International Journal of Evaluation and Research in Education (IJERE)
Vol. 12, No. 3, September 2023, pp. 1206~1211
ISSN: 2252-8822, DOI: 10.11591/ijere.v12i3.25271

Physics mathematization assessment: The nominal group technique as a context to investigate student understanding

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Article Info

Article history:

Received Aug 22, 2022
Revised Feb 11, 2023
Accepted Apr 3, 2023

Keywords:

Assessment
Half-life
Nominal group technique
Physics mathematization
Secondary students
Understanding

ABSTRACT

This work has its origin in physics learning with secondary school students in Morocco. The present work focuses on the relationship between physics and mathematics as well as the source of difficulties in learning the half-life concept. To highlight our research objectives, the researchers resorted to the nominal group technique (NGT) which is used not only to identify students' opinions about physics mathematization difficulties but also to assess the scientific education of this discipline. The results obtained showed that mathematics has an impact on Moroccan students' understanding of the half-life concept. The results also showed that coherent and simultaneous management of physics and mathematics favors the learning of Moroccan students in both disciplines.

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1. INTRODUCTION

Physics and mathematics are two disciplines deeply linked in the long history of science [1], [2] and often physics phenomena are explained via mathematical models [3], [4]. Indeed, the application of mathematics in physics is completely different from the ability to think mathematically in mathematics [5], [6]. In this sense, López-Gay, Sáez, and Torregrosa [7] argued that the mathematics used in physics, and pure mathematics, have distinct goals because the goal of physics is the description and understanding of a physics system, not the solution of equations.

However, the scientific literature proposes quite a few models to describe the essence of how we use mathematics in physics [8], [9]. But briefly, all the models described show that once the physics analysis of a real problem or phenomenon has been carried out, the crucial step is a process of mathematization or mathematical modelling. It consists of expressing the ideas of the initial analysis through mathematical concepts and relationships [10].

It appears from the body of work in several Moroccan educational fields that the non-acquisition of physics mathematization can hinder the understanding of some physics concepts taught [11]. If the teacher presents learning according to the student's learning style, this will have an impact on maximum student learning outcomes. Student learning outcomes could take the form of mastery of some concepts of nuclear physics [12]. In our case, this mastery has a relation to mathematics. In the same sense, several Moroccan teachers observe that students encounter great difficulties in physics mathematization. These teachers also note that students' mathematical skills are insufficient to learn certain physics concepts [11]. In our case, the teachers say that in order to calculate the half-life time, students need to master certain mathematical manipulations: Natural exponential and logarithmic functions to move from the radioactive decay law to the half-life time.

The present work highlighted the learning of the nuclear half-life concept. Nevertheless, Nash [13] have shown that the non-acquisition of mathematical problems related to nuclear can hinder the understanding of some matter elements concepts. Furthermore, Kabil [14] stated that, in many cases, students are not familiar with mathematics demonstrations, because of this, understanding nuclear radioactivity in the classroom can be quite limited. So, this content of nuclear transformation represents a content source of difficulties and obstacles based essentially on the mathematization of this content. In this sense, we assume that the coherent and simultaneous management of physics and mathematics in half-life comprehension favors the learning of Moroccan secondary school students.

Physics mathematization is thus revealed as an interesting research topic. However, it seems that the number of studies on physics mathematization in the Moroccan context is far from satisfactory; hence, the motivation behind this work. The general question of this research is: Is the interdisciplinarity of mathematics and physics taken into consideration in the Moroccan educational system?

Based on the conviction that the student represents the fundamental element in the success or failure of the learning activities, it seemed judicious to us to focus on the latter to bring elements of answer to the previous question. Thus, this general question is divided into two sub-questions: i) How do Moroccan students perceive the involvement of mathematics in the learning of physics?; and ii) Is the involvement of mathematics in physics a difficulty for understanding the discipline?

In this paper, the researchers have conducted a study with secondary school students, namely students in the last year of secondary education in Morocco. The study adopted an analysis based mainly on the nominal group technique (NGT) which is a highly structured face-to-face group interaction that empowers participants by allowing them to be heard and have their opinions taken into account by other members. Thus, the method aims to generate ideas from Moroccan students on nuclear half-life mathematization.

2. RESEARCH METHOD

2.1. Half-life concept

The radioactive half-life time in the Moroccan secondary school curriculum is a method of describing the levels of radioactive substances about the time required for the radioactive substance to decrease to half its initial value. Thus, the half-life is the time required for the radioactive substance to decrease its radioactivity A_0 to $A_0/2$. Namely, the half-life is an inescapable fundamental concept of radioactivity. Its importance is also demonstrated by the fact that it is used in several completely distinct disciplinary fields [15].

2.2. Nominal group technique (NGT)

The nominal group technique (NGT) [16], [17] or the Round Robin technique [18] is a technique for sampling the perceptions of a group of individuals to obtain general agreement or convergence of opinion on a particular topic [19]. Indeed, the NGT is an optimal, objective, systematic and quantitative description of the manifest content of communications. The strength of this technique lies in the fact that it combines and alternates individual work and group discussion [17].

On the other hand, NGT is a very adaptable method and generally follows several well-defined steps. These steps may be influenced by, on the one hand, the time available for the research and the participants, or by the level of clarification, and generalization required of the subject. NGT can be varied in the idea generation process of combining steps with optimal clarification [17]. So, how NGT is defined and operationalized varies from study to study, depending on the objectives of each research [20].

2.3. Participants

The target population for this research was students in the final level of Moroccan secondary education. Indeed, this level of education is the terminal of Moroccan secondary education, which opens with the first cycle of three years of college secondary education, after which students enter qualifying secondary education (high school), which also comprises three years: one year of common core and two years of the baccalaureate. The study is therefore carried out with students in the second year of the baccalaureate (the final year) of the general education stream with a physics option. The research sample consists of a class in the second year of the baccalaureate, physics option, aged 17 to 19 years (18 students), during the autumn semester of the 2021-2022 school year.

2.4. Experimentation

After students had learned the part about nuclear transformations: The physics part contains the concept of half-life time, the researchers gathered a group of 18 students of the second-year baccalaureate option physics in a classroom. Researchers got the group to express themselves freely and we asked them the following nominal question: What difficulties did you encounter when you were learning the half-life concept?

To answer this question by implementing the NGT, the experiment is structured in several steps. First, each participant writes down the solutions that they feel answer the nominal question. Participants are given up to 20 minutes to reflect by writing down their ideas. Second, collection of the ideas generated by the participants in a round-robin format until no new answers emerge. The ideas collected by the facilitator are shared and displayed to the group: Each idea is written on an editable whiteboard. The facilitator then asks one participant at a time to present one idea to the group, using the "Round Robin" principle. Participants can think of new ideas during this process but must wait their turn before they can share them with the group and write them on the board. This step lasts as long as necessary until there are no more new ideas. Third, the facilitator clarifies the meaning of the different proposals. He/she may cancel some of them if they are deemed redundant or irrelevant to the problem. The facilitator in this step should not lead the participants in the clarification process, which can make this step particularly difficult. This step takes up to 30 minutes to write down all the answers that are deemed relevant;

The next step is group discussion after the presentation of the selected answers. All ideas should be discussed to ensure that participants understand them so that they can make an informed decision when voting on the ideas in the next step. The facilitator should emphasize that participants do not have to agree with all the ideas listed because, at the end of the clarification phase, participants can ignore the ideas by voting on their personal preferences in the next step. This step lasts up to 30 minutes. Finally, the last participants are invited to vote and choose 8 proposals from those presented and prioritize them. This step lasts as long as necessary until the participants rank the 8 most important proposals. Recognizing that the most significant responses are the ones listed first, each response is given a weighting score of p_i which decreases from the first response. Once the data was collected, Table 1 was drawn up.

Table 1. Students' answers according to descending $\sum p_i$

Students' answers	% answers=$\frac{p_i}{\sum P_i}$	Order
Difficulty related to the weak interdisciplinarity between physics and mathematics in the terminal program.	86	1
Difficulty related to the lack of mathematical skills necessary for the calculation of half-life times.	77	2
Difficulty related to the lack of interpretation of the symbols used in the concept of half-life time.	54	3
Difficulty in understanding the connection between the law of radioactive decay and the half-life time.	52	4
Difficulty with mathematical demonstrations in half-life time calculations	40	5
Difficulty in assimilating the concept of half-life time as a new concept in the high school physics curriculum.	35	6
Difficulty related to the lack of experience in nuclear transformations.	28	7
Difficulty related to the lack of application of information and communication technology (ICT).	20	8

3. RESULTS AND DISCUSSION

Examination of Table 1 reveals that students attribute their difficulties in half-life learning mainly to interdisciplinarity between physics and mathematics. Indeed, 86% of the responses refer half-life concept requires mainly in mathematics. By analyzing the program, we can say that half-life calculation is necessarily based on mathematical manipulations related to natural exponential and logarithmic functions. In this sense, Jensen, Niss, and Jankvist [9] in their research report on a similar situation whose formalization requires mathematical manipulations and the study showed that mathematization and physicalization have the same objectives for solving any physics situation. Thus, the idea of Guerrero-Ortiz and Huincahue [21] also showed that physics teachers insist that all physics topics require some mathematical knowledge. Then, physics can be a simple catalog of mathematical manipulations that just differ in their applications from one situation to another [22].

However, the results also show that mathematical skills and their analogies in physics are far from satisfactory for Moroccan secondary school students [11]. There were 77% of the respondents agree for a lack of the necessary mathematical skills for half-life calculating. Indeed, physics mathematization in secondary education is very convenient in attributing students' difficulties to the lack of mathematical knowledge in their science lessons [14]. Physics and mathematics lessons are closely related and therefore students need to transfer their mathematical knowledge and skills to understand and solve problems in physics [23], such as the calculation of half-life times.

In this sense, 40% of the responses are for the difficulty of mathematical demonstrations in half-life time calculations. This confirms the research done by Kim, Cheong, and Song [24] who concluded that mathematical demonstrations of a physics equation always represent a relationship between symbols by mathematically modeling the conceptual knowledge of physics. Therefore, the mathematical meanings of half-life can enhance students' understanding of this concept. So, the mathematical implications in physics can influence the students' understanding of the subject matter. Learning some concepts would be more difficult as long as they have a close relation with mathematic demonstration. Consequently, the student considers physics as a discipline as difficult.

In another context, van Hemmen [25] showed in his research that physics mathematization is completely different from that of pure mathematics. Hence, the difficulty in assimilating new physical concepts (35%) and interpreting the symbols used in the half-life concept (54%). In this context, Kabil [14] stated that physics teachers are often surprised by the fact that their students seem to know so little mathematics despite their good results in mathematics classes. The reason is that the symbols used in physics, unlike mathematics, are not arbitrarily chosen, but are loaded with certain physical meanings [14]. As a result, physics students fail to attach physical meanings to symbols in equations and formulae (52%).

Thus, generally, the involvement of mathematics in physics needs to be done with harmony between the physics curriculum and mathematics [26]. Moreover, this integration has to be achieved either with physics teachers programming mathematical reminders and their analogies in physics with their students or in the form of sustainable and practical interdisciplinarity between physics and mathematics [27]. So, the development of an interdisciplinary program using a cooperative study with physics and mathematics teachers or a process that brings together all mathematical and physical skills in solving physical problems [28], is essential to attribute to the understanding of Moroccan students in physics. Thus, the stated hypothesis that mathematics has an impact on students' understanding in learning the calculation of radioactive half-life time has been well verified.

The present work has also indicated the importance of practical experiments in learning physics [29], [30] as 28% of the responses concern experiments in the whole part of nuclear transformations. By analyzing the program, we can conclude that nuclear seems to be either dangerous for experimentation or requires a long time to perform. Therefore, success in physics teaching and learning requires innovation in the mathematization of the subject curriculum by applying for example information and communication technologies (ICT) (20%) [11], [31]. Indeed, the scientific literature argues that the science, technology, engineering, and mathematics (STEM) curriculum [32]–[34] remains a good solution to improve Moroccan secondary school students' learning of physics mathematization.

The analysis of all the difficulties grouped in this study showed us that mathematics has a significant impact on the physics understanding of Moroccan secondary school students. This study relied on the nominal group technique (NGT) as an optimal operationalization technique of the opinions and views of the students questioned in this work. The results obtained allowed us, on the one hand, to conclude that Moroccan secondary school students do not have the necessary capacity for physics mathematization which poses a difficulty in learning the subject. On the other hand, the results clearly show that the involvement of mathematics is a difficulty that hinders the understanding not only of some physics concepts but also the understanding of the whole discipline.

4. CONCLUSION

The calculation of half-life times in the Moroccan curriculum illustrates that mathematics is a crucial part of physics, as it has been shown that in this field, in particular, secondary school students have difficulties understanding the complex nature of the half-life concept. The end of this work aims to address the difficulties in learning about half-life, with an approach based on the nominal group technique. This method of idea generation confirmed that interdisciplinary management between physics and mathematics in half-life calculating favors the understanding of Moroccan secondary school students.

Finally, the research on the understanding of half-life by secondary school learners showed that mathematical cognitive knowledge and physics mathematization skills can play an important role in learning not only the half-life concept but also all physics concepts needed mathematics. So, learning with optimal interdisciplinarity between mathematics and physics among Moroccan students is therefore far from satisfactory because the Moroccan educational system so far does not take into consideration this interdisciplinarity that can help students understand the scientific physics issues and make the physics classroom a comfortable classroom for scientific learning.

In such cases, we can conclude with some recommendations. On the one hand, teachers should advise their colleagues who teach either physics or mathematics to overcome these difficulties of physics mathematization by adding more mathematics-related hours to the student's schedules. On the other hand, students need to learn physics concepts outside their mathematical formulations and physics should not be reduced to mathematical manipulations only.

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