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# MATHEMATICAL MODELING IN PHYSICS AND CONCEPTIONS OF LEARNERS: FORCE AND DIFFERENTIAL EQUATION

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**Abstract**- Mathematical modeling is an important tool for probing the physical realities encoded in phenomena, but the majority of teachers and students do not use it in the right direction. Therefore, the population targeted by this study is physics-chemistry teachers from the Beni-Mellal Khenifra Academy, a total of 68; 64.7% are secondary school teachers, and 35.3% are middle school teachers. About the sample of learners, it consists of 43 learners continuing their studies in secondary school from in Khenifra city (one in the rural area and the other area) during the school year 2021-2022 from the academy of Beni Mellal Khenifra. In this study, we showed through a survey based on two questionnaires addressed to teachers and learners. The results show that most teachers around 88,2% are unable to detect the limits and legitimate criteria of such a concept, in addition, 66% of teachers believe that mathematical modeling (MM) is strictly sufficient and necessary and 34% think (MM) Necessary but insufficient to be precise we have chosen two capital physical concepts namely the force and differential equations that govern the dynamics of kinetic variables of electrical phenomena in circuits. Based on these two concepts, we have provided learner guidance questions and the results show that almost 90% of learners are unable to answer the questions, and 10% of them gave correct answers. Therefore, this indicates that learners do not master mathematical concepts on the one hand and on the other hand the fatal analogy worn by them, learners are unable to relate the differential equation with the phenomenon reigning in the circuit. As a result, the interaction between modeling violently influences conceptions in learners.

**Keywords:** Mathematical Modeling, Didactics of Physics, Conceptions, Investigation, Differential Equations, Force.

## 1. INTRODUCTION

The teaching of experimental sciences in general, and the teaching of physical sciences in particular, has become a fundamental objective for large countries because of the increasingly important role played by science in society. The improvement of the scientific mind among learners has become a major objective of the teaching of the physical sciences [1, 2]. In the real world, understanding a given physical phenomenon is too complex and impossible in the majority of cases, due to the largely hidden parameters that steer these phenomena. As a result, mathematics become a paramount tool in teaching physics and understanding at several levels, ranging from upper secondary to university. Recently, it was shown in a series of papers, that mathematics can help learners to overcome serious pedagogical barriers [3-6]. Nevertheless, using mathematics gives arise to the same often-hidden effects that discourage learners from making the cognitive blend of physics concepts with mathematics models, which generates robust and difficult misconceptions [7-9]. Additionally, Conceptions of teaching can be seen as the result of the interaction between the taught concepts, the teaching tools, and the learner [10]. Generally, teaching physics with the help of mathematical modeling negatively affects the conceptions of learners [11-13].

Force is the cornerstone of mechanics science because the main mechanical concepts lean on it. As a result, studying its effects on mechanics learning has a paramount role to steer the conceptions of learners and enhance them in the learning situation. In this direction, several works were made. Particularly, in [14], it was shown that misconceptions related to force, negatively affect the understanding of the next concepts, including free-fall motion, friction force, and a force on a non-moving object. Moreover, it was shown in a qualitative study [15], that gravity related to the force remains conceived by teachers which entail in turn misconceptions for learners.

The differential equation is a huge mathematical tool harnessed to modelized dynamic phenomena, including electrical circuits, nuclear reactions, and mechanical motions. In a recent study [16], the authors show that majority of students have serious problems in solving linear ordinary differential equations. As a consequence, this will dramatically affect their conceptions of modeling a dynamic physical system. Additionally, it was shown for instance that Mexican physics teachers have 17 misconceptions about the treatment of Simple Pendulum [17]. Motivating by the above studies, in our paper we seek a didactic analysis whose objective is to study mathematical modeling together with conceptions for the learner, which aims to bring solutions to the obstacles encountered by teachers in the construction of one of the fundamental concepts of mechanics: force, and phenomena of charge and discharge of a capacitor, based on an investigation.

We will focus our didactic analysis on the main question which is:
- What are the limitations of mathematical modeling in physics and what is its impact on students' conceptions?

## 2. CONCEPTS AND DEFINITIONS

### 2.1. Mathematics and Physics

No one can deny the importance of mathematics to rigorously model physical concepts [1, 18]. Indeed, mathematics plays a paramount role in modeling physical concepts, accomplishing theories, and strengthening didactic tools [19]. However, the role of mathematics sometimes is restricted to solving problems. As a result, this perception may give the impression that using mathematics could negatively affect understanding the concepts of physics. Thus, the reconciliation between the concepts of mathematics and physical concepts is one of the difficult topics in modern didactic [22-25].

### 2.2. Mathematical Modeling in Physics

MM is acknowledged as important in education at all levels [20, 21]. This fact is due to the power of mathematical concepts in modeling several physical phenomena. In particular, the variation is modeled via derivatives, and the interplay cause-effect widely employed in physics is modeled as.

### 2.3. Derivative of (CAUSE) Gives the Effect

In the following Figure 1, we present the machinery of mathematical modeling of physical concepts. A given physical concept is mathematically modeled using a suitable mathematical element (point, vector, function…). Subsequently, by using mathematical machinery (derivatives, cross, and dot products…), we end up with mathematical results and interpret them to understand physical phenomena [26, 27].

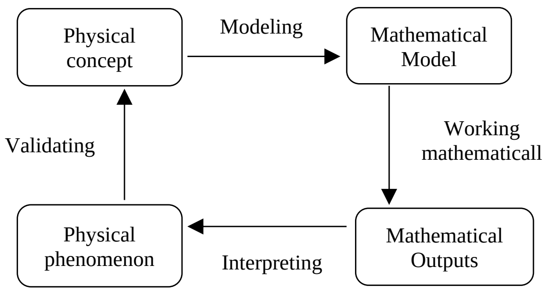


Figure 1. Clarification of mathematical and physics concept interplay

### 2.4. Conceptions

The main objective of teaching physics in general during the process of learning and teaching is to help students understand physical phenomena in real and objective ways [28]. Besides, the interaction between students, concepts, and mathematical tools generates misconceptions [29]. Consequently, misconceptions happen when concepts that students acquire are not in accordance with physical reality [30]. The field of physical misconceptions attracts several researchers [31-33]. These papers show that misconceptions in physics teaching prove that this problem deserves more attention, Furthermore, we emphasize that if the problem of misconception is well controlled, learning situation will be nicely handled [34].

## 3. METHODOLOGY

### 3.1. Population and Sampling of the Research

Therefore, the population targeted by this study is physics-chemistry teachers from the Beni-Mellal Khenifra Academy, a total of 68; 64.7% (44/68) are secondary school teachers, and 35.3% (24/68) are middle school teachers. The majority of teachers have less than 6 years of seniority, 23.5% have more than 6 years and less than 12 years of service and more than 7% have more than 12 years of service.

Table 1. Information about teachers

| Factors | | Frequency | Percentage (%) |
|---|---|---|---|
| Type of School | Middle school | 24 | 35.3 |
| | High school | 44 | 64.7 |
| | Total | 68 | 100.0 |
| Teaching Experience | < 6 years | 47 | 69.1 |
| | [6-12] years | 16 | 23.5 |
| | >12 years | 5 | 7.4 |
| | Total | 68 | 100.0 |

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Our didactic problem insists that mathematical modeling creates conceptions among students, and these are intimately linked to the prior learning of students, hence the need to address teachers of the middle school. In addition, we chose a part of the teaching staff with less than 6 years of seniority for two crucial reasons, one to investigate the impact of the teachers' professionalism on the degree of representation among students, and the other to measure the effectiveness of action research carried out in regional education and training centers Table 2.

The sample of learners consists of 43 learners continuing their studies in secondary school during the school year 2021-2022 from the academy of Beni Mellal Khenifra. The majority of learners are graduates of experimental sciences, as far as the gender of the population is concerned, it is more or less homogeneous. With regard to age, majority are almost 18 years old, and majority of learners belong to middle class.

Table 2. Information about learners

| | | Frequency | Percentage (%) |
|---|---|---|---|
| Gender | Male | 21 | 48.8 |
| | Female | 22 | 51.2 |
| | Total | 43 | 100.0 |
| Place of residence | Popular area | 40 | 93.0 |
| | residential area | 3 | 7.0 |
| | Total | 43 | 100.0 |

### 3.2. Research Tools

We used the Google Form system to distribute questionnaires to teachers and students. and collect information and statistical curves using Statistical Package for the Social Sciences (SPSS). The questionnaire contains two sections, one intended to define a pseudo-profile of the teacher and the student, and the other intended to measure the problem being questioned (interaction of modeling and the physical concept). The majority of questions are guided (i.e., MCQs).

## 4. RESULTS AND DISCUSSION

### 4.1. Questionnaire of Teacher

In this question, we discussed the sufficiency and necessity of mathematical modeling when constructing physics concepts. To say that mathematical modeling is sufficient means that the physics concept is nothing other than a concretization of an abstract mathematical being which implies the bijection of the physical and mathematical worlds, and in this sense Lobachowski said that all mathematical notions are applicable to model physical phenomena, to be clearer the sufficiency of mathematics will radically destroy the experimental side. The necessity of mathematics is trivial, indeed how to speak of force without vectors or Torsors or tensors, how to speak of speed without derivatives?

Table 3. Mathematical modeling in your opinion

| | Frequency | Percentage (%) |
|---|---|---|
| Necessary and sufficient | 23 | 33.8 |
| Necessary but insufficient | 45 | 66.2 |
| Total | 68 | 100.0 |

Mathematics is an indispensable tool for a serious physicist or didactical [1], to be clearer, the phenomenon goes through two important generic phases: qualification and quantification, it's the last one where mathematics is the backbone of physics. Table 3 shows that the majority of teachers believe in the necessity and inadequacy of mathematical modeling when constructing physical concepts [20]. Noting also that 51.4% of teachers with less than 6 years of seniority, that is to say, those who have benefited from RCET (Regional Center of Education and Training), see that the modeling is insufficient but necessary.

Table 4. The modeling of a force by a vector in teaching is the modeling

| | Frequency | Percentage (%) |
|---|---|---|
| Sufficient | 19 | 27.9 |
| Satisfying (acceptable) | 44 | 64.7 |
| Insufficient | 5 | 7.4 |
| Total | 68 | 100.0 |

The force is a phenomenon due to the mechanical interaction between two objects that have a common generalized charge (gravitational mass, electric charge, color charge, hypercharge, and isospin), which is initially modeled by a vector, this is Newton's rational mechanics. To discuss the legitimacy of this modeling, it is essential to compare the two concepts; force and a related vector. The force is an interaction between two systems say A and B, the interaction has a sense of action (e.g., from A to B), line of action (AB), point of application, and an intensity measurable by the dynamometer. The bound vector is a point characterized by a sense, a Euclidean standard, a direction that runs straight parallel to its support, and an origin. By virtue of these characteristics, we see that there is a very strong analogy between the vector and the force hence the legitimacy of the vector-force modeling. From the above question, you can see that we have guided the teachers to 4 choices, through which we can measure the degree of mastery of the teachers.

In Table 4, the results show in a striking way that the majority of teachers accept this modeling [11], which is the case for the mechanical program at the Moroccan high school because modeling is only valid for macroscopic objects at low speeds, and for very short movement duration [14]. The other professors, the majority think that modeling is sufficient, which means that these professors ignore the criteria for the validity of this modeling.

Table 5. Limit of modeling a force by a vector

| | Frequency | Percentage (%) |
|---|---|---|
| Yes | 8 | 11.8 |
| No | 60 | 88.2 |
| Total | 68 | 100.0 |

From Table 5 onwards, we can see that 88.2% of teachers do not know the limits of modeling, which is catastrophic. A trivial question arises how will these teachers be able to reveal the effects of this modeling to the learners [35], and how will they manage their conceptions? The naive answer is how to avoid the unknown. It is concluded that teachers are epistemologically handicapped so they are part of a misunderstanding of physical concepts.

Table 6. If yes, give a specific example

| Answers suggested by the professors |
|---|
| - Think that representation is inadequate. In fact, the latter does not specify the elements exerting or the elements that undergo this force.<br>- Only if the force's characteristics are constant.<br>- In solid mechanics a Torsors is used in fluid mechanics tensors can be used.<br>- Nuclear Force. |

The majority of professors provide for answers, the first two answers are wrong, and the last two are more or less vague, in fact, the Torsors of forces are antisymmetric fields of the vectors forming two classes namely the resultant and the moment which are vectors.

Table 7. Influence of modeling on students' conceptions

| | Frequency | Percentage (%) |
|---|---|---|
| Yes | 42 | 61.8 |
| No | 26 | 38.2 |
| Total | 68 | 100.0 |

The majority of these concepts have been understood mathematically, and the physical concept is not important for learners, as the majority of assessments even in national examinations, do not consider the physical meanings of the concepts and the experimental side of the phenomenon, which makes the mathematics of the phenomena and the optimal solution whether in the cognitive or didactic side [7]. Table 7 shows that the majority 61.8% of teachers believe that mathematical modeling influences concepts [8], while 38.2% believe that modeling does not influence concepts. It is concluded that a significant percentage of teachers do not detect these conceptions, as this identification requires a good mastery of the physical and mathematical concepts as well as the modeling criteria and their limitations.

Table 8. Consideration of conceptions by teachers

| | Frequency | Percentage (%) |
|---|---|---|
| Yes, often | 35 | 51.5 |
| Yes, sometimes | 32 | 47.1 |
| No | 1 | 1.5 |
| Total | 68 | 100.0 |

Table 9. The importance of taking into account the teachers' point of view

| | Frequency | Percentage (%) |
|---|---|---|
| Yes | 60 | 88.2 |
| No | 5 | 7.4 |
| I do not know | 3 | 4.4 |
| Total | 68 | 100.0 |

Tables 8 and 9 show that almost all 88.2% of teachers feel that consideration of conceptions is paramount, indicating that teachers detect these types of problems in diagnostic and formative evaluations. According to Table 9, only half of the teachers take into account the conceptions of their learners. It is concluded from this study that the teachers find serious problems in the face of this didactic problem [31], namely the treatment and diagnosis of the conceptions of the learners, and this and probably due to the several reasons the temporal envelope of the program because the teacher is responsible for this envelope and he does not have the right to modify the official pedagogical orientations intended to organize the march of the courses during the school year. This didactic task is the most difficult for a teacher [34] because this requires a significant scientific and professional accumulation, this will allow us to say that taking into account these tasks in the regional centers and guiding the teaching trainees in this direction will allow us more at least to overcome these tedious problems.

### 4.2. Learner Questionnaire

For this questionnaire, simple mechanical situations were given, so that the treatment of the learners was easy.

#### 4.2.1. Situation 1

A red car and a black car are placed on rails, themselves placed on a table. An experimenter pushes the red car which then hits the initially stationary black car.

Table 10. After throwing the red car and before the collision between the two cars, who exerts force on the red car?

| | | Answers | | Percentage of observations |
|---|---|---|---|---|
| | | *N* | Percentage | |
| Question 1 | Earth | 18 | 23.4% | 41.9% |
| | The car red | 4 | 5.2% | 9.3% |
| | The investigator | 26 | 33.8% | 60.5% |
| | The rails | 22 | 28.6% | 51.2% |
| | The table | 7 | 9.1% | 16.3% |
| Total | | 77 | 100.0% | 179.1% |

Table 11. After the launch of the red car and before the collision between the two cars, who exerts a force on the rails?

| | | Answers | | Percentage of observations |
|---|---|---|---|---|
| | | *N* | Percentage | |
| Question 2 | The car red | 20 | 23.3% | 46.5% |
| | The black car | 15 | 17.4% | 34.9% |
| | The investigator | 5 | 5.8% | 11.6% |
| | The table | 24 | 27.9% | 55.8% |
| | Earth | 22 | 25.6% | 51.2% |
| Total | | 86 | 100.0% | 200.0% |

These two questions are intended to identify the ability of the students to identify the actor systems in the case of a car animated by a straight movement on parallel tracks. The survey discharge is shown in Table 10, we notice that the majority of learners are unable to identify the forces' actors correctly because the majority of them announce that the experimenter is part of the actor's systems, which is not the case. Because the experimenter is not in contact with the studied system (the red car), and therefore the experimenter does not exert any force on the car, it is only giving an initial amount of movement, and it is the variation of the amount of motion that generates the notion of force (Newton's second law), and moreover, the action of the experimenter is unclassifiable in the known classes of force (remote and contact). In Table 11, the majority of the participants were concerned with good rethinking, just 11.6% of the learners added the experimenter to the family of the actor.

It is therefore concluded that the majority of learners are unable to identify force actors [35], and this naturally indicates that the learners did not fully grasp the concept of force.

Table 12. Can we represent interaction by force?

| | Frequency | Percentage (%) |
|---|---|---|
| Yes Always | 16 | 37.2 |
| Not necessarily | 17 | 39.5 |
| I do not know | 10 | 23.3 |
| Total | 43 | 100.0 |

This question aims to detect the power to distinguish between strength and interaction in learners because in reality force is a preliminary model of interaction. It is noted from Table 12 that the majority of learners could not distinguish the interaction of force and vice versa which again indicates that the learner does not master the triplet (interaction, force, force vector).

Table 13. Why does the red car slow down after the experimenter launches and before the collision between the two cars?

| | | Frequency | Percentage (%) | Percentage (%) of observations |
|---|---|---|---|---|
| Question 2 | The experimenter gave the red car a force whose value decreases over time | 4 | 9.3 | 9.3 |
| | The red car is held back by friction | 19 | 44.2 | 53.5 |
| | The force given to the car by the experimenter is eventually compensated by friction | 15 | 34.9 | 88.4 |
| | I do not know | 5 | 11.6 | 100.0 |
| | Total | 43 | 100.0 | |

This important question aims to detect learner conceptions in the face of friction force [36]. In particular, these forces are difficult to understand because they are non-conservative forces, and no ultimate model has been set. So, all we deal with in the high school program is its effects. The majority of students do not understand the characteristics of this force, based on Table 13, the majority of learners are unable to characterize this friction force, and it is thought that this is mainly due to the following reasons:

- The absence of feasible models that describe friction forces;
- Concentration of learners on the mathematization of physical concepts; the force of friction poses problems for learners because they do not have models that describe them.

It is therefore concluded that the friction force is an example important enough to illustrate the impact of the mathematization of the force [37]. In this case, the majority of learners are unable to detect the characteristics of this force.

### 4.2.2. Situation 2

The differential equation is a powerful modeling of dynamic phenomena (variable with time) [38]. In the high school program of physics, this mathematical notion is widely used in mechanics and electricity to model the movement of mechanical and electrical oscillators and to determine the laws of variation of the dynamic quantities characterizing a phenomenon [16]. Let us take the example of the charge and discharge of a capacitor, where the phenomenon called into question is the charge and discharge, in order to understand the phenomenon, the laws of variation of the quantities that characterize the phenomenon are sought; current and voltage at the capacitor terminals. Where the majority of students forget the phenomenological aspect of the charge/discharge and concentrate on the mathematical aspect of the phenomenon. Three targeted equations are proposed for learners to measure the effect of the mathematization of dynamic quantities:

$$\frac{dq}{dt} + \frac{q}{RC} = 0 \quad (1)$$

$$\frac{du_c}{dt} + \frac{q}{RC} = \frac{E}{R} \quad (2)$$

$$I_0 = \frac{Q}{\Delta t} \quad (3)$$

Table 14. This differential Equation (1) corresponds to

| | Frequency | Percentage (%) |
|---|---|---|
| The capacitor charge; | 12 | 27.9 |
| The discharge of the capacitor | 30 | 69.8 |
| Other | 1 | 2.3 |
| Total | 43 | 100.0 |

The above question is used to measure the insufficiency of mathematical modeling to explain phenomenology [1]. We gave a differential equation without a second member, and we suggested 2 rethinking guidelines, we notice that the majority of learners say this is a discharge, why? we think that because there is no second member, while in all cases discharge or charge we have the same differential equation, but what will differentiate the two phenomena is the initial conditions, and the majority of learners do not feel the importance of these conditions.

Table 15. How many existing solutions for this differential Equation (2)

| | Frequency | Percentage (%) |
|---|---|---|
| Single solution | 31 | 72.1 |
| Two solutions | 7 | 16.3 |
| Infinity of solutions | 5 | 11.6 |
| Total | 43 | 100.0 |

We gave this question because the majority of learners do not know that the differential equation has an infinity of solutions and that the initial conditions that will fix the single solution of the differential equation, one notices according to table 15, that almost 90% could not answer the question, this indicates that mathematical modeling itself requires a mastery, because legitimate modeling does not influence the physical concept but it makes a king, because when the model is given under constraint or limits this will highly value the concept, and thus the concept and never touched.

Table 16. Can we consider this written expression a differential Equation (3)?

| | Frequency | Percentage (%) |
|---|---|---|
| Yes | 5 | 11.6 |
| No | 32 | 74.4 |
| I do not know | 6 | 14.0 |
| Total | 43 | 100.0 |

According to this differential equation, the aim is to test the learners' knowledge of the definition of a differential equation, the expression given above is a differential equation verified by the electric charge during a linear charge of the capacitor. And besides this question was asked in the national examination option mathematical sciences A and B in Morocco. From Table 16, 90% of learners are unable to answer this question, and this is mainly due to their ignorance of the definition of the differential equation, and according to our professional experience (6 years), the majority of students do not master the mathematical or phenomenological aspect of the phenomenon. This means that the teaching of physics requires a strong foundation in mathematics and elementary concepts of physics [5, 6].

To conclude, the results of this study show that teachers play an important role in the treatment of representations caused by mathematical modeling [13]. Indeed, the majority of teachers are unable to detect the limits of the mathematical modeling used to reformulate the laws of physics. This can be explained by the caress of the level of training provided by the teachers and the inspection guidelines; hence the need to strengthen the training of teachers in this respect. The educational inspectors must also enrich their meeting directives with themes concerning modeling and effective use. For the breeders, the majority of them are unable to answer the questions of pure physical types, besides the questions that relate the modeling with the phenomenon in question (question 3 of situation 1 and questions 1-2-3 situation 2). All this tells us about the great effect of modeling on cognitive and skill development in learners.

## 5. CONCLUSION

The results of this research show that Mathematical Modeling is an essential tool for understanding physics, but it is insufficient. The research clearly showed that the teachers do not have the necessary background to treat the Concept-Modeling duality, in fact, it requires a high mastery of the physical and mathematical concepts, and the majority of teachers are unable to locate the concept in the appropriate cognitive field, so this means that the epistemological study of science is very important. The majority also do not even have sufficient basic ideas about the limits and criteria of modeling even for fairly important and widely used concepts (force and differential equation).

In addition, we have shown that the majority of learners are unable to identify the basic characteristics of force [14], indicating that mathematical modeling is insufficient to understand the phenomenon, and we have also shown that most learners do not know how to classify a force (from distance or with contact). For the differential equation, the results are more significant, since almost 90% are unable to link the model (the differential equation) with the suitable phenomenon (charge/discharge), and determine the criteria of a differential equation. According to this study, it is concluded that rigorous mathematical modeling does not affect the physical concept, but it values it. However, incomplete modeling will negatively influence the physical content of the concept [30], which will generate a set of misconceptions in the learners. Finally, these problems must be addressed by the Ministry of High Education, Scientific Research, and Centers of Training, through the inclusion of physical science epistemology and mathematics modules in training specifications, and condensing action research into the mathematical modeling theme and pedagogical methods in teaching.

## NOMENCLATURES

### 1. Acronyms

| | |
|---|---|
| MM | Mathematical modeling |
| RCET | Regional Center of Education and Training |

### 2. Symbols / Parameters

$R$: Resistance (Ω)
$C$: Capacitance (F)
$I_0$: Current through the circuit (A)
$i$: Current through the circuit in instant t (A)
$q$: Quantity of charge in instant t (C)
$Q$: Quantity of charge (C)
$t$: Interval in time (s)
$U_C$: Charging voltage on the capacitor (V)
$E$: Electromotive force (V)

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