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The effects of a teacher training program on neuroeducation in improving reading, mathematical, social, emotional and moral competencies of secondary school students. A two-year quasi-experimental study☆

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ABSTRACT

Teacher training is directly related to the quality of the educational process. In recent years, the contributions of neuroeducation have begun to be valued as an important element to improve teachers' skills. The current study has the objective of measuring the effectiveness of a teacher training program in neuroeducation through the improvement of three key competencies, reading, mathematical, social, emotional and moral competencies in secondary school students. This quasi-experimental study was carried out over two years, in which there have been two experimental and one control group, with 209 participants from all three schools in the same town of Spain (53.2% girls and 46.8% boys). The subjects are from all the classes of 1st grade of Secondary Education in the pre-test (M = 12.18 years old, SD = .45). After carrying out a repeated-measures ANOVA, the results show a significant effect of the intervention on reading competence, mathematical competence and empathy (social and emotional area) between the experimental groups and the control one. These findings invite us to think about the potential of neuroeducation in schools and have implications for educational policies, teacher training and school practice.

Los efectos de un programa de formación docente en neuroeducación en la mejora de las competencias lectoras, matemáticas, sociales, emocionales y morales de estudiantes de secundaria. Un estudio cuasi-experimental de dos años

Palabras clave:
Neuroeducación
Formación de profesores
Competencias lectora, matemática, sociales, emocionales y morales
Empatía
Educación Secundaria

RESUMEN

La formación docente está directamente relacionada con la calidad del proceso educativo. En los últimos años, los aportes de la neuroeducación han comenzado a valorarse como un elemento importante para mejorar las competencias del profesorado. El presente estudio tiene como objetivo medir la efectividad de un programa de formación docente en Neuroeducación a través de la mejora de tres competencias clave, lectora, matemática, y socioemocionales y morales en estudiantes de secundaria. Este estudio cuasi-experimental se ha llevado a cabo durante dos años, en los que ha habido dos grupos experimentales y uno control, con 209 participantes de los tres colegios de la misma localidad de España (53,2% niñas y 46,8% niños). Los sujetos son de todas las clases de 1º de Educación Secundaria en el pretest (M = 12,18 años,

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DT = ,45). Tras realizar un ANOVA de medidas repetidas, los resultados muestran un efecto significativo de la intervención sobre la competencia lectora, la competencia matemática y la empatía (área social y emocional) entre los grupos experimental y control. Estos hallazgos invitan a pensar sobre el potencial de la neuroeducación en las escuelas y tienen implicaciones para las políticas educativas, la formación docente y la práctica escolar.

Introduction

The need to incorporate brain research advances into education was already anticipated in the 1960s by Gaddes (1968), when he approached learning problems from a neuropsychological perspective. Since then, numerous authors (Dehaene, 2020; Shonkoff, 2017; Tokuhama-Espinosa & Nouri, 2020) have pointed out the importance of knowing the brain's functioning as a starting point to improving learning. Educational neuroscience or neuroeducation is an emergent new field that combines this research in neuroscience, psychology, and education to adapt the findings on neural mechanisms to educational practice (Thomas et al., 2019) with the aim of improving all the teaching-learning processes involved (Martínez-González et al., 2018). Explaining and understanding the brain processes supposes a complete view of learning, which could optimize pedagogical innovations to adequate teaching more effectively to the characteristics of individuals and their specific needs (Fischer et al., 2010). Neuroscience helps understand the brain as an interconnected circuit that works in a network. Therefore, it is crucial to consider all the processes involved simultaneously, from physical aspects, instinctual, socioemotional, to cognitive processes (Thomas et al., 2019). Including its research in learning implies assuming the double perspective, both of the teacher and the student. In this sense, the contributions of neuroscience can reinforce teacher training, providing them with knowledge about the brain that ultimately helps design more suitable learning contexts for students (Dweck, 2015).

Regarding students, one of its objectives is to create mechanisms that enable them to adapt their behavior successfully to the demands of their social and cultural environment (Frith et al., 2011). The purpose of education is the integral development of the individual, and one of the most important challenges of the school community is to improve the performance of key competencies, especially three basic ones, literacy, mathematical, social, emotional and moral competencies. These three key competencies are considered essential to developing the rest (UNESCO, 2015).

As part of literacy competence, reading competence is one of the pillars of education since it facilitates the understanding of reality, the construction of knowledge, and self-regulation (Gnaedinger et al., 2016). It can be defined as the ability of people to use texts to achieve their goals in a useful way in the society around them. It is directly related to the individual, their intellectual and their social and emotional capacities (OECD, 2003). Mathematical competence is also considered one of the key pillars of education since mathematical ideas and concepts are tools to act on reality. The OECD (2003) defines it as the ability to identify and understand the role of mathematics in the world. This competence includes aspects related to the organizational capacity and the manipulation of information to solve problems by reasoning appropriately. Social, emotional and moral competencies encompass the ability to manage one's own emotions, interpersonal interactions and socially accepted behaviours, in ways that can simultaneously benefit oneself and others, at school, in the workplace, and all other relationships (Álamo et al., 2020; Zych et al., 2018). They also play an important role in learning since they are usually related to students' self-awareness about their learning processes, and it is reflected in the willingness to assume and persist in challenging tasks (Dweck, 2015). Due to the importance of these three competencies in learning, the impact of an intervention based on neuroeducation should be perceived in the development of all of them.

Neuroeducation applied in the classroom to develop students' competencies

There seems to be agreement on the importance of including the knowledge of the brain in education (Dehaene, 2020; Tokuhama-Espinosa & Nouri, 2020). However, its translation to this field has not been solved yet, as it implies, assuming the multifactorial nature of learning in any attempt to integrate it into real settings (Jolles & Jolles, 2021).

It is important to emphasize that neuroscientific research does not provide exact rules that can tell the teachers what to do in every situation. Instead, the knowledge of the physiology and functioning of the brain helps the teacher be better prepared to face diversity in the classroom, facilitating attention in inclusive education (Jolles & Jolles, 2021). Therefore, one of the main problems that neuroeducation faces is considering simultaneously the different aspects of children's functioning and behavior, because as Kandel (2019) points out, brain and mind are inseparable, and any problem can modify all the brain processes: from perception, attention, memory, emotion, and among others, awareness.

In this context, there is a need to determine what teachers should know about neuroscience, and especially how to use it, while keeping their own educational goals and, simultaneously, checking to what extent it may affect students' outcomes (Dehaene, 2020). Regarding what teachers should know about mind, brain, and education, Tokuhama-Espinosa and Nouri (2020) evaluate the previous research conducted by the International Delphi Panel, confirming six basic universal principles, equal for every human being, that every teacher should know: all human brains are made up of unique combinations of genetics and life experiences; each individual's brain is differently prepared to learn; previous experience influences new learnings; there are constant changes in the brain due to experience; neuroplasticity occurs all the life, though there are differences by age; memory and attention systems are essential for learning.

Assuming the relevance of teaching training in this field, the precepts of neuroeducation have already been used in different formats. The positive impact on teachers of a single workshop of 15 hours on foundational neuroscience has been ratified in different studies (Howard-Jones et al., 2020; McMahon et al., 2019). On his part, Thul (2019) analyzed the influence of a one-semester teacher-training neuroeducation course that altered the attendees' perceptions of learning with positive results. Arwood and Merideth (2017) also provide evidence of the potential gains from incorporating brain-based instruction, shifting the focus from teacher-led pedagogy to a framework that views learning from the child's perspective. Some other researchers give evidence of specific improvements for the students, as Green-Mitchell (2016), who used a neuroeducation model to study the connection between the functional acquisition of the language of 10 students from alternative schools and their pro-social and moral development. A blended approach was carried out by Anderson et al. (2018), who observed

the change in teachers' beliefs and behaviors and simultaneously improved math achievement of 5th-grade students. Although these are inspiring studies, most of them lack the simultaneous description of the teachers' program and the evaluation of the students' outcomes. In this sense, a recent scoping review on neuroscience applied to teacher training found only ten papers that included a detailed description of the neuroscience course that enabled a comprehensive evaluation of the research. One of them was conducted in secondary school through classroom observations (Privitera, 2021).

Considering the above points, the primary need that justifies this study is the scarcity of quasi-experimental studies that measure the implementation of a global model based on neuroscience in a real learning context through the change in the basic competencies of the students.

Hence, the general objective of this article is to study the impact on reading, mathematical, social, emotional and moral competencies of students of Compulsory Secondary Education, derived from the application of a teacher-training program based on neuroeducation. Specific objectives are: (1) To study the impact of a global teacher training program in neuroeducation on the three previously mentioned competencies in a real learning context of secondary education; and (2) To compare the impact on the previously mentioned competencies between experimental and the control groups.

The hypotheses raised in this study are: (1) Reading, mathematical, social, emotional and moral competencies develop more after implementing a global training program for teachers in neuroeducation; and (2) These competencies are more developed in the experimental groups than in the control group.

Method

Participants

The sample was selected by convenience, including 209 participants (53.2% girls and 46.8% boys) from all three public secondary schools of the same town of Spain with two class groups in each school. It is located in a rural area whose economy depends mainly on agriculture, with a small immigrant population, which barely reaches 2%. The subjects are from all the classes of 7th grade in the pre-test (M = 12.18 years old, SD = .45) and 8th in post-test (1st and 2nd of Compulsory Secondary Education in the Spanish School System). The schools, with the same socioeconomic context, were divided into three groups according to the intervention: experimental 1 (n = 72, 51.4% girls and 43.1% boys.), experimental 2 (n = 58, 48.2% girls and 51.8% boys.) and control (n = 79, 55.7% girls and 44.3% boys). The sample is different for each of the variables analyzed, since those cases that did not perform the pre or post-tests in any of the measured competencies have been excluded (29.76% of average on each scale, because of particular absences and mainly because of the students repeating grades in both years).

Instruments

Data were collected using two instruments: an exam with two tests (reading and mathematics competence) and a questionnaire about social, emotional and moral competencies. The exam was composed of two open-access tests of PISA (Program for International Student Assessment) (OECD, 2016): one on reading comprehension and the other one on mathematical competence. The tests were respectively *Lake Chad* and *Chat*. Each test consists of a common text and/or image, followed by five questions in the case of reading comprehension and two questions in mathematical competence. These tests assess the development of students' competencies through their ability to extrapolate what they have learned in school to real-life situations, evaluating students' knowledge to solve daily tasks. Student performance is estimated through the successfully overcome tasks. The questionnaire is made up of a first part that collects information on the basic student's information (age, sex and school), and a second part focused on social, emotional and moral competencies: *Social and Emotional Competencies Questionnaire* (Zych et al., 2018, Spanish version) consists of 16 items (about self-awareness of emotions, self-management of emotions to achieve goals, social-awareness and prosocial behaviour, and responsible decision making according to ethical values) with good internal reliability (pretest: α = .78, Ω = .79, AVE = .34, CR = .89; postest: α = .78, Ω = 73, AVE = .39, CR = .91). The *Basic Empathy Scale* (Jolliffe & Farrington, 2006); validated in Spanish by Villadangos et al. (2016). This scale of empahy, understood as part of this social and emotional dimension (Llorent et al., 2020), is made up of 20 items, with adequate reliability (pretest: α = .64, Ω = .75, AVE = .26, CR = .87; postest: α = .75, Ω = .82, AVE = .32, CR = .90). The *Moral Emotions Scale* (Álamo et al., 2020; Zych et al., 2019) is made up of 5 items and has adequate reliability (pretest α = .79, Ω = .83, AVE = .52, CR = .81; postest: α = .77, Ω = 75, AVE = .51, CR = .84). These are scales with 5-point Likert-type responses ranging from 1 (1 = strongly disagree to 5 = strongly agree).

Design and procedure

This is a quasi-experimental study carried out with pre-post-tests and control and experimental groups. The researchers selected three schools interested in participating in the research, and the necessary authorizations were obtained from the schools. The pre-test questionnaire (Time 1) was passed to all research participants at the beginning of the 2017/2018 academic year, and the post-test at the end of 2018/2019 (Time 2). The intervention was carried out by the teachers involved in the experimental group during class hours. The curriculum of the subjects (competencies, objectives, contents, and assessment) was developed as expected, although there was an innovation in methodology derived from the training in neuroeducation. The teachers remained in permanent contact with the researchers during the intervention to facilitate the adequate application of the program in neuroeducation. The intervention was not implemented in the control group, and the curriculum was followed as usual, without any connection with the neuroeducation perspective. The questionnaires were completed individually by the students, as one more class activity, during school hours. The teachers themselves always carried out data collection. The researchers collected and scored the evaluation tests. The schools were informed that the data obtained would be used for scientific and anonymous purposes only, and all the ethical national and international standards were followed, according to the Ethical Committee of the blinded university.

Intervention

The intervention consisted of training the teachers in neuroeducation as a prior step to the methodological change in the classroom. The variables finally assessed were the impact on the students' learning outcomes. Over two years, three teachers participate in this study including the neuroeducation program in their respective subjects. The two experimental conditions are derived from the different number of teachers participating in each experimental group and their further training. No teacher engages in the neuroeducation program in the control school.

- *Experimental 1*. One teacher, who is an expert in neuroeducation, develops the program in the English subject, being the only par-

ticipating teacher out of the 12 teachers in the groups of students. Therefore, the two group classes of Experimental 1 have received the program since the first day of the 2017-18 academic year.

- *Experimental 2*. Two teachers (one for English, and one for Geography and History), without any previous knowledge of neuroeducation, participated in this school. The two group classes received the program to a lesser degree than Experimental 1. Both teachers have been acquiring training in neuroeducation throughout the two years of the intervention program.
- *Control*. In these two group classes of this school, no teacher has received training in neuroeducation, so there was no intervention in the control group. The curriculum did not change and was developed as usual.

The teacher-training program was carried out over two years with biweekly meetings lasting for two hours, with a total of 60 hours of group meetings, completed with individual private study of the material. It was divided into two phases. The first year (2017-18) teachers were trained in the knowledge of the neural bases of learning. The second year (2018-19) training was provided in the knowledge of neuroeducation applied to the methodology in the classroom. Parallel to this training, the teachers included the knowledge acquired in a practical way in their classrooms and their respective subjects (English, and Geography and History). The material used for teacher training is collected in two neuroeducation books (Caballero, 2017, 2019) (see Chart 1).

Phase I. Teacher training in the basic knowledge of the brain and its influence on learning

In this first phase, teachers were introduced to fundamental knowledge of the neurological bases of learning and its classroom implications (see Chart 2). The book *Neuroeducación de profesores y para profesores* was used (Caballero, 2017). Its meaning for the educational process is established through a practical orientation with examples taken from the author's daily practice as a teacher, establishing links between neuroscience and the skills that need to be developed in the educational field.

Phase II. Application of the holistic methodology in the subjects of the curriculum

For the training on the global methodology, which allows attending to the classroom diversity, the book *Neuroeducación en el currículo* was used (Caballero, 2019). Its writing and publication took place throughout the second year of the teacher training. The impact on the teachers' opinions and the outcomes in their pedagogical practice was considered in a continuous process of feedback between theory and application in the real context, which was crucial to designing this part of the program.

It includes the *Brain-Based Holistic Methodology* (BRAIM) and its application. The universal neurological basis of learning is complemented with specific knowledge of neurodiversity that helps the teacher attend to diversity in the ordinary classroom through a methodological change, which guarantees individual attention when teaching any subject in the curriculum. See Chart 3 for a summary of the content discussed.

The BRAIM model was complemented with specific attention to the development of executive functions. *The Integrated Model of Executive Functions and Metacognition,* that was also used in this program, is based on the idea that there is a general domain (executive functions) always in connection with the cognitive and emotional aspects regulated by metacognitive processes. In this way, the model is divided into three parts that include, making learning visible ("clarifying the reasons of the brain"), developing skills strategically ("providing practice"), and making appropriate decisions ("generating learning for life"). Although used in the training program between 2017-2019, this model was finally published in a third book that completes the trilogy in 2021 (Caballero et al., 2021).

Data analysis

Cronbach's alpha, McDonald's omega, Composite Reliability and Average Variance Extracted have been used to analyze the reliability of the questionnaires. Frequencies, means, and standard deviations were calculated to analyze the sample. Thus, the two moments of their evaluation are compared in each school for the different variables. The effect of the intervention program in the school was calculated with the Cohen's *d* through the Campbell Collaboration Calculator. The impact of the teacher-training program on the development of reading, mathematical, social, emotional and moral competencies was studied through the repeated-measures ANOVA test. The development of each variable was calculated from the difference of all the variables between the pre-test and post-test in all the research schools. The differences between the schools and the differences by pairs in reading, mathematical, social, emotional and moral competencies were also analyzed by schools. Except for Cohen's *d*, all analyses were carried out with the SPSS 25. The pairwise deletion was applied to missing data.

Results

Descriptive data were analyzed in the pre-test showing no differences among the schools in *reading* ($F = 2.10$, $p = .13$) and *mathematical competencies* ($F = 2.26$, $p = .11$). Differences were found in the area of *social, emotional* and *moral* competencies. In *social and emotional competencies* ($F = 10.81$, $p < .001$) experimental 1 has a higher score than experimental 2 and the control schools. The *empathy* was different among schools ($F = 3.21$, $p = .04$), but the post-hoc tests do not show specific differences between groups. *Moral* emotions show significant differences among schools ($F = 3.20$, $p = .04$), where experimental 1 has higher scores than the control. Descriptive data were analyzed in the pre-test, and post-test tests in each of the variables analyzed, and they were compared for each school. As shown in Table 1, there is a significant development in *reading competence* in the three schools, with a higher effect size in the experimental groups. *Mathematical competence* has improved significantly in the two experimental schools. The *social and emotional competencies* scale shows a significant but negative change in experimental 1 and control groups. However, *empathy* experimented a significant and high improvement in the three schools, with a higher effect size in the experimental groups. *Moral emotions* do not show any significant change in the three groups.

In the three schools there is a significant improvement in *reading competence* between the pre-test and the post-test ($F_{1,164} = 112.21$, $p < .001$, $\eta^2_p = .406$). Moreover, in turn, there are significant differences between the three schools in these improvements ($F_{2,164} = 8.67$, $p < .001$, $\eta^2_p = .096$) (see Figure 1). In the pairwise comparisons of schools, significant differences are identified between the experimental 1 and the control group ($F_{1,189} = 13.38$, $p < .001$, $\eta^2_p = .102$) and between the experimental 2 and the control group ($F_{1,109} = 10.37$, $p < .01$, $\eta^2_p = .087$). There are not significant differences between the experimental groups ($F_{1,101} = 0.26$, $p = .61$, $\eta^2_p = .003$).

Regarding *mathematical competence* in the three schools, there is a significant improvement between the pre-test and the post-test, ($F_{1,158} = 36.32$, $p < .001$, $\eta^2_p = .187$). Also, there were significant differences between the three schools in these improvements

Chart 1. Structure of the teacher-training program on neuroeducation

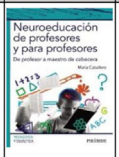
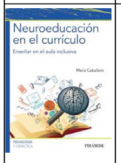
2017-2019 Progressive acquisition of knowledge/ Progressive application of the recently acquired knowledge in the ordinary classroom							
	Teachers' training Two teachers				Application in classroom Two subjects		Students' competencies
Phases	Timing of teacher´s training	Material for teacher´s training	Content	Teacher's learning	Application in the classroom	Timing in the classroom-	
1 2017-18	Biweekly meetings – two hours 100 hours approx.		Neurological bases of learning and classroom implications	Progressive acquisition of knowledge about the brain Universal keys	Progressive development of all cognitive processes Positive emotional context	1rst ESO 4+4 hours per week – 37 weeks	Pre-test RC-MC-SEC Beginning 1st ESO
2 2018-19			Special Needs *Brain-based holistic methodology (BRAIM)*	Neurodiversity Methodology and method in the ordinary classroom	Working in levels in the ordinary class to attend diversity	2nd ESO – 3+3 hours per week - 37 weeks	Post-test RC-MC-SEC End 2nd ESO

Table 1
Descriptive and comparison pre-and post-test of reading, mathematical competence, social and emotional competencies, empathy, and moral emotions

		Pre-test *M* (*SD*) *n*	Post-test *M* (*SD*) *n*	*d* (95% *CI*)
Reading competence	Experimental 1	1.92 (1.20) 72	3.54 (1.19) 56	**-1.35 (-1.74; -0.97)**
	Experimental 2	1.83 (1.06) 58	3.43 (1.06) 47	**-1.51 (-1.94; -1.07)**
	Control 1	2.20 (1.09) 74	2.88 (1.49) 69	**-0.52 (-0.86; -0.19)**
Mathematical competence	Experimental 1	0.41 (0.63) 70	1.20 (0.76) 55	**-1.14 (-1.53; -0.76)**
	Experimental 2	0.53 (0.67) 53	0.81 (0.68) 47	**-0.42 (-0.81; -0.02)**
	Control 1	0.66 (0.75) 73	0.81 (0.79) 69	−0.19 (-0.52; 0.14)
Social and emotional competencies	Experimental 1	66.13 (7.80) 61	62.61 (6.10) 51	**0.50 (0.12; 0.87)**
	Experimental 2	60.45 (8.04) 49	60.72 (7.71) 43	−0.03 (-0.44; 0.38)
	Control 1	61.06 (6.21) 69	58.73 (8.53) 60	**0.32 (0.03; 0.67)**
Empathy	Experimental 1	62.70 (7.80) 63	74.17 (8.83) 54	**-1.39 (-1.79; -.98)**
	Experimental 2	60.75 (7.20) 48	75.15 (9.86) 39	**-1.70 (-2.19; -1.20)**
	Control 1	62.52 (7.38) 58	69.87 (9.30) 55	**-0.88 (-1.26; -0.49)**
Moral emotions	Experimental 1	22.62 (3.37) 63	22.54 (2.32) 56	0.03 (-0.33; 0.39)
	Experimental 2	21.57 (3.19) 54	21.24 (3.22) 46	0.10 (-0.29; 0.50)
	Control 1	21.04 (4.19) 73	20.40 (4.14)65	0.15 (-0.18; 0.49)

($F_{2,158} = 10.52$, $p < .001$, $\eta^2_p = .118$) (Figure 2). In the comparisons by pairs of schools, significant differences are also observed between experimental 1 group and control group ($F_{1,117} = 20.95$, $p < .001$, $\eta^2_p = .152$) and between both experimental groups ($F_{1,94} = 11.39$, $p < .01$, $\eta^2_p = .108$). There are no significant differences between experimental group 2 and control group ($F_{1,105} = 0.34$, $p = .56$, $\eta^2_p = .003$).

Social, emotional and moral competencies only changed significantly in the dimension of *empathy*. Assessing the *social and emotional competencies* between the three schools, no significant difference is observed in their learning trajectory between the pre-test and the post-test ($F_{1,129} = 3.72$, $p = .06$, $\eta^2_p = .028$). In the same way, there are not significant differences by pairs between the three schools in these changes ($F_{2,129} = 0.18$, $p = .84$, $\eta^2_p = .003$) (see Figure 3). Complementing the social and emotional area, *empathy* was analyzed. This variable shows, significant change between pre-test and post-test ($F_{1,118} = 128.03$, $p < .001$, $\eta^2_p = .52$), but in the comparison by pairs between the three groups no significant differences appeared ($F_{2,118} = 2.26$, $p = .11$, $\eta^2_p = .037$) (see Figure 4). *Moral emotions* are not significantly modified between pre-test and post-test ($F_{1,150} = 1.03$, $p = .31$, $\eta^2_p = .007$), and there are not significant differences by pairs between the three groups ($F_{1,129} = 0.14$, $p = .87$, $\eta^2_p = .002$) (see Figure 5).

In the pairwise comparisons of schools, no significant differences were identified between experimental 1 and the control group in *social and emotional competencies* ($F_{1,95} = 0.08$, $p = .78$, $\eta^2_p = .001$), in *empathy* ($F_{1,88} = 1.78$, $p = .19$, $\eta^2_p = .020$) and in *moral emotions* ($F_{1,109} = 0.26$, $p = .61$, $\eta^2_p = .002$). Nor between experimental 2 and the control school in *social and emotional competencies* ($F_{1.87} = 0.37$, $p = .55$, $\eta^2_p = .004$) and in *moral emotions* ($F_{1,101} = 0.05$, $p = .83$, $\eta^2_p < .001$), but there are significant differences in *empathy* ($F_{1,71} = 4.79$, $p = .03$, $\eta^2_p = .063$). And no significant differences were found between both experimental schools in *social and emotional competencies* ($F_{1,76} = 0.10$, $p = .76$, $\eta^2_p = .001$), *empathy* ($F_{1,76} = 0.57$, $p = .45$, $\eta^2_p = .007$) and *moral emotions* ($F_{1,76} = 0.08$, $p = .78$, $\eta^2_p = .001$).

Discussion

The discussion is raised from the double perspective that guides this study. On the one hand, the students' learning results are ana-

Chart 2. Neurological bases of learning and classroom implications

Integrate the knowledge of the brain in the classroom by understanding the reasons for behavior Teaching as the student learns		
Objective	Contributions of neuroscience	Classroom implications
	Physical variables	
Considering neurofunctional maturation and the influence of physical aspects on learning.	Appropriate physical activity, as well as the alternation of activity and active stops, favors cerebral blood flow, greater oxygenation, as well as the activation of hormones that finally promotes greater attention, and in short, better brain functioning.	• Take care of physical aspects: light, air, water, and basic needs. • Activate body and mind through movement. • Favor adequate sleep hours, a balanced diet, and sufficient hydration.
	Affective-motivational variables	
Create a positive emotional context.	Integrate mirror neurons into the classroom. Create a context in which positive emotions and experiences are associated with learning. Achieve clear rules of behavior with equally clear consequences.	• Reinforce appropriate behaviors in the appropriate way. • It is not enough to say do it! We must teach how to do it. • Generate patterns, habits ... • Enhance positive beliefs (Pygmalion effect, Growth Mindset.) • Create an atmosphere of trust and appropriate emotional ties • Treat error as a part of the learning process. • Propose challenging, motivating and novel activities • Use emotions as allies, without judging the person ... • Encourage the knowledge and mastery of one's own emotions. • Link social and emotional development to intellectual development.
	Social variables	
Achieve greater acceptance and respect for diversity, greater collaboration, social commitment, and the reduction of conflicts.	The myelination process is associated with collective play. Mirror neurons and peer interaction develop executive functions through the assumption of norms and rules.	• Peer learning and tutoring • Collaborative work • Favor the development of empathy as a pillar of emotional learning.
	Cognitive variables	
Develop the cognitive processes that allow to carry out any academic task and in real life.	• Attention • Perception • Memory • Thought • Language • Intelligence • Creativity Assuming the functioning of the brain as an interconnected circuit The development of the management frontal cortex together with the management of unconscious processes favors the development of all cognitive processes	Favor attention and perception. • Surprise students with new knowledge. • Organize times appropriately, alternating moments of attention, activity, and reflection. Favor the management of memory and forgetfulness. • Short-term memory • Long-term memory •Working memory • Regulate the effect of review and recovery Teach to think. Use language in an operational way. Approach the intelligence construct from multiple perspectives. Encourage creativity
	Executive functions	
Management of their own resources.	Know the neurophysiological development, in this case, the maturation of the prefrontal cortex, responsible for these functions. Promote adequate self-regulation as a basis for autonomous learning.	Empower and direct voluntary attention Inhibit impulses. Planning towards goals. Cognitive flexibility to adapt the processes. Self-regulation of emotions. Memory management: working memory Enhance memory versus recognition. Manage emotions. Learn to manage thinking (metacognition self-instructions ...).

Chart 3. Brain-based holistic methodological model (BRAIM)

General content	Specific content	General objective
Inclusive school and attention to diversity	Special needs (SN)	Know the SN with the highest prevalence in the classroom • Dyslexia • ADHD - Attention Deficit Hyperactivity Disorder. • Borderline intelligence. • ASD-Autism Spectrum Disorder • Gifted students…
Methodology	Multi-level class	Adapt our way of teaching, as well as the contents to the different levels, capacities, preferences, and aptitudes of each person.
	Cooperative work	Encourage greater collaboration between equals, including all students in the ordinary classroom.
	Physical, Social, emotional, and cognitive aspects.	Development of all aspects of the person generating responsibility, autonomy, and self-confidence in the student.
	Communicative skills	Development of communication skills.
	Meaningful learning	Give responsibility and autonomy to the student. Generate meaningful learning.
Teaching method tips	Teach to understand	Understanding the task
	Help remember	Get material organized so that it guarantees optimal learning. Strengthen neural connections Generate a permanent memory of the new knowledge acquired.
	Assess learning	Individual profile assessment. Formative / reflective assessment. Summative evaluation.

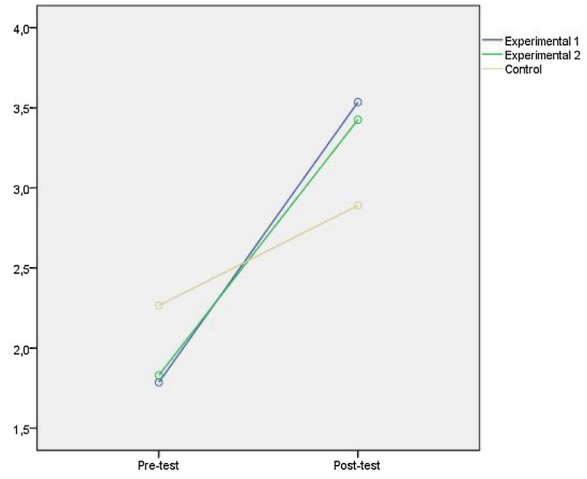


Figure 1. Pre-post-tests of reading in the three schools.

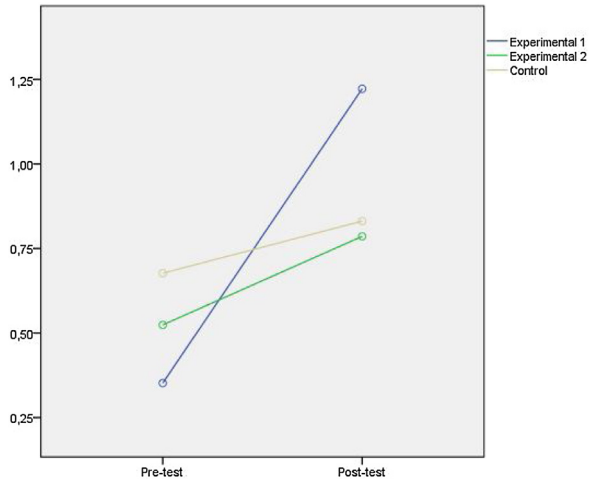


Figure 2. Pre-post-tests of math competence in the three schools.

lyzed by assessing the change in the reading, mathematical, social, emotional, and moral competencies; and the comparison among experimental and control groups. On the other hand, those analyses facilitate examining the proposed teachers' training program based on neuroeducation.

Students' competencies

The development of reading, mathematical competence, and empathy has been significantly positive in the three schools, indicating that schooling has a positive effect on these variables. Regarding the general objective of observing the extent to which neuroeducation can increase key competencies in school practice, there has been a significant improvement in reading and mathematical competencies and empathy. This is also found when the starting point and the effect are considered for each student, after the application of the program. These results reinforce the idea of the effectiveness of including the principles of neuroeducation in the classroom (Jolles & Jolles, 2021), and confirm the effectiveness of inserting the contributions of neuroscience in teacher training as a preliminary step for improving key competencies (Anderson et al., 2018).

Although the objective has not been achieved in social, emotional, and moral competencies, empathy, a part of this area, has improved, raising new questions that require specific work to be clarified (Llorent et al., 2020). On the one hand, the greater devel-

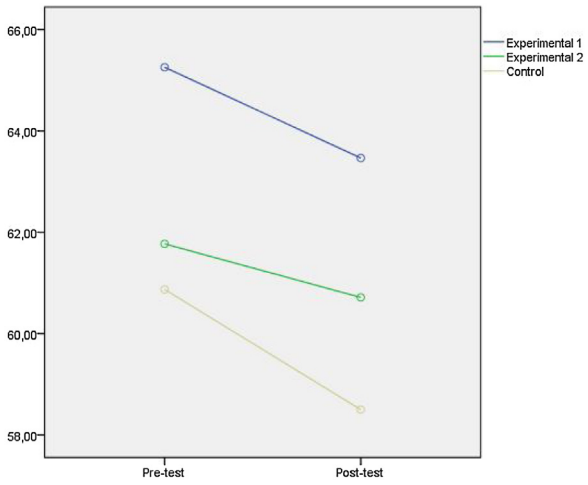


Figure 3. Pre-post-test of social and emotional competencies in the three schools.

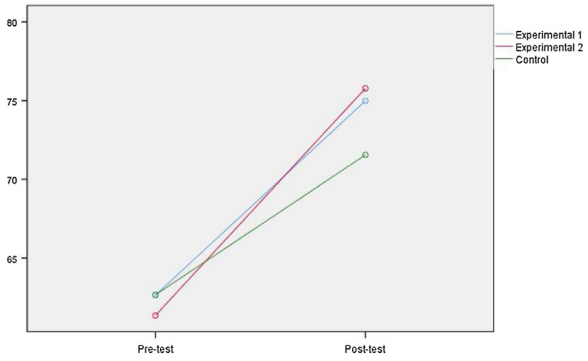


Figure 4. Pre-post-test of empathy in the three schools.

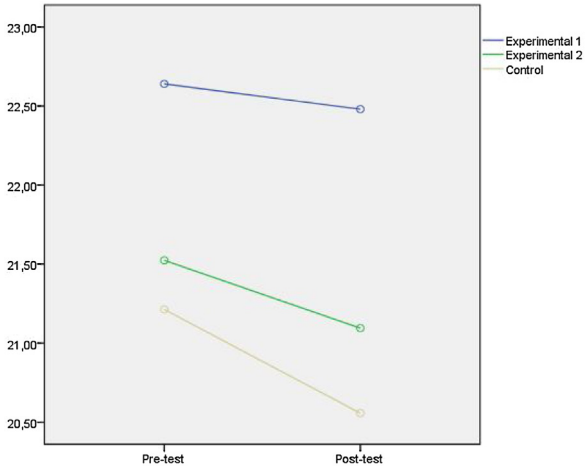


Figure 5. Pre-post-tests of moral emotions in the three schools.

opment of reading competence, mathematical competence and empathy could be more related to the development of executive functions and subsequent self-regulation skills than to positive emotions, as shown by Arwood and Merideth (2017). This may suggest the need to develop the three aforementioned competencies explicitly, with specific social and emotional training for students, since it could indicate that the far transfer of some skills to others is scarce (Kassai et al., 2019). On the other hand, instead of a real reduction in these competencies, this decrease might be justified by a more realistic self-evaluation, derived from the natural development of the frontal lobe in adolescence and, subsequently, more realistic self-knowledge (Frith et al., 2011). Maybe methodology based on cooperative learning might have been more effective to develop social and emotional competencies, as current studies show (González-Gómez et al., 2021; Llorent et al., 2022). In both experimental groups, the improvement in empathy might indicate that executive functions may influence the student's ability to regulate behavior and cognition through adequate inhibitory control (Xie et al., 2021). It may also lead to the conclusion that the same cognitive flexibility that facilitates the regulation of reading and reasoning processes through metacognitive skills (Gnaedinger et al., 2016) may also influence social and emotional competencies such as empathy, facilitating social interactions. These results suggest the necessity to develop all competencies from a neurological point of view, assuming the influence of executive functions and metacognitive processes in reading literacy, mathematical, social, emotional and moral competencies. Thus, more research is required to shred light in these areas.

Training program in neuroeducation

The advances in brain research in education have been taken up by institutions (OECD, 2016) and researchers (Thomas & Ansari, 2020; Tokuhama-Espinosa & Nouri, 2020) as a starting point to improve teaching practices in the classroom. The shortage of quasi-experimental studies in a real context (Privitera, 2021) makes the implementation of this comprehensive program based on neuroscience especially valuable. In this sense, one of the main contributions of this study has been the effective curricular integration of a holistic methodology, through a global model of teacher training in neuroeducation (BRAIM) that has allowed to address the multidimensional character of education, as suggested by Thomas et al. (2019).

Another important contribution of this research has been "building a bridge between neuroscience and education" through the creation of a specific material for teacher training from three complementary perspectives: the knowledge of the brain (Caballero, 2017), the methodology that allows attending to diversity in the inclusive classroom (Caballero, 2019), and finally, the development of executive functioning, based on the visibility of self-regulation processes and learning itself (Caballero et al., 2021). Evidence derived from this research provides a clear relationship between the visibility of learning mechanisms for both teachers and students and the improvement of key competencies, especially in secondary education when greater self-control and self-management are required.

The current study implies an advance in the incipient line of neuroeducation research from an integrating vision, with educational and political implications in the curricular development of education. Neuroeducation should be another piece of the complicated puzzle of the teaching-learning process and education (Jolles & Jolles, 2021; Murphy, 2016), contributing to teachers' professional development in a practical way by creating a teacher training program based on neuroeducation that helps to attend diversity in the regular class.

Even though this study makes interesting contributions to the field of education, certain limitations must be recognized. Firstly, not having discriminated the differential performance of students with special educational needs, even when the program had included special training on neurodiversity. Secondly, the sample size is not very large. However, it includes all the students in 1st/2nd of secondary education, from the three schools in a Spanish town, more participants and other localities are required to strengthen the results. Moreover, it must be considered that the teacher training program was only used with one or two

of all the teachers in these groups (there are usually more than ten teachers per class group). This low teacher participation rate invites to think about the Neuroeducation program's great potential. Finally, another intermediary variable needs to be considered in this research related to the teacher, because their role is determined by their training and skills but, also, by their attitude to pedagogical innovation, as the result of a combination of desirable personality traits and permanent professional growth (Jazukiewicz, 2020).

There is no doubt about the relationship between the quality of teachers and students' performance (Hattie, 2008; Hattie & Yates, 2013). An important role in this process is played by teacher-student interactions (Llorent et al., 2021), the types of activities initiated and supervised in the classroom, the knowledge of one's cognition (Caballero, 2019; Roebers, 2017) and the learning process itself (Frith et al., 2011). In this regard, the knowledge provided by the program seems to have modified the teachers' attitude to pedagogical innovation, changing the way they perceive students' learning and implementing more individual instructional strategies that ultimately improve students' performance.

Now more than ever, teachers need answers with scientific rigor that guide us as leaders of the educational change, combining emotion and knowledge in the right balance, "making science the art of teaching". To achieve it, neuroeducation offers a potent tool, offering clues to understand better the mind of both, the teacher and the learner. As Eric Kandel (2019) suggests, neuroscience can improve our understanding of thought, feelings, memory, etc. and who knows if, in the future, a unified theory of mind will provide the keys to holistic, personalized and inclusive education.

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