THE LEARNING EFFECTS OF A TEACHING LEARNING SEQUENCE (TLS) ABOUT BUILDING THE CONCEPT OF DENSITY OF PURE SUBSTANCES AND SOLUTIONS IN PRIMARY SCHOOL STUDENTS

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ABSTRACT

This paper (which is a part of a doctoral research) studies the learning outcomes of an integrated Teaching Learning Sequence (TLS), which, by first approaching the necessary background knowledge of the concepts of mass and volume, aims to build the concept of density of both pure substances and solutions. This TLS was developed based on students' already known alternative ideas from the existing literature about the difficulties of understanding density and its intensive character. The analysis of the results showed quite satisfactory learning outcomes of the TLS, with the exception of some difficulties and failures expected to some extent based on the literature, for both primary grades' students, with a predominance of the 6th grade students, which showed higher percentages of better understanding of density and its intensive character.

Keywords: density, 5th - 6th grade students, Teaching Learning Sequence (TLS)

INTRODUCTION

The importance of 'alternative ideas' in Science teaching

In recent years, it has been scientifically accepted within constructivism, both in the international and Greek literature, that a very important factor influencing learning is the ideas that students have formed, from a very young age, depending on the environment in which they live and their respective experiences **[1] [2]**. These pre-existing ideas are often referred to as 'alternative ideas' as they contradict or do not fit into a scientifically accepted framework **[2] [3]** and there is growing evidence for the existence of alternative conceptions in children's understanding of natural phenomena **[4]**. Indeed, some of these are so strong that they are not easily changed, bringing about what is known as cognitive conflict in the learner. Teaching science encounters more obstacles than teaching other subjects, as most scientific concepts are abstract and difficult for students to understand **[5]**. Indeed, according to Borreguero et al. **[6]**, the scientific knowledge acquired by students during traditional textbook-based instruction does not allow for the conceptual change of alternative ideas presented by students, which implies that concepts are not learned in a meaningful way and end up being forgotten over time. Teachers' knowledge of students' alternative ideas about different subjects in science, helps teachers to choose the appropriate teaching approach or even to write more targeted school textbooks and curricula.

The concept of density to be studied

The density of an object is defined as the mass per unit volume of the object. Density is an abstract concept **[7], [8], [9], [10]** and a deep understanding of density is based on an understanding of the concepts of mass and volume and the relationship of density to each **[11]**. In Greece, density is a concept that is introduced in Science course in the 5^{th} grade, according to the curriculum of the Greek Ministry of Education. Density is a concept in Science that is difficult to understand for children aged 10-12 years old, which is confirmed in the literature **[11], [7], [12], [13]**, etc. The difficulty of understanding lies in the fact that children of this age have many misconceptions about matter and thus cannot differentiate the concepts of weight and density **[14], [15], [16]**. Another difficulty is the fact that density is an intensive quantity, which, in order to be calculated, requires the simultaneous consideration of the mass and volume of a material body and according to Rowell & Dawson **[17]** and Seah et al. **[18]** students of this age have difficulty understanding the concept of the ratio of two quantities. Although students successfully calculate density by dividing mass and volume when given physical numbers (building on their mathematical knowledge of fractions) **[18]**, they still struggle to understand what this ratio means **[2], [19]**. It is no coincidence that four out of ten Greek school students, who have the scientific idea of density, also have some good or relatively good opinion about the defining quantities of density **[20]**. As an extension of the concerns about students' problems with the concept of density in pure substances **[21]**, another thing that children have difficulty with is the density of solutions, since in order to decide whether a solution is dense or dilute, they must consider both the mass of the solute and the volume of the solvent. In order to improve children's understanding, the concept of density is approached qualitatively (e.g. the experimental setup of the study of the density of sugar water) and from this, through the discovery model of teaching, its quantitative expression is derived.

The Teaching Learning Sequence (TLS)

Many studies, that attempt to identify students' perceptions around different concepts, are based on Teaching Learning Sequences (TLS), that attempt to develop improved ways of teaching the underlying topics **[22], [23]**. In the European science education community, this trend is being implemented through the design, development, implementation and evaluation of Teaching Learning Sequences (TLS), which are a mid-scale curriculum product covering a scientific topic **[23]**. According to Fassoulopoulos et al. **[24]** and Zongo et al. **[15]**, students' approach to the concept of density is best done with the help of liquids, because they have advantages over solids and gases. That is why this experimental teaching intervention contains experiments mainly using liquids, thus making experimental use of the so-called "density column". The difficulties, that students usually face in understanding the concept of density, usually identified after traditional teaching, as well as their alternative ideas known to the research community, were taken into account in the design of the relevant activities of this Teaching Learning Sequence (TLS) **[25], [26]**.

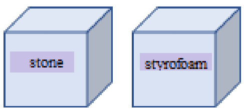
METHODOLOGY

The population for the present study consists of students aged 11-12 years old, attending the 5th and 6th grade of primary school. 90 students in 5th grade and another 90 students in 6th grade were selected from primary schools throughout Greece. More specifically, the 5th grade students were taught the units on mass, volume and density from the textbook 4 to 7 months before the main research was conducted, while the 6th grade students were taught the corresponding units 16-19 months before. An attempt was also made to distribute between boys and girls, such that it was consistent with the distribution in the general population. Consequently, 72 boys (40%) and 108 girls (60%) participated in the research. An effort was also made to ensure that all students were at a similar socio-economic level, in order to limit the influence of other factors as much as possible.

More detailed, as to the process and timing of the main research: First, the initial questionnaire (Pre-test) was given to the students, in order to record and study their initial ideas - "alternative ideas" as before understanding the concepts of mass, volume, density of pure substances and density of solutions. After one week, the three experimental teaching interventions of the Teaching Learning Sequence (TLS) were implemented in the classroom over a maximum of two weeks with the corresponding worksheets. At the end of the experimental teaching and after 7-10 days from the first experimental teaching intervention, the students were given the final questionnaire (Post-test) to evaluate the learning outcomes of the experimental teaching interventions.

The questionnaire, that was distributed, consists of 21 questions and both the Pre-test and the Post-test are the same questionnaire, precisely to better assess the room for improvement of students' learning outcomes. The coding of the answers differs from case to case. Furthermore, all questions are closed-ended, but there are some open-ended sub-questions, where students are usually asked to justify their answer to the main close- ended question [Figure 1, 2]. In addition, it is worth noting that the questions deal with both mass and volume and density of both pure substances and solutions. Furthermore, groups of questions were created, which will be used later, targeting different aspects of the topic under study.

18) I have two cubes of the same volume. One is made of stone and the other of Styrofoam. Which cube do you think has a lower density of material? Put an X in the correct answer and briefly justify your answer.



A) The stone cube has a lower density	
B) Styrofoam cube has lower density	
C) Both cubes have the same density	

α) Justify your answer: You can use some of the words (mass, volume, smaller, larger, same):

The cube made of_________________ has a lower density because ____________________________________

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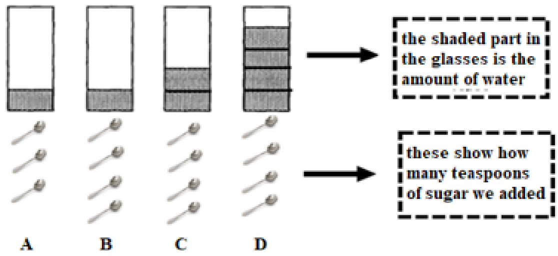
Figure 1: A closed-ended question from the questionnaire with the corresponding open-ended question that serves as a justification for the first

21) I prepare 4 solutions with water and sugar. All four solutions have different volumes and different amounts of sugar dissolved in them. Observe them carefully.



α) Which solution do you think has the largest volume of solvent (water)?

A	B	C	D

b) Which solution do you think has the highest solute (sugar) content?

A	B	C	D

c) Which solution do you think is the most dense of all and why?

A	B	C	D

d) Justify your answer: (You can use some of the words: sugar teaspoon, water, more, less, mass, volume, quantity, solute)

The .... mixture is the most concentrated solution of all, because ___________________________________

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e) Arrange the containers starting with the thickest/sweetest tasting solution of water and sugar:

_______>_______>_______>_______

Figure 2: A question from the questionnaire with closed or open-ended sub-questions to be answered by observing the figure with four solutions of different solvent volumes and different solute masses

RESULTS

Statistical analysis and processing of the results was carried out using SPSS 23 statistical software and application of the non-parametric Mann-Whitney test to determine whether there was a significant difference between the two groups of students in terms of their total score on each factor of the research.

As Table 1 shows, during Phase 1 of the research (Pre -test Phase), students in the two classes had approximately the same scores on the factors being studied. The only exception was the total score on understanding the density of solutions with different solvent volumes and different solute masses ($U=3378.000$, $p=0.020$). In this case, the students in 6th grade showed a significantly higher score (M.=0.81, S.D.=1.13) than the students in 5th grade (M.=0.41, S.D.=0.81). On the other hand, it appears that after the implementation of the teaching intervention, there was a significant difference between the 5th and 6th grade students in their scores on each of the two major factors studied, concerning the knowledge of the density of pure substances (U=2844,000, p=0.001) and solutions (U=3308,500, p=0.033). In fact, in both factors, a higher score is noted among the 6th grade students (M.=17.23, S.D.=2.43; M.=10.93, S.D.=2.58 respectively) compared to the 5th grade students (M.=15.84, S.D.=2.62; M.=10.18, S.D.=2.37).

Furthermore, students in the two classes also appear to differ significantly in the remaining scores of the smaller factors, that were formed and studied in relation to density. Specifically, students in the two classes scored significantly differently on understanding density as an intensive quantity that depends solely on the type of material (U=3338,500, p=0.037), on understanding the concept of mass (U=2918,500, p<0.001), and on intuitive understanding of density through floating and sinking theory (U=3287,500, p=0.025). In each of these factors, a higher score was obtained by the 6th grade students (M.=3.46, S.D.=1.26; M.=3.39, S.D.=0.75; M.=6.16, S.D.=1.23 respectively) compared to the 5th grade (M.=3.02, S.D.=1.41; M.=3,01, S.D.=0,79; M.=5.69, S.D.=1.37 respectively). Finally, the two groups of students also seem to differ significantly in their understanding of the density of solutions with different volumes of solvent and different masses of solute (U=3128.000, p=0.005). Once again, there was a significant superiority of the students of the 6th grade (M.=1.60, S.D.=1.28) over the rest of the 5th grade students (M.=1.09, S.D.=1.26). However, as the averages show, the teaching intervention was successful for both classes in all factors, sometimes a little and sometimes a lot.

Table 1: Results of the difference tests on the total score obtained by students in the 2 phases (where M.=Average and where S.D.=Standard Deviation)

Factors	1st Phase (Pre-test Phase)			2nd Phase (Post-test Phase)		
	M. ± S.D. (5th grade)	**M. ± S.D. (6th grade)**	**U (p)**	**M. ± S.D. (5th grade)**	**M. ± S.D. (6th grade)**	**U (p)**
Knowledge of the mass, volume and density of pure substances (0 – 22)	9,17 ± 2,89	9,29 ± 2,20	3974,500 (0,827)	15,84 ± 2,62	17,23 ± 2,43	2844,000 (**0,001**)
Knowledge of mass, volume and density of solutions (0 – 15)	5,87 ± 2,35	6,31 ± 2,53	3738,000 (0,368)	10,18 ± 2,37	10,93 ± 2,58	3308,500 (**0,033**)
Understanding density as an intensive quantity that depends solely on the type of material (0 – 5)	1,12 ± 1,22	1,33 ± 1,13	3498,500 (0,099)	3,02 ± 1,41	3,46 ± 1,26	3338,500 (**0,037**)
Understanding of volume concept (0 – 3)	1,92 ± 0,81	1,77 ± 0,81	3742,500 (0,340)	2,52 ± 0,57	2,34 ± 0,69	3542,000 (0,103)
Understanding the concept of mass (0 – 4)	1,96 ± 1,02	2,09 ±0,88	3799,000 (0,448)	3,01 ± 0,79	3,39 ± 0,75	2918,500 (**<0,001**)
Understanding mass/density differentiation (0 – 7)	1,64 ± 1,26	1,49 ± 1,07	3783,000 (0,428)	4,06 ± 1,39	4,41 ± 1,38	3482,500 (0,097)

Intuitive understanding of material density through floating/sinking theory (0 – 8)	3,36 ± 1,28	3,13 ± 1,07	3591,000 (0,174)	5,69 ± 1,37	6,16 ± 1,23	3287,500 (**0,025**)
Understanding material density based on particle structure (0 – 1)	0,31 ± 0,47	0,36 ± 0,48	3870,000 (0,528)	0,83 ± 0,38	0,74 ±0,44	3690,000 (0,145)
Understanding the parts of the density fraction (0 – 3)	1,19 ± 0,78	1,27 ± 0,83	3790,000 (0,426)	2,02 ± 0,79	2,10 ± 0,82	3806,500 (0,451)
Understanding the density of different materials with the same volume and different mass (0 – 3)	1,44 ± 0,72	1,46 ± 0,64	4032,000 (0,954)	2,18 ± 0,76	2,23 ± 0,65	3962,500 (0,783)
Understanding the solvent/solute ratio for solution characterization (0 – 9)	2,54 ± 1,60	2,86 ± 1,90	3725,500 (0,344)	5,62 ±1,80	6,04 ± 2,17	3564,000 (0,159)
Same volumes of solvent and different mass of solute (0 – 3)	1,26 ± 0,82	1,14 ± 0,74	3640,000 (0,204)	2,50 ± 0,68	2,54 ± 0,71	3828,000 (0,458)
Different volumes of solvent and	0,41 ± 0,81	0,81 ±1,13	3378,000 (**0,020**)	1,09 ± 1,26	1,60 ± 1,28	3128,000 (**0,005**)

different mass of solute (0 – 3)		

CONCLUSIONS

The statistical analysis of the responses revealed that both 5th grade and 6th grade students showed very positive learning outcomes after the implementation of the Teaching Learning Sequence (TLS) on all factors of the survey, either on a small scale or on a large scale. It should be noted that students in both grades, during the first phase of the research, i.e. before the implementation of the TLS, had generally the same success rate on the questions, which is reasonable, since they had been taught the same items from the textbook, while after the implementation of the TLS, the superiority of the 6th grade students over the students in 5th grade was evident, in most of the factors of the research. It should be noted that the scores of the students in Phase 1 of the survey were quite low on most of the survey factors, i.e. below 50%, with the exception of their responses related to their intuitive understanding of material density through floating/sinking theory, which is normal, given that children of this age already have enough knowledge through systematic observation from their daily life. Of particular interest is the fact that after the experimental teaching intervention they scored quite satisfactory (almost three times as high) in terms of understanding the concept of density as an intensive quantity, which depends exclusively on the type of material and not so much on the deep understanding of the concept of the ratio of two quantities (mass/volume in the case of density). Besides, regarding the density of different materials with the same volume and different mass, a slight improvement was observed with a relative difficulty in interpreting and justifying it, due to the difficulty at this age of simultaneously considering both parts of the density fraction (d= m/V).

Difficulty and partial failure, even after implementation of the experimental intervention, was observed in the students of both grades in understanding the density in solutions with different solvent volume and different solute mass, while on the contrary, all students understood the density of solutions with the same solvent volume and different solute mass to a very good level. Besides, and according to the literature **[2], [17], [18], [19]**, students of this age find it difficult to manage the simultaneous consideration of the mass and volume of a material body, let alone a solution.

In general, on the whole, the TLS was successful in terms of learning to understand the difficult for this age concept of density of both pure substances and solutions. It would be best, of course, if density were to be included in the 6th grade Science Curriculum and introduced for the first time as a concept in the 6th grade science class rather than in the 5th grade science class, in order to be understood to a greater extent by the pupils in the last grade of primary school and to achieve a smooth transition to high school. It is also proposed to use this TLS as a teaching material for the concept of density, as the textbook, according to phase 1 of the research, showed low learning outcomes for students in both grades. Finally, the revision of the new Primary School Science Curriculum, which has not yet entered into force but has already been implemented in the Experimental Schools, proposing the abolition of the teaching of density in primary education, resulting in an abnormal transition to the concept of density directly in secondary education, which is confirmed by the literature **[15]**.

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ETHICAL STATEMENT

This study was approved by the Ethics committee of the Aristotle University of Thessaloniki (Protocol Number: 19960/19-01-2023). This research protocol was also approved by the Ministry of Education, Religious Affairs and Sports of Greece and the Institute of Educational Policy (Protocol Number: Φ15/7024/ΑΛ/9288/Δ1/26-01-2023). Participants were well noticed the research purpose and research methods. Signed consent was obtained for all participants and their parents.

DATA AVAILABILITY STATEMENT

Data will be supplied upon request (all in Greek).