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Measuring Students' Dimensional Analysis Knowledge of Mechanics Concepts of Physical Quantities in Kwara State, Nigeria

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Abstract

To measure and examine the students' knowledge and understanding of dimensional analysis of mechanics concepts of physics' physical quantities of two or more dimensions, a questionnaire tagged "Mechanics Concepts of Physics Physical Quantities' Dimensional Analysis Questionnaire" was administered to five hundred (500) post-basic III students selected through multistage sampling technique. Descriptive (mean and standard deviation) and inferential statistic (t-test) was used to analyze the collected data. The results of the study revealed that students have average knowledge and understanding of dimensional analysis and its procedure of all observed mechanics concepts of physics' physical quantities. In addition, the study revealed that gender does not influence the understanding and knowledge of dimensional analysis of physics' physical quantities. The study recommended that the students should be exposed to dimensional analysis and its procedure of all observed mechanics concepts and other branches of physics and further investigation should be launched on the students' knowledge and understanding of other branches of physics like thermodynamics, electricity, and magnetism's concepts' dimensional analysis.

***Keywords**: Dimensional Analysis, Physics Physical Quantities, and Post-Basic Students*

Introduction

The dimensional analysis of physics physical quantities means dependence of derived quantities on fundamental/basis quantities. The seven base/fundamental quantities with their unit as highlighted by the World Conference on Weight and Measure are length, L (meter), mass, M (kilogram), time, T (second), electric current, I, (Ampere), amount of substance, N, (mole) and luminous intensity, J, (Candela). The derived physical quantities were measured by the combination of two or more base/fundamental physical quantities. Different branches of physics' concepts depend on the seven fundamental physics physical quantities (Length, L, Time, T, Mass, M, Electric Current, A, Temperature, Ɵ, Amount of Substance, N, and Luminous Intensity, J) for their definitions and formula/equation formulation.

Branches of Physics	**Fundamental Physics Physical Quantities Dimension**
Mechanics	Length, L, Mass, M, & Time, T
Fluid Mechanics	Length, L, Mass, M, Time, T, & Temperature, Ɵ
Electricity and Magnetism	Length, L, Mass, M, Time, T, & Electric Current, A
Thermodynamics	Length, L, Mass, M, Time, T, Temperature, Ɵ, & Electric Current, A
Atomic & Molecular Physics	Length, L, Mass, M, Time, T, Electric Current, A, & Amount of Substance, N

Source: *Yildiz, 2015*

Shen and Lin (2018) opined that dimensional analysis stems from the theory that physical quantities must not be dependent on units used in the measurement. In another submission, Misic et al. (2010) asserted that physics physical quantities may have dimension if its numeric value will depend on the choice of system of measuring units, and it won't if it's dimensionless. The scholars concluded that the process of dimensional analysis of physics physical derived quantities involves three steps:

Step 1: the first step is to identify the dimensions of variables. This implies that the dimensions of base/fundamental quantities involved in the definition of derived physical quantities which could comprise of the seven identified basic quantities.

Step 2: The second step is to choose the base/fundamental quantities.

Step 3: The last step is to transform other variables into dimensional or dimensionless using base quantities.

Redish (2021) highlighted the following dimensional analysis advantages:

1. Dimensional Analysis serves a leading step in learning the connection and relationship between physics physical quantities and mathematics concept/functions;
2. Dimensional Analysis helps to check the originality and equation error of any physics physical quantities equation and formulas
3. Dimensional Analysis helps to focus on dependence functionality of physics physical quantities;
4. Possible equation for new physics physical phenomena can be generated through dimensional analysis.

The use of symbols to represent a measurement is the first step in showing a relationship between physics physical quantities and mathematical functions (Redish, 2021). The scholar further asserted that students in an introductory physics class often confronted with the problem of making meaning with the relationship of physics physical quantities and mathical functions. The usage of dimensional analysis can be literally termed as another language to describe physical phenomena or quantities (Robinett, 2015). The scholar asserted that students of physics should be familiar with dimensional analysis in other to make sure that the units of quantities work in their final answer of problem solving activities.

The quantitative relationship between physics physical quantities expresses the physical laws in the forms of mathematical terms (Menin, 2017). The reduction of complex physical problems to simplest form to have quantitative answer is referring to dimensional analysis (Somin, 2001). Bridgman (1969) asserted that the main use of dimensional analysis of physics physical quantities is to deduce from a study of the variables dimension in any physical system on the form of relationship between variables.

Fluid mechanics as branch of physics and engineering has several methods of analyzing its physical quantities dimension. Islam and Lye (2009) highlighted Rayleigh's method, Buckingham (Π) theorem, matrix method, and method of synthesis as methods for determine the physical quantities' dimension in physics and engineering and their dependence level on base/fundamental physics physical quantities. Colley (2018) asserted that learning difficulties of dimensional analysis of physics physical quantities contributed partly to the students' failures in physics.

Lassri and Lassri (2022) opined that the use of dimensional analysis in physics physical science teaching and learning reduces student and teacher's error. Reichelova and Teleki (2013) asserted that dimensional analysis is a simple and qualitative means of determining the level of dependence of derived physics physical quantities on verified base/fundamental physics physical quantities' symbol and unit.

Research Questions

RQ 1. What is the mean score of the students' dimensional analysis' knowledge of mechanics concepts of physics physical quantities?

RQ 2. Does gender influences the mean score of the students' dimensional analysis' knowledge of mechanics concepts of physics physical quantities?

Research Hypothesis

Gender does not significantly influence the mean score of students' dimensional analysis' knowledge of mechanics concepts of physics physical quantities.

Literature Review

The introductory part of physics teaches dimensional analysis of one, two or more dimensional/dimensionless physics physical quantities. The base/fundamental quantities are quantities with one dimensional variable. All derived physics physical quantities are either having two or more dimensional variables. The quantities that are defined in term of one variable are refers to one-dimensional quantities while other quantities are categorized into two or more-dimensional quantities otherwise known as derived quantities. Physics students derive much of their understanding of mathematical symbols and operations from introductory aspects of mathematics-related aspects of physics. The knowledge of units and dimensional analysis otherwise refers to as "Metadata" were connected with symbolic expression which may not be observed or understood by novice in the field of science and engineering (Amos et al., 2020).

Yildiz (2015) conducted a search on a discussion on an expression written about dimensional analysis in physics textbooks. The study was qualitative study and data used were gathered from careful examination of the some selected textbooks and scientific publications and articles on the dimensional analysis with the use of document analysis method. The findings of the study revealed that the books or Scientifics papers written in both virtual and conceptual can aid students' understanding and correct their misconceptions among individuals.

Lassri and Lassri (2022) worked on the dimensional analysis and its role in the learning of physical sciences in secondary qualifying school. The study engaged 123 Moroccan secondary school students in the province of Essaouira during 2016-2017 academic sessions. The study used a questionnaire with content of student's opinion on difference between unit and dimension, the rules of homogeneities, the principle of homogeneity, the determination of the dimension of the physical quantities and the roles of dimensional analysis. The result of the study revealed that students learning of dimensional analysis faced set of constraints and difficulties due to insufficient attention to teaching and learning of dimensional analysis by the physical science curriculum planner or physics teachers.

Methodology

Respondents

In this study, five hundred senior secondary school three (III) students were engaged through multi-stage sampling techniques. Stratified sampling techniques was used to categories the state into three educational districts. The central part of the state has the highest number of students' population follow by the southern and northern parts respectively. Proportional sampling techniques enable the researchers to select 10 schools from central district, 6 schools from southern district and 4 schools from northern districts. Purposive sampling technique was employed in selecting the sample schools based on their physics students' population. The schools with post-basic III class population not less than thirty (30) students were considered so as to ensure fairness and give room for random selection process of the study samples. Twenty-five (25) students were randomly selected each from the twenty (20) sample schools across the three districts of the state totaling five hundred (500). One hundred and ninety four (194) representing 38.8% of the total sample size was female while three hundred and six (306) representing 61.2% of the total sample size are male students.

Instrument

"The Mechanics Concepts of Physics Physical Quantities Dimensional Analysis Questionnaire" was used to collect the data. The instrument was divided into two parts. The part A of the instrument elicits information about students' demographic data while part B was used to elicit the data on dimensional analysis' knowledge. The instrument was used to assess the students' knowledge and understanding of mechanics concepts of physics physical quantities dimensional analysis like area, volume, force, density among others. The instrument was open ended in nature with the list of mechanics concepts and space was provided in the instrument for students to write each concepts dimensional analysis. The instrument was validated by the three experienced physics teachers and validity and reliability indexes are 0.88 and 0.92 respectively. The collected data were analyzed using descriptive (mean and standard deviation) and inferential statistics (t-test).

Findings

Table 1

Mean Score Rating Scale

Range	Remarks
1.00-2.00	Low
2.01-3.00	Average/Medium
3.01-4.00	High/Substantial

Research Question 1: What is the mean score of the students' dimensional analysis' knowledge of derived physics physical quantities?

Table 2. *Mean Score Table of the Students' Dimensional Analysis Knowledge of Derived Physics Physical Quantities*

Physics Physical Quantity	Physics Physical Quantity' Symbol	Dimensional Analysis	*ri M*	*ri L*	*ri T*	*ri I*	*ri Θ*	*ri N*	*ri J*	Mean	SD	Remark
Area	*A*	$M^oL^2T^o\Theta^oI^oN^oJ^o$	0	2	0	0	0	0	0	2.95	0.22	Average
Volume	*V*	$M^oL^3T^o\Theta^oI^oN^oJ^o$	0	3	0	0	0	0	0	2.94	0.22	Average

Acceleration	*a*	$M^oL^1T^{-2}\Theta^oI^oN^oJ^o$	0	1	-2	0	0	0	0	2.95	0.22	Average
Force	*F*	$M^1L^1T^{-2}\Theta^oI^oN^oJ^o$	1	1	-2	0	0	0	0	2.95	0.23	Average
Work	*w*	$M^1L^2T^{-2}\Theta^oI^oN^oJ^o$	1	2	-2	0	0	0	0	2.95	0.23	Average
Kinetic energy	*K.E*	$M^1L^2T^{-2}\Theta^oI^oN^oJ^o$	1	2	-2	0	0	0	0	2.95	0.22	Average
Potential energy	*P.E*	$M^1L^2T^{-2}\Theta^oI^oN^oJ^o$	1	2	-2	0	0	0	0	2.95	0.23	Average
Power	*P*	$M^1L^2T^{-3}\Theta^oI^oN^oJ^o$	1	2	-3	0	0	0	0	2.95	0.23	Average
Stress	*Σ*	$M^1L^{-1}T^{-2}\Theta^oI^oN^oJ^o$	1	-1	-2	0	0	0	0	2.94	0.23	Average
Linear momentum	*P*	$M^1L^1T^{-1}\Theta^oI^oN^oJ^o$	1	1	-1	0	0	0	0	2.85	0.36	Average
Impulse	*I*	$M^1L^1T^{-1}\Theta^oI^oN^oJ^o$	1	1	-1	0	0	0	0	2.84	0.36	Average
Density	*P*	$M^1L^{-3}T^o\Theta^oI^oN^oJ^o$	1	-3	0	0	0	0	0	2.84	0.36	Average
Strain	*ε*	$M^oL^oT^o\Theta^oI^oN^oJ^o$	0	0	0	0	0	0	0	2.85	0.22	Average
Frequency	*F*	$M^oL^oT^{-1}\Theta^oI^oN^oJ^o$	0	0	-1	0	0	0	0	2.95	0.22	Average
Period	*P*	$M^oL^oT^{-1}\Theta^oI^oN^oJ^o$	0	0	1	0	0	0	0	2.88	0.33	Average

The table above explained that the students' knowledge of dimensional analysis of derived physical quantity "Area" was average. Area as a derived quantity as zero dependence on mass, M, time, T, absolute temperature,Ө, amount of substance, N, electric current, I, and luminous intensity, J but depends on length, L.

It is also revealed that the mean score of students' knowledge of Volume dimensional analysis was average (M=2.94, SD=0.22). Volume is a derived quantity that doesn't depends on base/ fundamental quantities except length, L.

Acceleration is a quantity defined in term of displacement and time. The dimensional analysis of acceleration depends on length, L, and time T. The table 2 shows that the students' knowledge of acceleration dimensional analysis was average (M=2.95, SD=0.22).

Workdone, force, kinetic energy, potential energy, power, and stress among others are quantities analyzed mass, M, length, L and time, T. the table 2 shows that the students' understanding of dimensional analysis were average.

Research Question 2: Does gender influences the mean score of the students' dimensional analysis' knowledge of physics derived physical quantities?

***Table 3*:** Mean Score Table of Student's Dimensional Analysis' Knowledge of Physics Derived Physical Quantities when Influenced by Gender

Physics Physical Quantity	Physics Physical Quantity'Symbol	Dimensional Analysis	Female (N=194)		Remark	Male (N=306)		Remark
			Mean	SD		Mean	SD	
Area	*A*	$M^oL^2T^o\Theta^oI^oN^oJ^o$	2.95	0.21	Average	2.94	0.24	Average
Volume	*V*	$M^oL^3T^o\Theta^oI^oN^oJ^o$	2.95	0.22	Average	2.94	0.24	Average
Acceleration	*a*	$M^oL^1T^{-2}\Theta^oI^oN^oJ^o$	2.95	0.22	Average	2.94	0.24	Average
Force	*F*	$M^1L^1T^{-2}\Theta^oI^oN^oJ^o$	2.95	0.23	Average	2.93	0.24	Average
Work	*w*	$M^1L^2T^{-2}\Theta^oI^oN^oJ^o$	2.95	0.22	Average	2.94	0.23	Average
Kinetic energy	*K.E*	$M^1L^2T^{-2}\Theta^oI^oN^oJ^o$	2.95	0.21	Average	2.94	0.22	Average
Potential energy	*P.E*	$M^1L^2T^{-2}\Theta^oI^oN^oJ^o$	2.95	0.22	Average	2.94	0.22	Average
Power	*P*	$M^1L^2T^{-3}\Theta^oI^oN^oJ^o$	2.95	0.22	Average	2.94	0.23	Average
Stress	*Σ*	$M^1L^{-1}T^{-2}\Theta^oI^oN^oJ^o$	2.95	0.22	Average	2.94	0.23	Average
Linear momentum	*p*	$M^1L^1T^{-1}\Theta^oI^oN^oJ^o$	2.95	0.22	Average	2.94	0.23	Average
Impulse	*I*	$M^1L^1T^{-1}\Theta^oI^oN^oJ^o$	2.85	0.36	Average	2.85	0.36	Average
Density	*P*	$M^1L^{-3}T^o\Theta^oI^oN^oJ^o$	2.85	0.36	Average	2.85	0.36	Average
Strain	*E*	$M^oL^oT^o\Theta^oI^oN^oJ^o$	2.85	0.36	Average	2.85	0.36	Average
Frequency	*f*	$M^oL^oT^{-1}\Theta^oI^oN^oJ^o$	2.95	0.21	Average	2.94	0.22	Average
Period	*P*	$M^oL^oT^{-1}\Theta^oI^oN^oJ^o$	2.90	0.31	Average	2.90	0.32	Average

Table 4: t-test result testing significance level of students based on gender on the dimensional analysis knowledge of mechanics concepts of physics physical quantities.

Gender	N	mean	SD	df	t-value	p-value
Female	194	3.381	1.408	1.271	.297	.117
Male	306	3.501	1.137			

p-value >0.05 and t-value <1.98 critical values

The result from the table 3 indicated that students' gender does influence their knowledge and understanding of physics physical quantities dimensional analysis. Both female and male students have average knowledge and understanding of physics physical quantities without any outsmarting other. The p and t-values in table 4 implies that the null hypothesis that state gender does not significantly influence the mean score of students' dimensional analysis' knowledge of mechanics concepts of physics physical quantities was retained.

Discussion

The results obtained from the study revealed that the students' knowledge of identified physics physical quantities dimensional analysis was average. The result of the study was similar to Lassri and Lassri (2022) who reported that the performance of the students' knowledge of dimensional analysis was faced with constraints and difficulties which debar the students to perform excellently in it. The category of the students engaged in this study was those are currently waiting to write the exit external examination form secondary school. The choice of the respondents was premised on the planned curriculum that the concept should be taught as introductory part in senior secondary school physics and the researchers' believe that the respondents should be the proficient enough in the said concept. Teaching and learning of physics physical quantities' dimensional analysis is scheduled to come up in the first year as an introductory part to physics students at post-basic school in Nigeria as planned by the apex education policy maker.

Gender of the respondents as a variable that can function as a moderator and mediator do influences the research outcomes. Gender failed to influence the students' knowledge and understanding of dimensional analysis of the physics physical quantities. The result show in the table 3 shown that the knowledge of the students of dimensional analysis was evenly distributed.

Conclusion

The results obtained from this study revealed that students' knowledge and understanding of physics physical quantities' dimensional analysis was average and gender has no influence on students' understanding and knowledge of physics physical quantities. This implies that the students need to improve on their knowledge of physics physical quantities' dimensional analysis so as to prepare them for external examination and the future challenges for those willing to study physics, physics related courses and engineering.

Recommendations

The following recommendations are highlighted based on the outcome of this study:

a. The teacher teaching physics should keep emphasizing the importance of the knowledge of dimensional analysis of physics physical quantities to their performance to physics, formulas, units and its level of dependence on base/fundamental quantities;
b. Development of smart phone application on learning and teaching of physics physical quantities' dimensional analysis;
c. The future researches on dimensional analysis of physics physical quantities should be directed towards investigating one, two or more dimensional quantities;
d. The studies on the physical quantities dimensional analysis of physics branches like mechanics quantities dimensional analysis among others should be considered;
e. Higher education institution students that are studying physics and engineering courses should be considered as respondents in the future studies.

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