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The influence of teaching methodologies in the assimilation of density concept in primary teacher trainees

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Abstract

Density is one of the most misunderstood concepts amongst the most basic scientific ones, although it is studied even from the earlier academic stages. This is the reason teachers must know its implications as well as possible, including not only the classical definition or what students called “formula” (density is equal to mass divided by volume) but also the concept itself (that is, an intensive matter property). According to this concern, the current research focuses its interest in studying how different teaching methodologies have different outputs in the learning process of pre-service primary teachers. The main aim of this research is to compare the learning results of a control group ($n = 84$), where mainly oral-based expositions were used as the teaching instrument, with an experimental group ($n = 109$), where the main educative tool were laboratory activities. The results show statistically significant differences ($p < 0.05$) between both methodologies and reveal the existence of difficulties in the conceptual and experimental understanding of the concept of density. Although those students that were submitted to hands-on activities presented a significant

better comprehension of the density idea, the persistence of misconceptions regarding this scientific relevant concept is also confirmed at university level.

Keywords: Education, Physics

1. Introduction

Although mass, volume, and density are basic concepts in the science curriculum taught at all levels of education, different studies describe the difficulties that some teachers in training, both in primary and secondary education, have in teaching these concepts. Among the most common errors found in teaching the concept of density, many future teachers believe that heavy objects sink [1]. Other studies [2, 3] have also shown that density is not recognized as a property of substances. One of the most interesting aspects of science teaching is the specific training process for pre-service primary teachers. It should be borne in mind that people who are studying to become primary school teachers are strongly influenced by their own experience as primary school students [4], hence the importance of knowing what they remember about basic scientific concepts in order to prevent misconceptions from being transferred to their future pupils in school.

Previous studies [5] indicate that, despite being concepts taught in different educational stages, the difficulties to learn them persist in students of all levels, including the university. Some authors have analysed this notion and the previous ideas that primary school students usually have [6]. Other studies [7] analyse the different meanings that the term density usually has in everyday language (heavy, weight, viscous, thick, opaque, numerous...), ideas that students may have at higher levels. Others [8] investigate the effectiveness of the teaching material developed using various teaching methods and techniques for students to learn the concept of buoyant force. The sample group was made up of forty-eight students (Control Group = 23; Experimental Group = 25). The findings suggest that the students corrected some misconceptions about buoyancy force, but did not eliminate them completely. This indicates that it is not easy to completely alter some students' misconceptions.

Some authors [9] report a detailed analysis of two lessons on density in an Australian 7th grade science classroom using Distributed Cognition theory. The results of this study suggest that a deliberate effort is needed to establish a shared understanding not only of the purpose of the activities, but also of the meaning of scientific language and the usefulness of the tools. It also suggests the importance of appropriate use of instructional resources to facilitate students' scientific understanding.

2. Methodology

Density is a problematic concept that is often linked to the development of alternative conceptions and misunderstandings. Traditionally, this concept has been taught through oral lessons, and eventually with some problem-solving activities only to reinforce what the teacher said before (during the oral exposition). However, nowadays science education has a great variety of teaching tools to engage and improve the learning process. Among them, this work has focused its attention on hands-on activities (namely, laboratory activities). The research question would be: *Are there statistically significant differences in the process of learning density at university level depending on the teaching methodology employed (pure oral exposition vs. hands-on activities)?* If this question has an affirmative answer, the process of teaching these basic scientific concepts should focus more on hands-on and laboratory activities (even from the very moment the teacher begins to teach them) than on the purely theoretical explanation.

The study was carried out following a quasi-experimental design with control group and post-test. The teaching method used was assumed to be an independent variable. The dependent variable was the learning success achieved by the students. In addition, our institution determined that our work did not require ethical approval, as it did not involve experiments with human beings. The study focused on identifying whether so-called hands-on activities (laboratory) are more suitable for overcoming previous ideas and misconceptions about the concept of density than other teaching methodologies, such as oral exposition. Specifically, one group known as the Control Group (CG) has mainly used this oral methodology, while the other group, known as the Experimental Group (EG), has followed a methodology based on easy and simple laboratory experiments.

With this main scope, the present study was conducted according to two hypotheses that should be accepted depending on the statistical results:

- Null Hypothesis (H_0): The teaching methodology does not influence the understanding of the concept of density. The control and experimental groups do not present any significant difference in the level of understanding of this scientific idea.
- Alternative Hypothesis (H_a): The teaching methodology plays a relevant role in understanding the concept of density. The control and experimental groups present significant differences in the level of understanding of this scientific idea.

The sample used has been of an intentional type by means of non-probability sampling for convenience, due to the ease of access to the sample under study. The sample was made up of 193 students (aged 18 to 21) from the second year of the Grade of Primary Education from the University of Extremadura, who studied the subject “Didactics of Matter and Energy”. This sample was divided into two groups: 109

students were part of the CG and the remaining 84 students were part of the EG. The students from the GC were divided into 4 groups of 27–28 people. They attended a three-hour oral lecture in which the concept of density was theoretically explained without any hands-on activity. Some problems were solved to apply the concept. The students from the EG were divided into 4 groups of 21 people. Each group conducted a 3-hour laboratory session. In each group, students worked in pairs. Density measurements were made of various materials (regular and irregular solids; different liquids). Students, for example, had to predict whether a lemon would float or sink in two different situations, when it was untouched and when its skin was removed. Through this experience they saw that the peeled lemon, although having less mass, sank, so they found that to make a prediction they also needed information about the volume. In another experience the students determined the density of 5 cent coins, and were asked to repeat the procedure using a different number of coins. In doing so, they verified that the density data obtained was independent of the number of coins used for their determination.

The results of the intervention were collected through a survey. Students in both groups were asked to complete a questionnaire one month after the last class, once the concept of density was fully explained and worked on. The aim of waiting a while to pass the questionnaire was to check whether the participants had meaningfully assimilated the concepts explained, or whether they had forgotten them over time.

A written questionnaire with 8 questions was used to detect previous ideas. This questionnaire can be found in the Supplementary File. The first question deals with the concept of density. The objective of this question is to obtain information about the knowledge students have about this concept, whether they are able to provide a conceptually correct answer or whether they simply provide the mathematical equation to calculate the numerical value. The second and third questions were formulated with the intention of determining whether students had assimilated that density is an intensive property of matter, regardless of the amount of matter. In the fourth question, students are asked to explain how volume is calculated in three different solid objects: a cube, a sphere and a screw. This question aims to establish students' knowledge of the procedure for measuring the volume of regular and irregular geometric solids. In the next question, which complements the previous one, students are asked to explain how to experimentally measure the density of an object. Finally, the last three questions aim to determine whether students have understood that density is not calculated by direct measurement of a variable, but from the ratio of two: the mass and the volume of the object.

To verify the consistency of the questionnaire, the KR-20 (Kuder Richardson) index [10] was used. This index is applied to show the level of internal confidence of a complete test with statistical significance. The test itself can be adjusted according

to the index recommendation, and the discriminatory capacity of the enhanced questionnaire is also determined by this KR-20. The values of the coefficient are within the range [0, 1], and a good value [11] should be above 0.7. The current questionnaire obtained a KR-20 of 0.783, which gives a satisfactory reliability. Cohen's d and the effect size coefficient R were also determined, and the results were adequate as well, as shown below.

First, a descriptive analysis was carried out that measured the average grade of each student, based on the results of the questionnaire. Subsequently, an inferential statistical analysis was carried out to test the research hypothesis. In addition, to determine whether it was necessary to use parametric or nonparametric tests to compare the mean values of the control and experimental groups, the randomness of the sample, its normal distribution and the homogeneity of its variance were verified. The level of significance of the statistical test was set at $\text{Sig} = 0.05$. At the same time, a descriptive and inferential comparative statistical analysis was carried out for each question, in order to identify those responsible for the different mean scores obtained in the two groups of students that form part of this research.

3. Results

Table 1 summarises the mean scores obtained by the students after completing the aforementioned questionnaire, both for the control group and the experimental group. In addition, the table also includes the results of the descriptive statistical analysis, as well as the sample size, the mean values of the students' scores (on a 10-point scale), the standard deviation and the percentiles.

According to the data shown in **Table 1**, the mean scores obtained by both groups of students (experimental and control groups) are not satisfactory. This may cause alarm, as these groups are made up of teachers in training. In addition, the low mean score values seem to indicate that neither group has fully understood the concept of density, despite the years of formal teaching received in which this

Table 1. Descriptive statistics of the answers of the EG and CG students to the questionnaire.

	EG	CG
N	84	109
Mean score	4.724	2.498
Standard error of the mean	0.256	0.163
Standard deviation	2.342	1.697
Percentile		
	25	1.145
	50	2.202
	75	3.723

concept has been taught. In addition, [Table 1](#) shows a difference between the mean scores obtained by the EG and the CG (the former has better grades). In the percentile analysis, 75 % of the CG scored less than 3.72 (out of 10); this result is 6.25 in the EG. As mentioned above, the fact that the groups are made up of future primary school teachers makes these results particularly concerning. [Fig. 1](#) shows the histogram and the overlay normal distribution function for the EG (left) and the CG (right).

As [Fig. 1](#) shows, the distribution of scores of the left histogram (EG) is quite symmetrical with respect to the mean score obtained than that of the right histogram (CG). The latter presents a clear accumulation in the lower grades with only a few students having passed the questionnaire. On the contrary, in the case of the EG, the distribution of scores is more scattered, with 25 % of these scores above 6 (out of 10).

To check whether the difference in means between the two groups was statistically significant, an inferential analysis was performed. The Kolmogorov-Smirnov test was used to check the normality of the score distribution of each statistical population. [Table 2](#) shows the results of the test.

The normal distribution of the scores in both groups is confirmed by the data shown in [Table 2](#), since the p-value is greater than 0.05. In the EG, this value is 0.071 and in the CG it is 0.069. Therefore, a Student's t-test can be used to identify the differences between these two non-dependent groups. This is a parametric statistical test that aims to quantify the difference in mean scores and to analyse whether this difference is statistically significant. [Table 3](#) shows the results of the Student's t-test and the Levene's test for equality of variances.

The non-null hypothesis can be assumed in the current research since the significance of the Student's t-test (p-value < 0.001) is verified. This means that it can be asserted with 95 % confidence that there are statistically significant differences in the understanding of the concept of density between the control and experimental

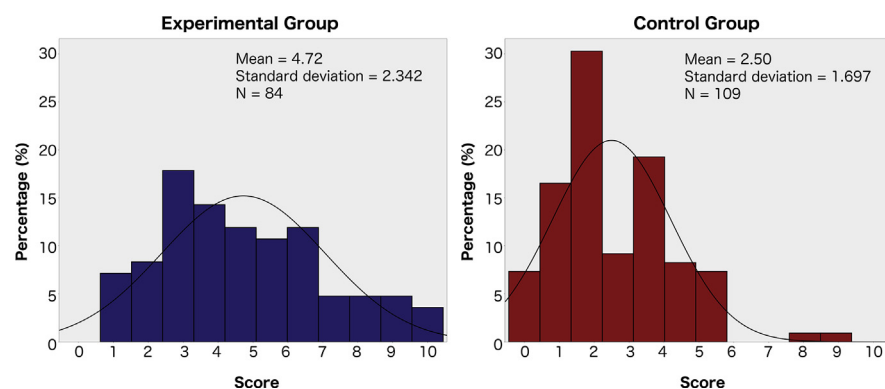


Fig. 1. Histogram and normal distribution for EG (left) and CG (right).

Table 2. Kolmogorov-Smirnov (K-S) test for checking the normality of the distribution.

		EG	CG
N		84	109
Poisson Parameter	Mean	4.724	2.498
	Standard Deviation	2.342	1.697
Most Extreme Differences	Absolute	0.141	0.124
	Positive	0.141	0.124
	Negative	-0.068	-0.094
Kolmogorov-Smirnov Z		1.292	1.297
Sig.		0.071	0.069

groups. An overall difference of 2,225 points (out of 10) was found in favour of the EG. However, since the mean scores were so low in both groups, a descriptive and inferential analysis per question was performed to discover which questions were most influential in the results. In addition, the possible influence of the work methodologies on the different responses, according to the answers presented in the theoretical and practical questions, has been studied in both groups. Fig. 2 shows the results obtained for each question by both groups in the questionnaire. It is observed that the number of correct answers of the EG is greater than that of the CG in all the questions, although some results are low in both groups.

The results shown in Fig. 2 indicate that there are differences between the scores of both groups. A Student's t-test was performed on each question to assess whether the difference in the mean of correct answers between the two groups is statistically significant. The results are presented in Table 4. Significant differences ($p < 0.05$) can be observed in questions Q1, Q2a, Q2b, Q3a, Q3b, Q3c, Q4b, Q4c, Q5, Q6a and Q6b. However, the differences in questions Q4a, Q7 and Q8 are not significant ($p > 0.05$).

These differences in the significance of each question indicate that density was probably poorly and inconsistently understood in the previous years (mainly in high school). This should be discussed in the next section.

As mentioned above, Cohen's d was used to improve the interpretation of the results and the effect-size correlation (r) using the means and standard deviations of two

Table 3. Student's t-test for independent samples (Sig = 0.05).

Levene test		Student's t-test for independent samples						
F	Sig.	t	df	Sig.	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
12.198	0.001	7.652	191	0.000	2.225	0.291	1.651	2.798

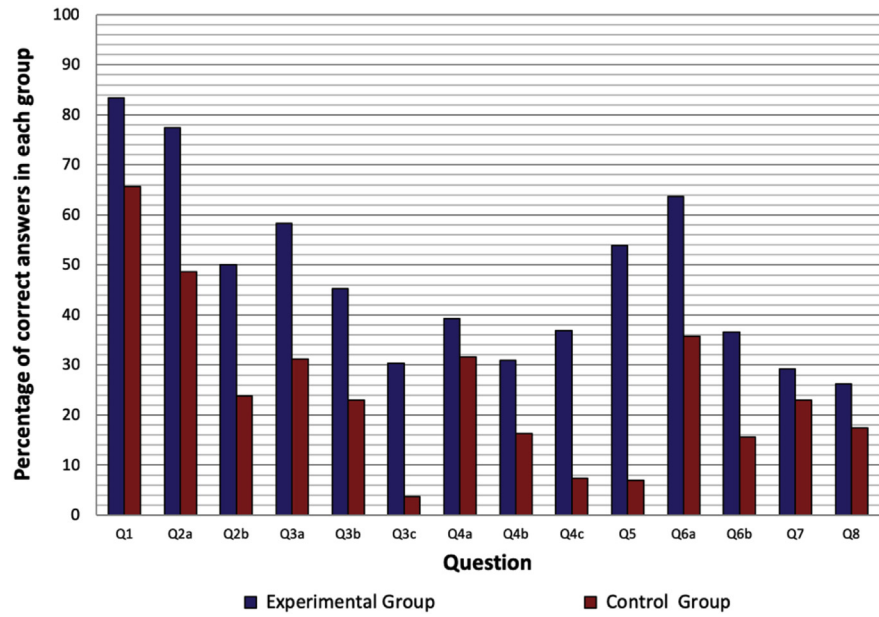


Fig. 2. Percentage of correct answers in each group.

Table 4. Statistical results of the comparison of both groups (t-test for equality of means).

Question	t	df	Sig (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the difference	
						Lower	Upper
Q1	-2.83	191	0.005	-17.74	6.26	-30.09	-5.39
Q2a	-4.25	191	<0.0001	-28.76	6.76	-42.10	-15.42
Q2b	-3.89	191	<0.0001	-26.15	6.71	-39.38	-12.91
Q3a	-3.90	191	<0.0001	-27.14	6.95	-40.86	-13.43
Q3b	-3.35	191	0.001	-22.30	6.65	-35.42	-9.19
Q3c	-5.49	191	0.000	-26.69	4.86	-36.27	-17.11
Q4a	-1.11	191	0.266	-7.63	6.84	-21.12	5.85
Q4b	-2.69	191	0.008	-14.67	5.45	-25.41	-3.93
Q4c	-5.74	191	<0.0001	-29.57	5.14	-39.71	-19.42
Q5	-9.55	191	<0.0001	-46.99	4.92	-56.69	-37.29
Q6a	-3.99	191	<0.0001	-27.91	6.99	-41.69	-14.13
Q6b	-3.46	191	0.001	-21.01	6.07	-32.99	-9.04
Q7	-0.99	191	0.323	-6.23	6.29	-18.64	6.18
Q8	-1.47	191	0.142	-8.76	5.94	-20.47	2.95

groups (experimental and control) [12]. The effect-size correlation allows differences between the two groups to be understood and compared without taking into account design variation or differences in sample size. The larger the r , the more the independent variable will influence the dependent variable. In this sense, the values obtained for these statistical parameters were $d = 1.087$ and $r = 0.477$. The first parameter ($d = 1.087$) is a very large value and should be considered as a confirmation of the consistent learning difference, measured as a mean, between the EG and the CG. The second parameter ($r = 0.477$) indicates a high effect-size correlation.

4. Discussion

A high percentage of students are able to identify the definition of density (Q1: 84 % in the EG and 65 % in the CG), offering as the most common answer the formula $d = m/V$. However, there are still some erroneous preconceptions that identify density with weight, mass, thickness, etc. This is in clear agreement with previous works, particularly with [13], where the author discovered a large number of misconceptions related to density. Along the same lines, the results of this work are illustrated by Unal's statement:

It appears that the instruction accompanied with hands-on activities did have a significant positive effect on students' understanding of flotation concepts and rules. Regarding the results, students indicated a clear increase in understanding about flotation. Each hands-on activity has shown great impact on students' understanding in the eight problematic areas where students commonly have difficulties and misconceptions. Moreover, the instruction based on the hands-on activities for the teaching of flotation concepts helped students to replace their misconceptions with the scientific ones.

(p. 142)

Students are generally able to apply the formula (Q2a and Q3a), but still think that density varies with the amount of substance or body size (Q2b and Q3c): "if we split an iron bar into two parts, the density of each part will be half the original density", "if we have twice the volume of gold, the density will double". These results are consistent with [2], who found that many pre-service middle school teachers did not fully understand the concept of density, since they were only able to recite the algorithm for density, or perform calculations with the density formula, but failed to understand density as a property.

In the more experimental questions (Q4 and Q5), the EG results are significantly better than the GC results, as the students are more accustomed to laboratory work. Similar results were obtained by [14] with 7th grade students. This work pointed out the importance and relevance of hands-on and personal observation in the scientific understanding of different phenomena such as buoyancy and density, among

others. Despite this, in our case study, the percentage of correct answers is low in both groups compared to that obtained in more conceptual questions. According to [15], students who can reason with ratios, which unfortunately are less than half of all students, will perceive that all of the above is derived from $d = m/V$. Most will not perceive this and will see no connection between m/V and the concept of density as denseness.

Most students are able to identify the lightest key (Q6a), but do not provide an elaborate explanation, and even identify weight or mass directly with density (Q6b). Moreover, they are unable to explain why the keys have a different mass but occupy the same volume (Q7), and most of them simply explain it by saying that the keys “are made of a different material”.

Lastly, most students are unable to place the labels on their corresponding bottles (Q8). In this question, which is more complex than the previous ones, the percentage of correct answers is low in both groups, indicating that pre-service teachers did not fully understand the concept of density.

From the results obtained it can be concluded that previous ideas on the concept of density persist at university level. This is especially critical in the case of students who will be future primary school teachers [16], where it is essential to master the basic concepts of the science curriculum in order to explain them adequately to their future students and identify their preconceptions. One of the causes of these results may be due to the teaching methodology received throughout their school years, so it would be necessary to propose new teaching strategies to promote truly meaningful learning.

5. Conclusions

Basic scientific concepts, such as density, often present problems in their understanding and learning process, even at university level. This work has shown that the understanding and achievement of learning can be improved by using certain teaching methodologies rather than others. For example, a teaching path based on hands-on activities has proved to be a more efficient methodology compared to classical oral exposition. Statistically significant differences can be established between the CG and the EG. The CG was subjected to a pure oral exposition of concepts, while the EG was driven to the concept of density through laboratory experiences. Once the acquisition of knowledge was measured, it was clearly higher in the case of the control group.

These results should be taken into account to overcome traditional concerns about science teaching, especially when it comes to students who are neither scientists nor science-oriented, but who would need to teach science more thoroughly, such as primary school teachers.

Declarations

Author contribution statement

Guadalupe Martínez-Borreguero, Francisco Luis Naranjo-Correa, Florentina Cañada Cañada, David González Gómez, Jesús Sánchez Martín: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

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