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Teaching first-degree equations to students with dyslexia

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ABSTRACT

The teaching of first-degree equations is a key point in secondary school curricula and requires the careful planning and selection of appropriate teaching materials. On the other hand, dyslexia, a specific learning disability, is increasingly common in the classroom. Thus, in the context of inclusion, the teaching methodology used by the mathematics teacher to present the concept of equation is a crucial factor for ensuring the equal and active participation of all students in the educational process. In this article, we present a two-month teaching intervention on first-degree equations that we carried out with forty students with dyslexia randomly divided into two classes, who were attending a special vocational high school in Greece. In one group, we used manipulative materials, while in the other group, we used traditional teaching methods. The results, which are derived from a combination of quantitative and qualitative methods, showed that the students in the first group achieved better results in the final test than did the students in the second group, while at the same time, they showed increased engagement in the learning process and, to some extent, improved their social skills and gained confidence.

Keywords: manipulative material, inclusive education, first-degree equations, dyslexia, teaching intervention

INTRODUCTION

Dyslexia is the most common specific learning disability of the twenty-first century, with an increasing number of children being diagnosed with the disorder today, and there are even films dedicated to this disability ("Like Stars on Earth" (2007), "Mical" (2020), etc.). Dyslexia is a specific learning disability characterized by difficulties in reading, spelling and mathematics (Erbeli et al., 2021; Wu et al., 2022). These difficulties are not directly associated with phonological deficits, the provision of ineffective instruction, or a deficit of cognitive skills.

On the other hand, the term *manipulative materials* refers to physical objects that children can move in a specific way to facilitate the learning process (Hall et al., 2022). According to the literature, manipulative materials are differentiated according to their origin and the quality of the user-operator interaction. This distinction creates four main classes:

a) *Concrete manipulatives* (physical artefacts such as fraction strips, Montessori materials, etc.),
b) V*irtual manipulatives* (digital artefacts/visual representation of math objects),
c) *Historic-cultural manipulatives* (concrete artefacts created in the longstanding history of mathematics, e.g., abacus, polyhedra, bones, etc.), and
d) *Artificial manipulatives* (i.e., artefacts designed with specific educational aims) (Bartolini & Martignone, 2020; Moyer et al., 2002).

In this paper, the manipulative materials used belong to the fourth class. The use of manipulative materials in math classrooms enables all children of typical or nondevelopmental age to come into contact with mathematical concepts; thus, all children gain a deep understanding of mathematical knowledge (Baiduri et al., 2021; Ocampo et al., 2023). In addition, the use of manipulatives and visual aids during instruction appears to have positive effects on learning outcomes (Coles & Sinclair, 2019).

The concept of an equation is a fundamental aspect of mathematics curricula, appearing in both algebra and geometry, and is applicable to everyday situations and problems in children's lives (Papadakis et al., 2021). It is well established that children with dyslexia struggle with mathematics when taught using traditional methods (Bailey et al., 2020; Bhatti et al., 2020; Zoccolotti et al., 2021).

The *traditional method* of teaching mathematics, in general, is a teacher-centred model in which the instructor presents the lesson on the blackboard, asks questions to ensure that students are paying attention and understanding the material, and then summarizes the theory and solution techniques to aid students in memorizing the new knowledge. On the other hand, students must pay close attention to the teacher when speaking and take accurate notes from the information presented on the blackboard. This approach may limit opportunities for self-directed learning, especially in Greece, as it is primarily focused on exam preparation.

A review of the literature reveals that while there are studies investigating the use of manipulative materials in the general mathematics classroom, and others demonstrating that students with dyslexia encounter difficulties in mathematics when taught by classical methods, there is, as yet, no research, at least in Greece, focusing on the use of manipulative materials in the teaching of first-degree equations to students with dyslexia. The objective of this paper is to contribute to the filling of this research gap.

This paper investigates the spontaneous reactions of children with dyslexia using appropriate manipulative materials during mathematics lessons. The focus is on teaching first-degree equations of the form:

$$ax + b = cx + d \tag{1}$$

integrating manipulative materials such as paper, multi-coloured pens, and scissors. The equation of the form $ax + b = cx + d$ applies not only to arithmetic but also to operations between variables. Therefore, it is essential for math teachers to provide appropriate interventions during the transition from arithmetic to algebra, especially for students who are encountering algebra for the first time (Filloy & Rojano, 1989; Radford, 2022).

Therefore, our research idea could be linked to the difficulties faced by high school students with dyslexia during the transition from Arithmetic to Algebra, as well as those encountered by mathematics teachers who seek appropriate methods and teaching material to support their students in order to overcome these difficulties.

On this basis, inclusive education refers to the capability for all children to participate in the educational process without exclusion and discrimination (Byrne, 2022; Ydo, 2020). In this context, teachers try to use inclusive methods to attract the interest of all children, promoting their participation in the learning process (Hau et al., 2022; Messiou, 2019; Page et al., 2021). The use of manipulative materials and visual aids can attract the interest of all children in the classroom (with or without special educational needs) and lead to the acquisition of knowledge (Polo-Blanco & González López, 2021). Within this frame of reference, the phenomenon of labelling children due to difficulties they face in the educational process tends to be eliminated (Bishop & Kalogeropoulos, 2015).

Therefore, bearing in mind that the first-degree equations play a crucial role in secondary school curricula and that inclusion is part of widely accepted education policy, we implemented a two-month teaching intervention in a single special high school in Greece. The participating students were diagnosed with dyslexia and were in the 8th, 9th and 10th grades. Our intervention focused on teaching first-degree equations of the form $ax + b = cx + d$ using relevant manipulative materials. This particular form of equation was chosen deliberately because its solution by students marks their transition from arithmetic to algebra, as indicated above.

To the best of our knowledge, similar research on solving first-degree equations in high school students with dyslexia has not been conducted in Greece. Therefore, in our study, we focused on forty children with dyslexia who were divided into two groups (the experimental group and the control group) and who were in the 8th, 9th and 10th grades at a single special high school, and we posed the following research question:

RQ. Can the teaching of first-degree equations based on the use of manipulative materials produce better learning outcomes than traditional methods for students with dyslexia?

The results showed that students who were taught first-degree equations using manipulative materials assimilated the solving techniques and scored better on the final test than those who were taught the same subject using the traditional teaching method. Based on these results, we discuss some perspectives at the end of this article.

THEORETICAL CONSIDERATIONS

Notes about Dyslexia

The German ophthalmologist Oswald Berkhan was the first to describe the symptoms of dyslexia in 1881, while Rudolf Berlin introduced the term "dyslexia" (Werth, 2023). The term dyslexia refers to a developmental language disorder characterized by difficulties in the child's recognition of letters and words and decoding of phrases and sentences (Andresen & Monsrud, 2022). The categories of specific learning difficulties include dyslexia, dysgraphia and dyscalculia, which refer to reading, writing and mathematics, respectively (Kariyawasam et al., 2019). More specifically, children with this disorder have difficulty reading text, spelling words and understanding the content of written language (Snowling et al., 2020). The latest edition of the Diagnostic and Statistical Manual of Mental Disorders (https://doi.org/10.1176/appi.books.9780890425596) reports that dyslexia accounts for 80% of specific learning disabilities (Lin et al., 2020).

The occurrence of dyslexia is not correlated with the child's cognitive potential or with the lack of appropriate education provided at school (Bazen et al., 2020). The prevalence of dyslexia worldwide is high, estimated at 15-20% of the population (Maunsell, 2020). This percentage depends on the criteria used by each country to define dyslexia, and the disorder is more common in boys than in girls (Di Folco et al., 2022). The exact causes of dyslexia have not been clearly identified by the scientific community to date (Werth, 2019). The occurrence of the present disorder may be due to biological and genetic factors (Theodoridou et al., 2021).

In terms of academic skills, children with dyslexia show a multimodal way of thinking and solving mathematical problems in a creative way (Lambert et al., 2019). However, they may find it challenging to read math problems due to difficulties in reading and understanding the content (Wong et al., 2023). In terms of social skills, children with this disorder may experience difficulties in developing social relationships due to low self-esteem, behavioural problems, anxiety and more (Huang et al., 2020).

Key characteristics of children with dyslexia are difficulties in phonological awareness, phonological memory, processing of visual information, difficulties in organization, increased time needed to perform tasks, etc. (Yedra & Aguilar, 2022). In addition, children with dyslexia have low self-esteem due to the stress related to solving mathematical tasks and problems (Muhamad et al., 2016). Furthermore, dyslexia is not directly related to vision, but it has been observed that the eye movements of children with dyslexia are abnormal (Prabha & Bhargavi, 2020). Monitoring children's eye movements while they are solving mathematical exercises and problems can reveal significant differences in their cognitive abilities in mathematics (Manchado Porras et al., 2023). Medical and educational models have been used to explain the phenomenon of dyslexia, according to which dyslexia is a result of a neurological disorder (medical model) or a learning disorder (educational model) (Habib, 2021). In many European countries, for example, in Greece and France, in the context of inclusive education, children with dyslexia attend general classes with the help of parallel support teachers (Chatzipanteli et al., 2022).

The Use of Manipulative Materials in Mathematics Teaching

The integration of manipulative materials in teaching students with or without special educational needs appears to have positive learning outcomes (Rizos & Foykas, 2023b). A literature review carried out by Johnston (2019) showed that the use of manipulative materials is effective and leads to an in-depth understanding of the lessons. Rodić and Granić (2022) also conducted a literature review on the use of wooden manipulative materials during the teaching of children with dyslexia. The research showed that this teaching intervention had positive learning outcomes, as the children fully understood the concepts taught during the lesson.

A considerable amount of research has been carried out on the use of manipulative materials in mathematics teaching. In a study conducted by Arnal-Bailera and Arnal-Palacián (2023), the importance of the use of manipulatives in mathematics teaching was highlighted, as well as the necessity for teacher candidates to comprehend the concept of manipulative materials. Flores et al. (2023) conducted a study with 6th grade children in which they used manipulative materials to teach 3-D geometric shapes. The results showed that children understood geometric shapes in relation to traditional teaching methods. Another study was conducted by Meke et al. (2019), in which 40 children were given authentic math problems and asked to solve them using manipulative materials. The results showed that the use of manipulative materials increased children's learning engagement during problem solving and that the children correctly solved the problems given to them.

Abarquez (2020) carried out a study involving 80 preschool children who were given manipulative material to teach mathematical problems. The results of the research showed that the use of manipulative materials by children during the teaching of mathematics is more effective than the traditional teaching model. Another study by Baiduri et al. (2021) involving 32 children aimed to teach geometric shapes using concrete materials. The results showed that the children were able to design geometric shapes on their own using appropriate hands-on materials. O'Rear et al. (2023) presented two studies involving 103 and 93 children with the aim of teaching mathematical concepts using manipulative materials. The results showed that all the children understood the mathematical concepts taught.

A study by Delport (2021) showed that using manipulative materials in teaching mathematics to children with dyslexia and cognitive difficulties improved academic performance. Lafay et al. (2019), in a literature review of 306 studies on the use of manipulative materials in mathematics teaching, showed that children with dyslexia and mathematics difficulties had positive learning outcomes.

The number of studies on the use of information and communication technology (ICT) in teaching mathematics to children with dyslexia is limited. One study by Rizos and Foykas (2023a) showed that the use of Byrne's Euclid, a modern visual aid, in teaching Euclidean geometry to children with specific learning difficulties, had positive learning outcomes. Novembli and Azizah (2019) performed a literature review on the use of ICT and mobile learning in teaching children with dyslexia, and the findings showed that the use of mobile phones and ICT yielded satisfactory results in reading ability and solving mathematical problems. Furthermore, Forteza-Forteza et al. (2021) noted that the use of ICT helped children with dyslexia learn mathematics during the COVID-19 lockdown.

But also for children without learning difficulties, the results of the Bounou et al. (2023) research revealed the presence of a statistically significant correlation between students' proficiency in computational thinking and their performance in Science, Technology, Education and Mathematics (STEM) and Greek language courses. Furthermore, smart mobile devices and accompanying mobile apps provide preschool and early school-age children with opportunities to cultivate basic coding and computational thinking skills, and facilitate early STEM learning (Papadakis, 2022).

Another study by Tjandra (2023) showed that the use of manipulative materials should be part of an inclusive curriculum in mathematics, as such materials promote the participation of all children (including children with dyslexia) in educational instruction. Malliakas et al. (2021) carried out a survey of 124 children aged 13-14 years with dyslexia. The results showed that the use of board games (a type of manipulative material) can improve the performance of children with dyslexia and their understanding of mathematical concepts. In another study by Lafay et al. (2023), 123 children participated, 94 of whom were typically developing children and 29 of whom were children with dyslexia and secondary school learning difficulties, in solving mathematical exercises using manipulative materials. The results showed that all the children (typically developing and dyslexic) benefited from the use of manipulative materials and correctly completed all the exercises given to them.

DESCRIPTION OF THE TEACHING INTERVENTION

Teaching Practice

Mathematics teaching in a special vocational high school in Greece comprises three hours each week: two hours of Algebra and one hour of Geometry. The book used in high school is unique and is given free of charge to all children by the Greek Ministry of Education. The mathematics textbook used in all grades of high school consists of two parts. The first part, called "Algebra", includes first- and second-degree equations and basic functions. The second part, called "Geometry", includes elements of triangles, basic elements of geometry (line segment, angle, areas, the Pythagorean theorem, etc.) and basic trigonometry.

The chapter on first-degree equation is present in the 8th, 9th and 10th grades of high school and the expected educational outcomes according to the curriculum are as follows:

1) Students should be able to identify the terms "first-degree equation", "first and second part of an equation", "unknown" and "solution of the equation"
2) Students should be able to identify whether a number is a solution to an equation
3) Students should be able to solve equations of the form $ax + b = cx + d$ by applying the properties and preserving the equality and the facts.

In the 7th grade, there is a chapter on first-degree equations, and the expected learning outcomes according to the curriculum are as follows:

1) Students should be able to recognize the terms "first-degree equation", "first and second part of an equation", "unknown" and "solution of an equation"
2) Students should be able to determine if a number is a solution of an equation
3) Students should be able to solve specific equations of the following forms: $ax = b$, $x + a = b$, $x - a = b$, etc.

Every year, the Greek Ministry of Education gives teachers detailed instructions for the modules to be taught. For the chapter on first-degree equations, the instructions focus on understanding the concept of an equation, solving techniques and the importance of equations. However, the teaching of algebra in Greek high schools has a rather formalistic character, which could be placed in the context of behaviourism. More specifically, most teachers introduce students to the techniques for solving exercises without students having a deep understanding of the concepts involved. It should be mentioned that historical notes are included at the end of each chapter in all textbooks. However, these notes are not part of the curriculum and are often overlooked by students (see Rizos & Adam, 2022).

The Nature of the School and the Participating Students

The school where our intervention was implemented is a modern special vocational high school located in a semiurban area of Greece. The special vocational high school has four classes, as opposed to the general high school, which has three classes. The school consists of seventy-five children aged 12 to 18 years with special educational needs who come from the central town and from the neighbouring villages of the region by bus and taxi. The school has assistive handrails for children with mobility problems, a computer laboratory, a theatre room, a music room, a library and an electrical laboratory for high school students who pursue this field of study. The classrooms consist of blackboards and whiteboards, and in recent years, some classes have been equipped with interactive whiteboards through donations from some of the school's beneficiaries.

The school's teachers received postgraduate degrees and attended specialized seminars for training in special education. The children attending the school location were diagnosed with autistic spectrum disorder, dyslexia, mental retardation, motor problems, anterior attention deficit-hyperactivity disorder, severe school anxiety, etc., representing the majority of diagnoses of children at special vocational high schools in Greece. In addition, the students attending this school were mostly children with impaired social skills and learning deficits, such as difficulties in recalling information from long-term working memory. The school culture, however, is friendly and promotes cooperation between teachers and between teachers and pupils in the context of inclusive education.

Forty students with dyslexia in the 8th, 9th and 10th grades participated, and they were divided into two groups of twenty. One group was the experimental group, and the other was the control group. The students were randomly divided into two groups without any specific criteria. Each group consisted of students from all three classes, boys and girls, who participated voluntarily in the research. This gave the students the opportunity to cut the paperboard, write and draw together, thus developing a climate of cooperation between them and cultivating in a way their social skills. One of the two authors of the article is a math teacher at the special vocational high school where the intervention was implemented.

It is important to mention that we were familiar with the participating students from our math class in the previous academic year, both in terms of their academic and social abilities. These students have dyslexia and often experience additional learning difficulties as well as challenges related to socialization, school anxiety, and emotional disturbances. In particular, individuals with learning difficulties often struggle to comprehend written language. As a result, they are provided with both written and oral instructions for exercises. In higher grades, these students are directed to pursue technical professions such as electricians' assistants, gardeners, and nursery assistants. The primary goal of the special vocational high school they attend is to enhance their social skills and facilitate their integration into society.

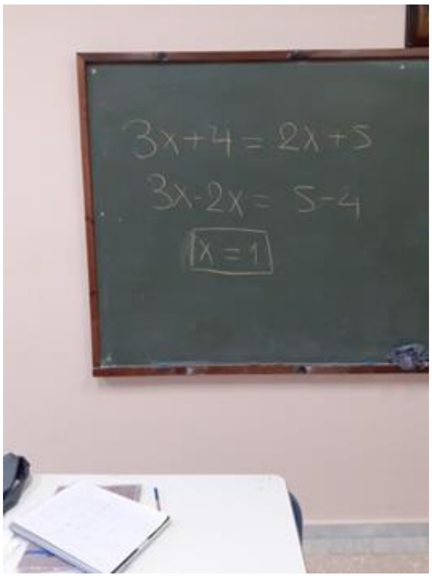

Figure 1. Solving the equation $3x + 4 = 2x + 5$(Source: Field study)

Overview of the Project

The research was conducted between October and November 2023 and lasted for twelve hours. It focused on teaching and solving first-degree equations of the form $ax + b = cx + d$ using manipulative materials such as scissors, paperboard, and multicoloured pencils. The study did not cover equations of the form $0x = c$ or parametric equations.

The first phase of the teaching intervention lasted two hours, one hour for the experimental group and one hour for the control group. In this phase, we discussed with the 9th- and 10th-grade students the basic terms of a first-degree equation such as "unknown", "solution", "first and second part", etc., while the 8th-grade students listened to the discussion without being encouraged to participate. Through the above dialogue, we found that the 9th and 10th graders in both groups did not remember the basic terms of the equation. In particular, several children in both groups indignantly gave us the following statement: "We don't remember anything of the equations we were taught last year". Therefore, all participants in our intervention began from the same starting point in terms of their knowledge of first-order equations.

The second phase of our intervention was implemented two weeks later and lasted two hours, one hour for the control group and one hour for the experimental group. In both cases, we discussed with the students the terms "equation", "unknown", "solution", etc., and we presented and solved examples on the blackboard of equations of the form:

$$\begin{gathered} a \cdot x = b \\ a : x = b \\ a + x = b, \end{gathered} \tag{2}$$

etc., taking steps with the students. Our purpose was to determine the basic definitions, as well as the main solving techniques for equations of the above forms. We observed that students in both groups had difficulty recalling solution techniques. There were also students in both groups who used the trial-and-error method to deal with the whiteboard examples.

The third phase of the intervention started one week later and lasted a total of four hours-two hours for the experimental group and two hours for the control group.

In the first hour of our intervention in the control group, we solved two equations on the blackboard of the form

$$ax + b = cx + d \tag{3}$$

More specifically, $3x + 4 = 2x + 5$ and $6x + 4 = 5x + 6$ (**Figure 1** and **Figure 2**), by verbally explaining what we did.

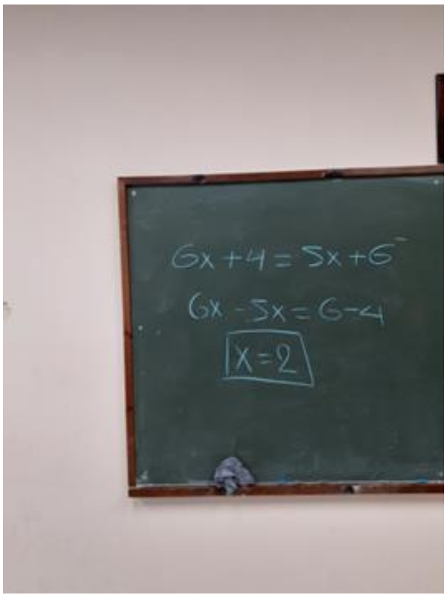

Figure 2. Solving the equation $6x + 4 = 5x + 6$ (Source: Field study)

Figure 3. Solving the equation $3x + 4 = 2x + 5$ (Source: Field study)

The students faced considerable difficulties, with one 9th grader complaining:

> I've been very confused about transferring terms from one part to another. I can't tell when I'm changing signs.

The following week, the second hour-long intervention was conducted in the control group. In particular, we presented and solved the equations:

$$\begin{gathered} 6a - 3 = 5a + 2 \text{ and} \\ 4t + 4 = t + 13 \end{gathered} \tag{4}$$

on the blackboard by going through the steps with the students, who we encouraged to actively participate. In this case, however, the students found it quite difficult to solve the equations since the techniques of changing the sign, transferring terms from one part to another and dividing by the coefficient of the unknown made it quite difficult for them.

The first hour of the third phase of our intervention in the experimental group began with the distribution of the manipulative materials (scissors, coloured markers, paperboard and pencils) to the participants (**Figure 3** and **Figure 4**). We gave exactly the same equations that we had given in the first lesson to the students in the control group. In addition, verbal instructions were given regarding the solving techniques, using numbers of different colours for symbols (e.g., for equal signs) and variables of different colours. In addition, each time they transferred terms from the first to the second part and vice versa, the students held a piece of paperboard with a "plus" or "minus" sign in their hands and changed them with each transfer. The students cut the cards with the numbers and variables with the scissors they had available. Then, they manually moved the numbers and variables from one part of the equation to the other, and when they had finished their solution, they put all the parts of the equations together. The students were very excited about solving the equations, as they viewed it as a game and had much fun.

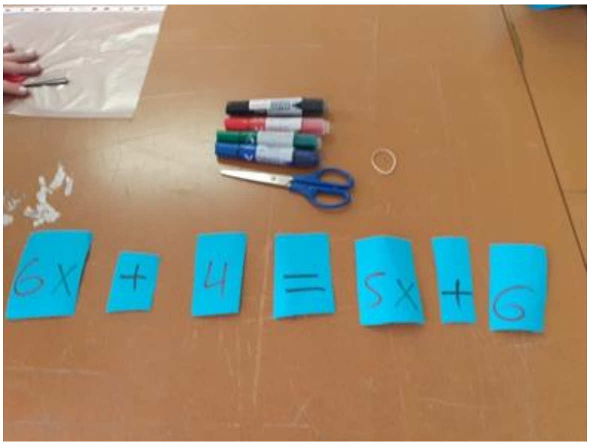

Figure 4. Solving the equation $6x + 4 = 5x + 6$ (Source: Field study)

Table 1. The grades corresponding to each step of the solution process

Group A	20	20	19	19	19	19	18	19	20	20	20	19	18	20	19	20	20	20	20	18
Group B	09	20	02	19	20	09	08	04	14	06	08	18	06	18	01	04	09	04	19	06

In the second hour of our intervention in the experimental group, we gathered all the students again and encouraged them to solve exactly the same equations that we had proposed in the control group using markers of a certain colour for the variables and a different colour for the numbers. The students were happy to cut out the paperboards depicting the terms of the equations, and following this activity, they joined all the pieces of the equations together. In fact, one 9th-grade student spontaneously said:

> I want to do my math lesson with scissors, markers and cardboard from now on. It's very nice.

The fourth phase of the intervention lasted for two hours, with one hour allocated to the experimental group and one hour allocated to the control group. In the control group, we wrote two equations on the blackboard:

$$2x + 4 = x + 6 \text{ and}$$
$$4x + 1 = 2x + 5 \tag{5}$$

and asked the students to solve them in their notebooks. We provided assistance to any student who requested it by going from desk to desk.

In the experimental group, the same equations were written on the blackboard, and the students were asked to copy and solve them in their notebooks. Any student who asked for help was assisted. The manipulative material acted as "scaffolding" for learning to solve first-degree equations of the form "$ax + b = cx + d$". This phase demonstrated that the manipulative materials were effective in aiding learning. Note that in each case, we only helped students when they were stuck or when we deemed it appropriate to take the risk of causing cognitive conflict.

In the fifth and final phase of the intervention, four weeks later, which lasted two hours-one hour for the experimental group and one hour for the control group-we gave the students a test with three equations to solve, without any help from us. However, when we provided the equations to the students, we used the word "activity" and not the word "test" because this would have created stress for the students. Furthermore, there was no time limit on the activity because we knew from our experience that this parameter would stress the students equally. The equations included in the activity were as follows:

$$4x - 2 = 1 + 3x,$$
$$5x + 2 = 3x + 6, \text{ and} \tag{6}$$
$$3x + 3 = 2x + 5$$

The results of the test are discussed below.

METHODOLOGY

Research Participants

The participants of the study were 40 students with dyslexia, who were attending the 8th, 9th and 10th grades of a special vocational high school in Greece.

Table 2. The grades corresponding to each step of the solution process

Steps to solve the equation	Grades
Changing the sign when transferring terms from the first to the second part	1
Changing the sign when transferring terms from the second to the first part	1
Performing operations correctly on the first part of the equation	1
Performing operations correctly on the second part of the equation	1
Finding the correct result after dividing by the unknown coefficient in the first part	1
Finding the correct result after dividing by the unknown coefficient in the second part	1
Dividing by the correct number (if any)	2

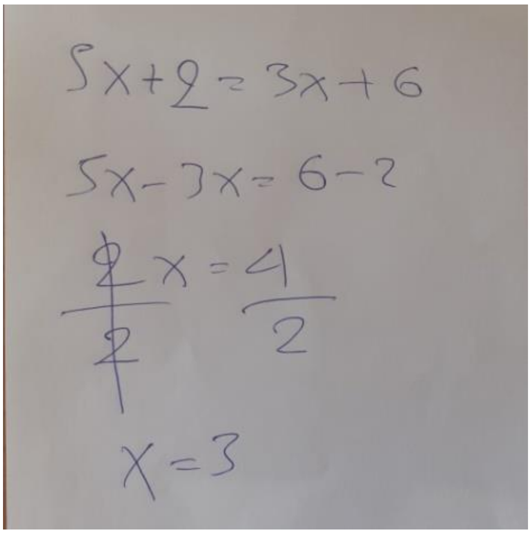

Figure 5. A student's solution showing the error in division due to a misunderstanding of the average value (Source: Field study)

Research Instruments

The tools we used to collect data related to our research topic were: classroom dialogue (which can be considered as a non-directive interview), focused interviews, and a final test.

Data Collection

During our intervention, which lasted approximately two months, we used a mixed research method to collect data, a method that provides a better understanding of the phenomenon under study, compared to the implementation of a single type of research (Guetterman et al., 2020; Timans et al., 2019). In addition, this method appears to be the appropriate one to properly answer the research questions posed, since it provides both quantitative data from the students' tests and from targeted questions provided by the qualitative research. We took seriously into account the students' responses from the dialogue we had with them in class during the first hour of the teaching intervention, we took detailed notes and appropriate photos of all the lessons we did in the two groups, and we evaluated the students' final tests and compared the final scores using the SPSS data analysis program. Although mixed-methods studies are complex, their reliability and validity are well documented (Krawczyk et al., 2019).

Data Analysis

As part of the quantitative research, we collected all the tests, in which there was a prior score for each step. At this point, we named the experimental group "Group A" and the control group "Group B". The scores are presented in **Table 1**.

As shown in **Table 1**, the students in Group A (median=19.5 and interquartile range=1) scored better on the final test than did the students in Group B (median=8.5 and interquartile range=14). A median test was then conducted, which showed that the difference between the teaching method utilizing manipulative materials and the traditional method was statistically significant (chi-square=5.833 and p value=0.008).

In addition, we proceeded to perform a qualitative analysis of the results because we wanted to investigate the type of errors observed in the final test, as well as the points that made it difficult for the students during the equation-solving process. We assigned a specific score to each step of the equation solving, as described in **Table 2**.

In the third equation of the test ($5x + 2 = 3x + 6$) in the experimental group, four students made exactly the same mistake in the division operation to find the solution to the equation, i.e., division by two in the last step (**Figure 5**). Therefore, we conducted separate focused interviews with the four children who made the same error. The children reported that this error was due to the definition of the average value that they were taught in physics class. Specifically, the physics teacher told the students that to calculate the average of two or more numbers, they should add them together and divide the sum by their number. In this context, he gave some examples on the blackboard.

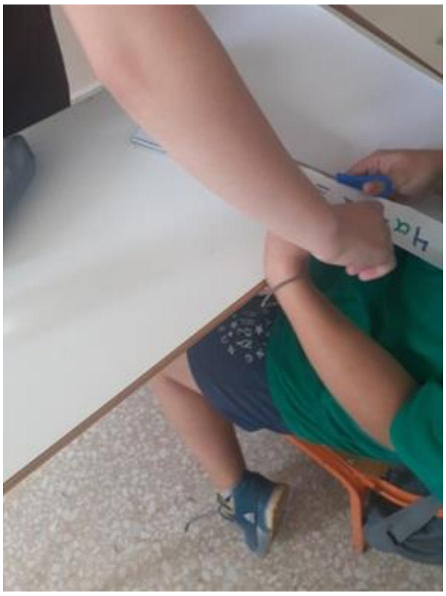

Figure 6. Students make use of the manipulative material (Source: Field study)

Figure 7. Students make use of the manipulative material (Source: Field study)

After rewarding all participants for their efforts, we discussed with the children in the experimental group how they approached the equations in the activity. The children reported that they remembered the steps to solve the equation due to their engagement with the manipulatives. Specifically, one student mentioned:

> For the change of sign, it helped me remember the paperboard we cut out *because I touched it and could move it* from one member to another.

Additionally, the children enjoyed solving equations using manipulative materials such as cutting paperboard with scissors (**Figure 6** and **Figure 7**). They even requested to take home the remaining paperboard to continue their work independently.

When we also examined the third equation in the control group, we found significantly more errors in the steps of solving it. In particular, a large number of children made errors in changing the sign of the first part to the second part and vice versa, in deleting coefficients and in dividing by the unknown coefficient. In this case, focused interviews were also conducted separately with each student in the control group who gave an incorrect answer.

The students reported difficulty in recalling the solution steps presented through traditional teaching methods, which involved written instructions on the blackboard and verbal guidance. Additionally, some students attributed mistakes in division to the definition of average value taught in physics (see **Figure 5**). After encouraging perseverance, we discussed the errors and provided the correct answers.

FINDINGS

As it emerged from the analysis of the data collected, students who were taught first-degree equations using manipulative materials assimilated the solving techniques, scored better on the final test, and developed a positive attitude towards mathematics, compared to those who were taught the same subject using the traditional teaching method.

The findings of this study support the literature suggesting that the use of manipulatives can aid children with dyslexia in gaining a deeper understanding of basic techniques for solving first-degree equations (Delport, 2021; Lafay et al., 2019). Therefore, the findings can be generalized to the teaching of other mathematical units, since the manipulative materials helped students with the specific learning difficulty to understand in depth the related mathematical unit. Our teaching intervention facilitated equal participation in this process, resulting in a high level of satisfaction. This highlights the importance of inclusion in education.

The participants in the experimental group with dyslexia correctly solved the equations presented in the activity, consistent with previous research (Flores et al., 2023; Lafay et al., 2023; Malliakas et al., 2021; O'Rear et al., 2019). Moreover, the children with dyslexia in the experimental group demonstrated increased engagement and satisfactory understanding of the math unit through the use of manipulative materials. This finding is consistent with previous literature (Johnston, 2019; Meke et al., 2019).

DISCUSSION, SUGGESTIONS AND LIMITATIONS

This study examined a two-month teaching intervention designed to teach first-degree equations of the form $ax + b = cx + d$ to children with dyslexia. Our experience in secondary and tertiary education has shown that students with dyslexia face difficulties in mathematics when taught using traditional methods. Therefore, we used manipulative materials, such as paperboard, scissors, and coloured markers, and measured the impact of this intervention.

The results of the research indicated several *positive outcomes*:

a) The manipulatives, acting as scaffolding, helped students understand the process of solving first-order equations of the form $ax + b = cx + d$ and to achieve the learning objectives set by the curriculum,

b) Students' engagement in the educational process as well as their attitudes towards the equations improved when manipulative materials were used, and

c) The implementation of the project for the children who worked with manipulative materials fostered a spirit of cooperation between them and gave them confidence.

However, our research has several *limitations*. The most significant of these are as follows:

a) We presented the rule of changing signs as an axiom. We did this because we believed that children with dyslexia, who face difficulties in understanding written language, would find it challenging to apply the properties of addition (such as associative and identity properties) and the cancellation law,

b) The equations were solved without a time limit. This was done intentionally as children with dyslexia can become highly stressed and may react unpredictably (e.g., crying, getting angry, or giving up) when there is a specific time limit for completing a task, and

c) It was uncertain whether the students in the experimental group would remember the methodology for solving a first-degree equation after an extended period of time, e.g., after three years. However, it is expected that a quick repetition would aid in the retention of the key points of the solution in comparison to the students in the control group.

The research question we posed, namely, whether teaching first-degree equations based on the use of manipulatives can produce better learning outcomes than traditional methods for students with dyslexia, was answered positively. From the data collected and analysis, it appeared that the students in the experimental group utilized the solving techniques and correctly solved the equations given to them in the final test compared to the students in the control group.

Based on the characteristics outlined above, it is suggested that manipulatives could be used to teach certain sections of the Algebra and Geometry curriculum in high schools, such as identities, areas, and comparing triangles. Currently, many teachers still use the traditional teaching model of writing mathematical concepts on a blackboard and asking students to copy them mechanically without always ensuring comprehension or allowing time for processing.

Additionally, the use of manipulatives by teachers when teaching mathematics to children with dyslexia can help them overcome some of their language difficulties. Children with dyslexia may struggle to comprehend mathematical techniques due to difficulties in understanding written language. The use of manipulative materials can help them overcome some of these challenges.

Furthermore, teaching with manipulative materials can promote the active and equal participation of all children in the educational process, promoting inclusive education. When implementing an activity using manipulative materials, children cooperate with each other, which ensures that all children are involved in the learning process and helps to prevent the phenomenon of child marginalization in the classroom.

The novelty of the research is that the use of appropriate manipulative materials for teaching mathematical units to students with dyslexia seems to be able to strengthen their mathematical background and enhance their active engagement in learning. More specifically, this article contributes to the introduction of teaching methods using appropriate manipulative materials in order to help students with dyslexia acquire basic mathematical skills. As already mentioned, research on practices and methods for teaching mathematics to students with dyslexia is limited worldwide and this article provides a new perspective for these students.

Based on our recent experience with Byrne's Euclid (https://www.c82.net/euclid/), which we successfully used to teach elements of Euclidean geometry to children with specific learning difficulties (Rizos & Foykas, 2023a), as well as similar experiences and suggestions for the utilization of ICT (Rizos et al., 2017; Rizos & Gkrekas, 2023), we believe that using educational software such as GeoGebra (https://www.geogebra.org/) or Wordwall (https://wordwall.net/en) to teach first-grade equations can lead to positive learning outcomes.

CONCLUSION

Research on solving first-order equations in children with dyslexia and other learning difficulties both in Greece and worldwide is limited. This study aims to contribute to filling this gap. The effectiveness of using manipulative materials combined with ICT in teaching the equation $ax + b = cx + d$ for children with or without dyslexia remains to be studied in the future. This article presents a didactic method for teaching first-degree equations that has not been tried before.

As indicated by our research, the use of relevant manipulative materials when teaching first-degree equations to high school students with dyslexia, socialization difficulties and emotional disturbances helped them comprehend the solution steps and achieve the learning goals set by the curriculum. The participating students studied and solved first-degree equations by cutting, colouring, touching and moving paperboard pieces, thus increasing their involvement in the learning process and improving, to some extent, their attitudes towards mathematics.

At the conclusion of our teaching intervention, it was noted that students who utilized manipulatives were able to solve first-degree equations in a paper-and-pencil environment. Additionally, we observed that they had gained self-confidence and developed a spirit of cooperation, both of which are essential qualities for their future beyond school.

The restrictions of the study included the lack of a time limit for solving the equations, the rule of changing signs as an axiom and the doubt that students will remember the techniques they acquired after years. Future research could be related to the simultaneous use of manipulative material and ICT in the teaching of mathematics to students with dyslexia attending inclusive classes in high schools.

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