts include the (N, Z) diagram (33%) and radioactivity (28.5%). Despite these obstacles, 92% of students would like further explanations. The Aston curve (26%), nuclear fusion (25%), and nuclear fission (24.5%) are perceived as the most difficult concepts. The concepts of binding energy (4.5%) and mass-energy equivalence (8%) are considered moderately difficult, while binding energy per nucleon and units are considered more accessible (4.5% and 4%). Adequate support and clear explanations are essential to help students [26], as seen in Figure 7.

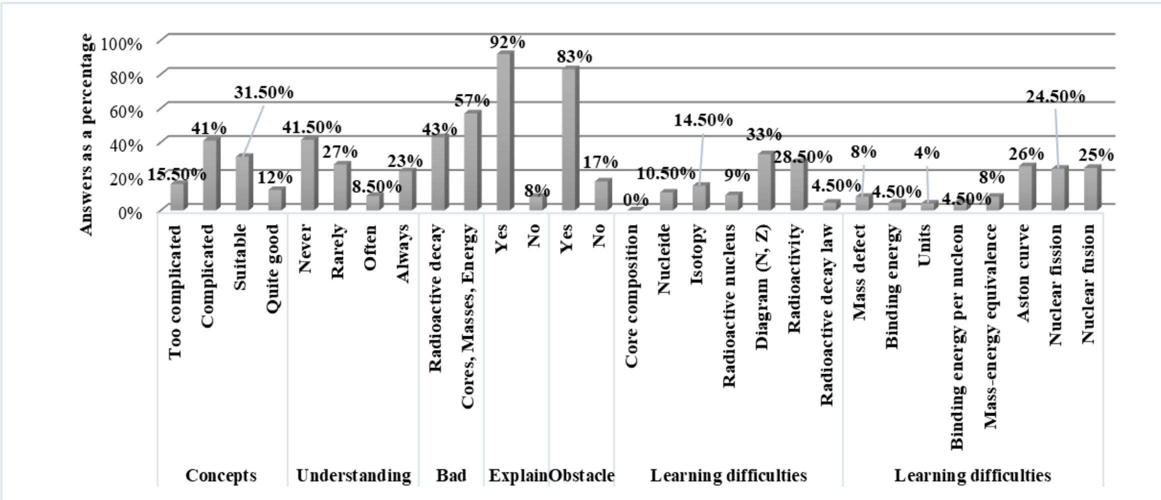


Figure 7. Learning difficulties in nuclear physics

- Integrating digital resources into teaching

The results in Figure 8 show that the use of digital resources in nuclear physics benefits the majority of learners, with 91.0% declaring that it improves their learning. Furthermore, 86.0% of learners recognize that digital resources can reduce difficulties in acquiring nuclear physics concepts. These results suggest that digital resources have the potential to improve understanding and assimilation of complex concepts. In addition, 80.5% of learners believe that digital resources are effective as academic remediation tools, indicating that they can help bridge gaps and overcome difficulties encountered in learning nuclear physics [27].

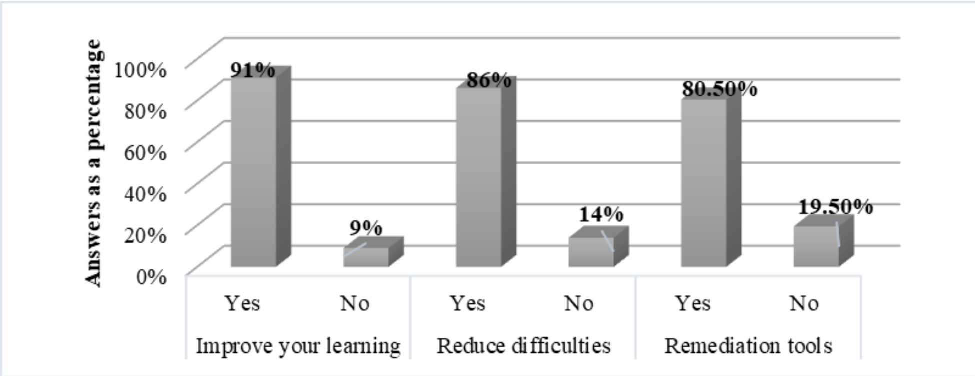


Figure 8. Integrating digital resources into teaching

- Solutions to nuclear physics challenges

As shown in Figure 9, 63.5% of learners recognize the importance of interactive animations and visualizations for understanding nuclear physics. The 5.5% mention the usefulness of online resources such as courses, while 8.5% express an interest in innovative teaching techniques. In addition, 22.5% stress the need to use digital resources adapted to the teaching of nuclear physics. These results underline the importance of visual tools, interactive approaches and specific resources to enhance learning [28].

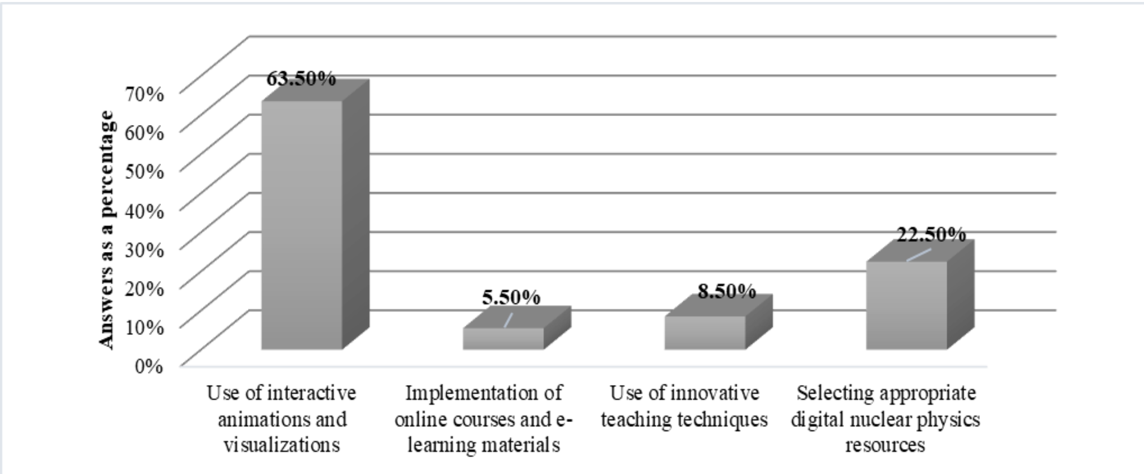


Figure 9. Solutions to difficulties in nuclear physics

3.2. Discussion

The results show that learning and teaching nuclear transformations in the final year of science in Morocco faces several challenges. Students struggle to understand complex concepts such as the Aston curve, nuclear fission and fusion, and the law of radioactive decay. The majority of learners regard these concepts as difficult, making it difficult for them to solve exercises, although 92% seek clarification from their teachers [29]. On the teachers' side, the main obstacles include insufficient time to cover the unit of nuclear transformations in depth, overcrowded classes (30 to 40 students) and difficulty in teaching specific notions such as mass-energy equivalence or the principles of nuclear fission and fusion, which negatively impacts student performance [30]. Despite 45.88% of teachers having an advanced command of digital tools, they express a need for adapted resources, in-service training and time to integrate these tools into their practice. However, digital resources are perceived as an effective solution: the 91% of students report that they improve comprehension, reduce difficulties, and increase motivation [31]. Interactive animations and visualizations make abstract concepts more accessible, while acting as a means of remediation [32]. These results underline the importance of providing teachers with relevant digital training and resources to address pedagogical challenges and improve students' understanding of nuclear physics concepts [33].

The added value of this research lies in its ability to identify and address the specific challenges associated with teaching and learning nuclear transformations, such as the complexity of the concepts and organizational constraints like limited time and overcrowded classrooms. It highlights the importance of digital tools and the specific needs of teachers, particularly in terms of training, adapted resources and logistical support, while offering a roadmap for better technological integration in teaching [34]. The results demonstrate the positive impact of digital resources, which improve students' understanding, reduce learning difficulties and boost their motivation, validating their relevance in a field as complex as nuclear physics [35]. In addition, the data collected provide concrete evidence to guide decision-makers and educators towards necessary adjustments, such as increasing the time dedicated to certain units or improving classroom conditions. Finally, this research enriches existing studies on the integration of ICT in specialized science subjects, while providing a valuable local perspective on pedagogical challenges in Morocco [36]. It offers practical recommendations for improving the teaching of nuclear transformations, and argues for the strategic adoption of digital tools in modern pedagogical approaches [37].

The study highlights major challenges in teaching nuclear physics in Morocco and offers concrete solutions. A key finding is the lack of teacher training in the use of digital resources and interactive approaches, which limits the accessibility of complex concepts such as radioactivity. To address this, initial and ongoing training modules focused on educational technologies, including simulations and interactive animations, are recommended. The lack of educational infrastructure, particularly in rural areas, represents another obstacle. Specific funding is needed to equip laboratories, provide digital libraries, and ensure internet access. Interactive digital resources could enrich the learning experience. The study also emphasizes the need to revise curricula to allocate more time to complex concepts and integrate practical activities, while promoting formative assessment to adapt teaching to the students' needs. We underline the importance of strengthening appropriate educational resources and creating institutional partnerships to develop content tailored to the Moroccan context. Involving all stakeholders and promoting interactive and motivating methods is a key lever to transform the education system and better address current challenges. Finally, this study aligns with the strategic vision of the Moroccan school reform 2030, developed by the Higher Council for Education, Training, and Scientific Research, after a thorough diagnosis and evaluation of the education system's situation, in order to address several dysfunctions and gaps in teaching physical sciences and identify the difficulties faced by teachers of this subject in transmitting scientific knowledge to students and achieving the competencies aimed by its teaching [37], [38]. Table 3 (see Appendix) shows the summary that compares the results of the search with those of previous searches, highlighting similarities and differences.

4. CONCLUSION

This study has highlighted the significant challenges associated with teaching nuclear physics in the scientific streams of Morocco's qualifying secondary cycle. Among the main difficulties identified, the insufficient amount of time devoted to the "nuclear transformations" chapter in particular stands out, limiting the in-depth study of complex concepts such as the Aston curve, nuclear fission and fusion. Teachers also have to cope with overcrowded classes, often comprising 30-40 students, which complicates pedagogical management and the individual attention required to ensure optimum understanding of concepts. The study discovered that students have major difficulties assimilating the abstract concepts of nuclear physics in the absence of laboratory experiments. These difficulties are accentuated by the intrinsic complexity of concepts such as radioactive decay, the mass-energy relationship and nuclear transformations. Despite these obstacles, the majority of students show a positive attitude towards the subject, demonstrating their willingness to deepen their understanding, particularly through further explanations from their teachers. In addition, the results of my research showed that the integration of digital resources into the teaching of nuclear physics was viewed favorably by both groups (teachers and students). These tools are deemed useful for visualizing abstract concepts, increasing student engagement, and offering flexibility in the pace of learning.

Nevertheless, teachers expressed the need for more relevant and adapted resources, as well as ongoing training to maximize the effectiveness of these tools. With regard to its limitations, this study focuses solely on identifying the difficulties and obstacles to teaching-learning physics (nuclear transformation) encountered by teachers and learners in Moroccan qualifying secondary classes. Therefore, it is recommended that further studies on the current topic is to develop interactive digital educational resources to nuclear physics, which directly address the difficulties identified. These resources should be designed to enable progressive understanding, with clear explanations and concrete examples illustrating complex concepts in collaboration with experts in physics didactics, developers of digital educational resources, and teachers to create pedagogical content tailored to the needs of Moroccan students.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Aziz Taoussi	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Ahmida Chikhaoui		✓	✓			✓		✓	✓	✓	✓	✓	✓	
Khalid El Khattabi		✓	✓			✓			✓	✓	✓		✓	✓
Hassan Yakkou		✓	✓			✓		✓		✓				

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.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

All national regulations and institutional policies regarding research involving human subjects were followed, in line with the principles of the Declaration of Helsinki. The research was approved by the authors' institutional review board.

DATA AVAILABILITY

The data supporting the results of this study are available from the corresponding author [AT], upon reasonable request.

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APPENDIX

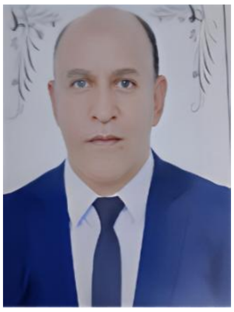
Table 3. Details to compare the results of the study with those of previous studies

Category	Results of the current study	Previous studies	Comparison and analysis
Objective	Identify teaching and learning difficulties in nuclear physics in Moroccan high schools and improve understanding of complex concepts through digital resources to enhance engagement.	- Identify learners' difficulties in physics and chemistry and propose solutions [6]. - Make physics more accessible through practical strategies [18]. - Collaborative approaches to develop analytical skills [14].	Both studies aim to identify learning difficulties, but your study specifically focuses on nuclear physics while integrating digital resources to enhance engagement and understanding.
Digital resources	A total 58.82% of teachers use digital resources, mainly animations and simulations. Recognized for their positive impact, 89.41% report increased motivation, and 91% of learners report improved learning outcomes.	- ICT integration enriches physical sciences teaching and addresses material shortages [11]. - Lack of multimedia tools and abstraction complicates learning. Simulations and projects recommended [15], [17].	Convergence in recognizing the benefits of digital resources, but your study highlights limited use and emphasizes animations and simulations as key tools, validating prior recommendations for interactive and concrete learning solutions.
Challenges encountered	Teachers and students face significant difficulties with nuclear physics concepts such as the Aston curve, isotopy, fission, and fusion. Insufficient time is allocated to units, student engagement is low, and resources are often inadequate.	- Difficulties often stem from abstraction and lack of experimental equipment [9]. - Lack of educational resources [14]. - Insufficient preparation and student reluctance [15]. - Challenges with abstraction and insufficient math skills [18].	Challenges identified in your study overlap with previous findings on abstract concepts and lack of resources. However, your study highlights specific issues in nuclear physics, such as insufficient instructional time and engagement, adding depth to the analysis.
Impact of digital resources	A total 91% of learners report improvements thanks to digital resources, and 80.5% consider these tools effective for academic remediation.	- Digital resources positively impact learning and maximize knowledge [8]. - Digital simulations help overcome abstraction and make concepts more tangible [17].	Agreement on the positive impact of digital resources in learning. Your study provides specific quantitative insights into their effectiveness in nuclear physics, including motivation and remediation.
Resource availability	A total 41.18% of teachers report not using digital resources due to lack of relevance (64.71%) and time and cost constraints (21.18%). Specific digital resources for nuclear physics are limited at the national level.	- Limited availability of rich digital resources for nuclear physics despite efforts from the ministry. - Lack of multimedia tools and appropriate materials for university learners [15].	Consistent findings regarding the limited availability of digital resources for nuclear physics. Your study identifies causes such as resource irrelevance and organizational constraints, enriching prior analyses with practical barriers.
Proposed solutions	Develop tailored digital resources for nuclear physics, integrate animations and simulations, adopt innovative pedagogies, and increase allocated time for critical units.	- Use ICT to simplify studied systems and complement experiments [9]. - Integrate tailored digital resources to learners' needs [22]. - Practical strategies to address abstraction [18]. - Active approaches and simulations [17].	Emphasis on creating specific resources and increasing time allocations aligns with prior work while addressing nuclear physics unique requirements. The study advances recommendations with practical and locally adapted strategies.
Role of digital resources	Recognized as essential for motivation (89.41%), remediation (80.5%), and accessibility to complex concepts (91%).	- Digital resources compensate for material shortages and better adapt to students' needs [11]. - Digital tools enhance interaction and understanding of abstract concepts [14], [15], [17].	Consensus on the critical role of digital resources. Your study specifies their impact in nuclear physics, particularly in motivating students and addressing conceptual gaps.
Recommend-ations	Increase teacher training on digital tools, develop resources tailored to nuclear physics, expand time for critical units, and encourage digital integration in classrooms.	- Integrate tailored digital resources to maximize pedagogical impact [8], [22]. - Practical strategies to make concepts less abstract [18]. - Promote interactive methods and multimedia resources [15].	Your study goes beyond by recommending structural changes, such as revising time allocations and emphasizing teacher training, providing actionable and context-specific recommendations.

BIOGRAPHIES OF AUTHORS

Aziz Taoussi is a Ph.D. student in Science Didactics, Laboratory of Interdisciplinary Physics, and Informatics (LIPI), University Sidi Mohamed Ben Abdellah, (USMBA), Fez, Morocco. His research focuses on the design of digital resources for the physical sciences. He can be contacted at email: aziz.taoussi@usmba.ac.ma.

Ahmida Chikhaoui is a professor of higher education (PES) at University Sidi Mohamed Ben Abdellah, USMBA, Fez, Morocco. His specialties are nuclear physics, computer science, and didactics of science. He can be contacted at email: ahmida.chikhaoui@usmba.ac.ma.



Khalid El Khattabi is a professor of higher education (PESA) at University Sidi Mohamed Ben Abdellah (USMBA), Fez, Morocco. His specialties are pedagogy and didactics of physical. He can be contacted at email: khalid.elkhattabi@usmba.ac.ma.

Hassan Yakkou is a Ph.D. student in Educational and Teaching Engineering. He is affiliated with Laboratory of Engineering Sciences, FP Taza, University Sidi Mohamed Ben Abdellah, Taza, Morocco. He can be contacted at email: hassan.yakkou@usmba.ac.ma.