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Dimensional Analysis and its Role in the Learning of Physical Sciences in Secondary Qualifying School

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Abstract The study of the relationship between physical quantities with the help of dimensions and units of measurement is essential because it keeps the units the same, helping us perform mathematical calculations smoothly. In this manuscript, we have highlighted the importance of dimensional analysis in learning the physical sciences in secondary qualifying schools. Our study presents the results of exploratory research that we conducted with baccalaureate students from secondary qualifying schools located in the province of Essaouira in Morocco. The objective of this study is to test students' knowledge of the notion of dimensional analysis and its role in learning the physical sciences. We used a questionnaire (Appendix) to collect the data from 123 students. The questionnaire was composed of 8 questions, generally closed to have a specific form of response and to obtain factual information, the completion of questionnaires by students is subject to anonymity. Analysis of this collected data indicated and revealed that many students have difficulty mastering the principle and rules of dimensional homogeneity. Therefore, they are not aware that they are making mistakes if they get inconsistent equations. The results of this questionnaire also reveal a set of constraints and difficulties that hinder the learning of physical sciences in secondary qualifying schools. These difficulties are due to insufficient attention to dimensional analysis, whether in the physical sciences curriculum of secondary education or by teachers of this discipline.

Keywords Dimensional Analysis, Learning, Physical Sciences, Questionnaire, Difficulties

1. Introduction

Dimensional analysis (DA) is a well-developed, widely-employed methodology in the physical and engineering sciences [1-6]. Apart from its instructional purpose on physical quantities and the system of units, DA enables one to check the homogeneity of a formula. DA is often used to make physical equations dimensionless and to focus on dimensionless characteristic numbers that are useful for detecting the physical regime of the studied phenomena (Reynolds number, Mach number...). Such an analysis may eventually lead to a simplification of the model, a reduction of the number of parameters, an extension of the domain of application, and the use of small-scale models [7,8].

Dimensional analysis is a qualitative method of investigation which consists of:

- Identify all the relevant parameters of a physical phenomenon;
- To deduce the dependence of a quantity as a function of these parameters.

We can cite two-dimensional analysis methods [9-12]:

i. the theorem of π, or Vaschy Buckingham's theorem;
ii. Rayleigh's method.

This study highlights the mistakes made by students who ignore dimensional analysis, which creates several difficulties.

It should be noted that several research studies in science teaching have shown that learning difficulties are partly responsible for school failures [13-18].

This manuscript explores the exploitation of the role of dimensional analysis. Writing results correctly is one of the goals of physical science, so our choice is also justified in another way because this study values the importance of unity to physical magnitude.

The main objective of our study is to determine the role of dimensional analysis on the learning of physical sciences in secondary school.

With this in mind, we ask ourselves the following question: What is the role of analysis dimension on the teaching of physical sciences for 2nd year baccalaureate students?

This question leads us to suggest the following hypothesis:

- The use of dimensional analysis in physical science learning decreases student errors.

To confirm or disprove this hypothesis, the method we are going to adopt consists of analyzing the information collected via the questionnaire.

2. Methodology

In this study, we used a questionnaire as a suitable tool to collect precise information from 123 students of Moroccan secondary schools in the province of Essaouira during the 2016-2017 school year. The questionnaire was composed of 8 questions, generally closed to have a specific form of response and to obtain factual information. The questionnaire concerns three classes (2^{nd} year Bac). On the one hand, the completion of questionnaires by students is subject to anonymity. Consequently, the latter can freely deliver their opinion on the subject. The questions formulated relate to the students' opinions on the difference between unity and dimension, the rules of homogeneities, the principle of homogeneity, the determination of the dimension of a physical quantity, and the roles of dimensional analysis.

We underlined the contribution of the study to provoke some of the difficulties that qualifying secondary learners face, as they make many mistakes in physics that affect their academic achievement because of their ignorance of the rules of dimensional analysis.

In the following chapter, we have presented the questionnaire results of the target students.

3. Results and Discussions

The objective of the questionnaire we conducted is to test students' knowledge of the notion of dimensional analysis and its role in learning the physical sciences.

The questions posed are aimed at knowing the students' opinions on the difference between unit and dimension, the rules of homogeneities, the principle of homogeneity, the determination of the dimension of physical quantities, and the roles of dimensional analysis.

- On the term dimension of physical quantities, only one question was asked. This question is to ask what students have heard or not heard of this term.
- On the difference between dimension and unit of a quantity, we asked two questions (2 and 3).

The first asks students for their opinion if they consider these two words (unit and dimension) to have the same meaning in physical science, while the second involves testing students for confusion between these two terms.

- Question 4 is intended to find out whether the students have mastered the rules of homogeneity dimensional.
- Question 5 gives us the information if the students have mastered the principle of homogeneity dimensional.
- Question 6 is an open question. The purpose of this question is to ask students about the roles of dimensional analysis in teaching physical science.
- Question 7 concerns the determination of the dimension or the unit of a physical quantity.

These relate to content falling within the official program and involving a relationship with simple physics, familiar to the students. This choice obeys the methodological concern of not interfering with the questioning by additional difficulties, of a conceptual or computational nature, irrelevant in relation to the object of study.

- Question 8 is made up of three small questions. The first asks the importance of literal application in writing the assignment. The second is whether the student is able to test for error on the literal application. And, finally, the last is to find out if the teacher gives a way to verify the error on the literal expression.

It seemed necessary to us to present the results in the form of two tables (Table 1, Table 2) in which the elements of answers relating to the eight preceding questions are identified, followed by their respective interpretation. We would like to note that the complete information to have these two tables, can be found in Annex 2.

Table 1. Results on the number of students according to principle and rules of homogeneity

Item	Classroom 1	Classroom 2	Classroom 3	Medium (%)
Number of Students	40	42	41	
Students' intention on the term "dimension of a physical quantity"				
Students who have heard the term "dimension of a physical quantity"	26	25	27	63,4
Ability to differentiate the unit and the dimension of a physical quantity				
Students are able to differentiate the meaning of the unit and the dimension of a physical quantity	15	18	17	40
Students who confused the unit and the dimension of a physical quantity	25	24	24	59,3
Mastery of the rules of homogeneity				
Students who have mastered the rules of homogeneity	17	16	18	41,4
Mastery of the principle of homogeneity				
Students who have mastered the principle of homogeneity	16	14	17	38,2

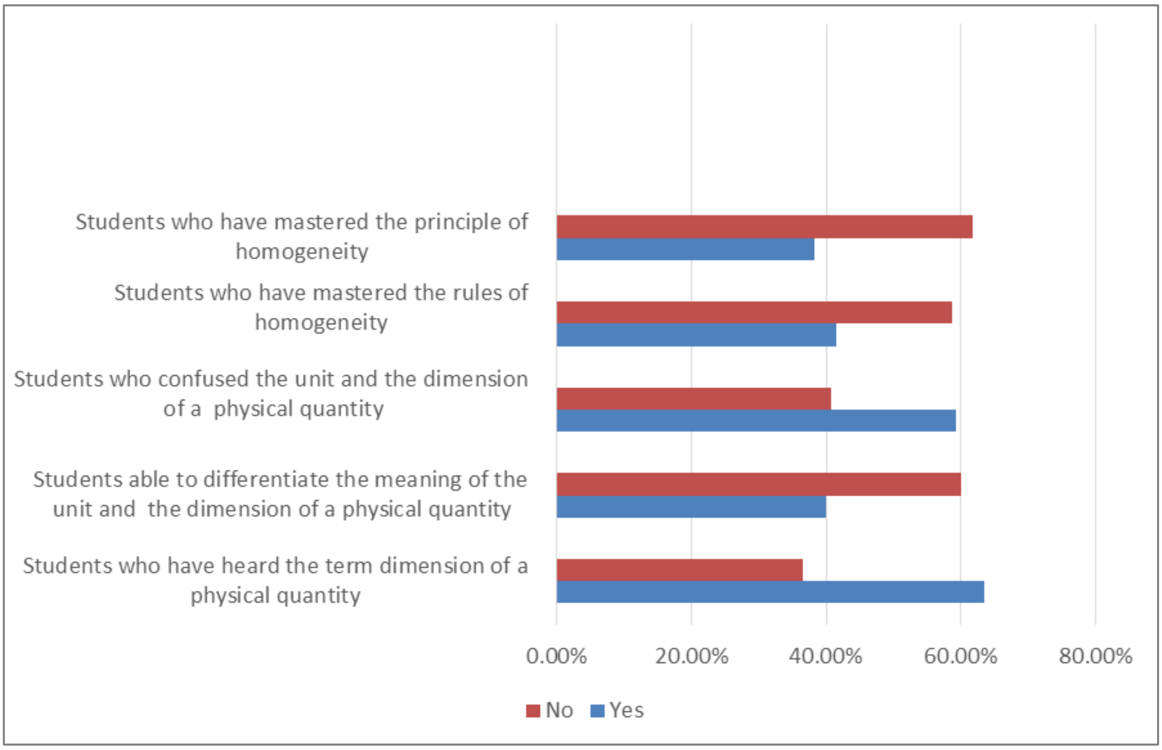

Figure 1. Presents the students' intention on dimensional analysis

Table 1 shows the following results:

- On the students' intention of the term "dimension of a physical quantity": 36,6% of students have not yet heard. This high rate may explain why this term is new to the student. However, dimension characterizes physical quantities of the same nature. So, this term is important in physical science.
- On the difference between the unit and the dimension: 59,3% of students confused these two words which have differences.
- On mastery of the principle of homogeneity: the table shows us that 65,4% of the students have not mastered the principle of homogeneity. This result shows us that the majority of students are not aware if they obtain a non-homogeneous result

Table 2 represents the students' intention of the term "dimensional analysis", the ability to use the principle and rules of homogeneity, the value of literal expressions, the ability to test the veracity of the literal expression, and the method used by the teacher to test for errors on the literal expression.

Table 2 shows the following results:

- On the intention of students to the term "dimensional analysis": 39,8% of students have not yet heard.
- The proportion of students unable to determine the role of dimension analysis in physic sciences reached 52%.

How can the student determine the unit or the dimension of a quantity if he is not able to use the principle and the rules of homogeneities? How can the student test his error if he is unable to use the principle and the rules of homogeneities? To reduce student error in learning physics, dimensional analysis is necessary for the student because it can test whether there are errors in the process to follow.

- the majority of students surveyed (63,4%) see the benefit of doing literal equations before making the numerical application. There is still a minority (36,6%) who did not know the importance of the literal expression. The different proportions show that literal expression is very important in writing the assignment. 52,8% of students are unable to test the veracity of the literal equation.

This is a normal situation because the dimensional analysis is not of great importance in the qualifying secondary school curriculum of physical sciences and does not attract the attention of some teachers. The fact of not being able to take the literal error test appears on the bad result of the baccalaureate in science series in Morocco because physics is a basic subject among the subjects to be studied in this series.

- Regarding the method given by the teacher to test for the error on the literal expression, it seems that a significant part of the students (55%) said the teacher did not give a method. This result may reflect that the teacher did not check the homogeneity of the formula before making the numerical application. Not surprisingly, students are unaware that they have non-homogeneous equations. Could it be the fault of the teacher who did not check the consistency of the literal expression?

Table 2. Results on the use of dimensional analysis and the test of the veracity of literal expressions

Item	Classroom 1	Classroom 2	Classroom 3	Medium (%)
The intention of students on the term "Dimensional analysis"				
Students who have not heard the term "dimensional analysis"	15	16	18	39,8
Ability to determine the rules of dimension analysis in physic sciences				
Students unable to determine the roles of dimension analysis in physic sciences	21	22	21	52
The interest in the literal expression				
Students who did not know the value of the literal expression	25	26	27	63,4
Testing literal expressions				
Students unable to test the veracity of the literal expression	19	22	24	52,8
The method used by teaching to test the veracity of a literal expression				
Students declared that the teacher did not give a method for testing the veracity of the literal expression	24	23	21	55,28

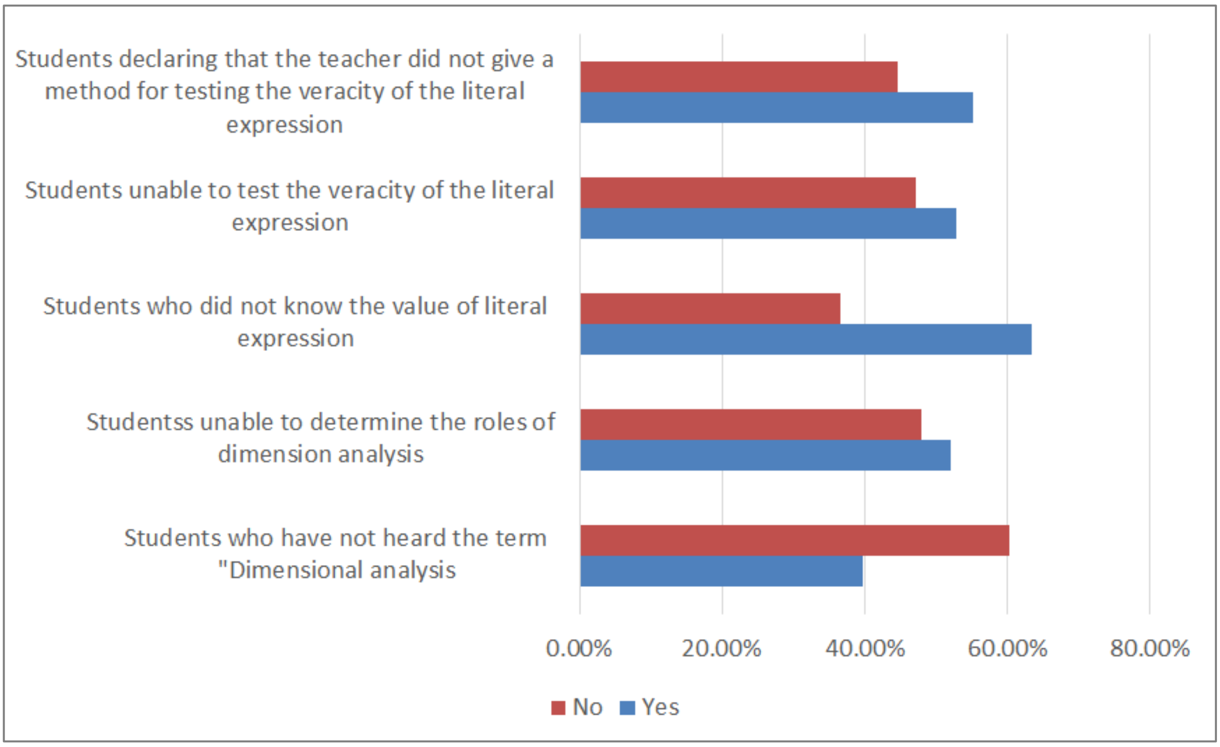

Figure 2. Results concerning the use of dimensional analysis and the test of the veracity of literal expressions

We point out that the presented study has addressed a topic that can help curricula and program designers in Morocco as well as physics teachers in reducing some of the difficulties faced by qualifying secondary learners who make many mistakes in physics that affect their academic achievement because of their ignorance of the rules of dimensional analysis.

4. Conclusions

The analysis of the results of our research, which we carried out with 123 students of the 2nd baccalaureate of a Moroccan secondary school in the province of Essaouira, using a questionnaire, revealed that many students have difficulties in mastering the principle and rules of homogeneity. Therefore, they are not aware that they are making mistakes if they get inconsistent equations in the literal expression.

The results of this questionnaire also reveal a set of constraints and difficulties hindering the learning of physical sciences in the 2^{nd} year of the baccalaureate. These difficulties are due to insufficient attention to dimensional analysis, whether in the secondary school physical sciences curriculum or by physics teachers.

Appendix: Questionnaires for Targeted Second-year Baccalaureate Students

Objective: To test students' knowledge of the notion of dimensional analysis and its role in learning the physical sciences.

General Information

Secondary School:…………………………………..Classroom:…………………………

I- Notion of dimension and rules of homogeneity

Check the correct answer (s)
1-Have you ever heard the term "dimension of a physical quantity"?
Yes ☐ No ☐
2- Are the unit and the dimension of a physical quantity two words with the same meaning in physical sciences?
Yes ☐ No ☐

3-Answer true or false
a-The dimension of a physical quantity is independent of the unit used. ☐
b-The dimension of a surface is the square meter (m^2). ☐
4- Choose the correct answer
To compare, add, subtract two physical quantities,
-they must have the same significant number. ☐
-they must have the same dimension.
-they must have the same symbol. ☐
5-Answer true or false
a-Any non-homogeneous literal result is necessarily false. ☐
b- Any homogeneous literal result is necessarily true. ☐

II-Dimensional analysis and its role in the learning of physical sciences

6-Have you ever heard the term "dimensional analysis"?
Yes ☐ No ☐
What are the roles of dimensional analysis in physical sciences?
……
…………………………………………………………………….
7- A-The time equation of a uniformly varied rectilinear movement:
$x = \alpha t^2 + \beta t + \gamma$
1/ What is the condition on the dimension of α
a) $[\alpha] = LT^{-1}$ ☐ b) $[\alpha] = LT^{-2}$ ☐ c) $[\alpha] = L.T^2$ ☐
2/ what is the dimension of β?
a) $[\beta] = m.s^{-1}$ ☐ b) $[\beta] = L.T$ ☐ c) $[\beta] = L\,T^{-1}$ ☐
3/ what is the dimension of γ?
a) $[\gamma] = m$ ☐ b) $[\gamma] = L$ ☐ c) $[\gamma] = L\,T^{-1}$ ☐

7-B- We consider a circuit in which we neglect all the resistances. It consists of a capacitor of capacitance C and an ideal coil of inductance L.
i- During the un-damped free electrical oscillations of a circuit (L, C), the voltage U_C at the terminals of the capacitor obeys the differential equation:

$\frac{d^2U_C}{dt^2} + \frac{L}{C}U_C = 0$ ☐ $\frac{d^2U_C}{dt^2} + \frac{1}{LC}U_C = 0$ ☐ $\frac{d^2U_C}{dt^2} + \frac{C}{L}U_C = 0$ ☐

ii- Mathematically the voltage U_C across the capacitor is written in the form:

$U_C(t) = U_m\cos(\frac{2\pi}{T_0}t + \varphi)$ ☐ $U_C(t) = U_m\cos(\frac{T_0}{2\pi}t + \varphi)$ ☐

T_0: the natural period of non-damped free electrical oscillations
iii- Verification of the unit of T_0 by dimensional analysis
The expression for the natural period is:

$T_0 = 2\pi\sqrt{LC}$ □ $T_0 = 2\pi\sqrt{\frac{L}{C}}$ □ $T_0 = 2\pi\sqrt{\frac{C}{L}}$ □

Put the correct expression of the natural period T_0 among those proposed above. Justify your choice by performing a dimensional analysis.
Justification
………
……
8-Before making the digital application, we will do the literal application as much as possible.
i- What is the point of doing the literal equation before making the numerical application?
-To decrease the error. □
-to increase uncertainty about the error. □
ii- Do you have a method to test or analyse the accuracy of the literal equation?
Yes □ No □
If yes, give an example of this method
………
……………………………………………………………………
iii-Has your physics teacher given you a method for testing the veracity of a literal equation?
Yes □ No □
If yes, give an example of this method

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