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Schweizerische Zeitschrift für Bildungswissenschaften 45 (2023) 3, S. 307-319

Quellenangabe/ Reference:
Croset, Marie-Caroline; Courtier, Philippine; Gardes, Marie-Line: The impact of the Montessori education on early number learning in french pre-schools - In: Schweizerische Zeitschrift für Bildungswissenschaften 45 (2023) 3, S. 307-319 - URN: urn:nbn:de:0111-pedocs-288009 - DOI: 10.25656/01:28800; 10.24452/sjer.45.3.7

https://nbn-resolving.org/urn:nbn:de:0111-pedocs-288009
https://doi.org/10.25656/01:28800

in Kooperation mit / in cooperation with:

Schweizerische Zeitschrift für Bildungswissenschaften
Rivista svizzera di scienze dell'educazione
Revue suisse des sciences de l'éducation

http://www.rsse.ch/index.html

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Varia

The impact of the Montessori education on early number learning in french pre-schools

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There is a paucity of research on Montessori Education's impact on learning, especially in France. In this article, we present a study comparing the development of early number learning in preschoolers through Montessori Education with "conventional" education in France. Using a cross-sectional design and random assignment of children, we evaluated 131 French preschoolers (aged 5-6) enrolled at the same public school following either Montessori Education or conventional education over three years. Students were evaluated with the Woodcock-Johnson III (WJ-III) Applied Problems sub-test and a test designed by researchers in math education. The Montessori curriculum was associated with outcomes that were comparable to the conventional curriculum on math.

According to recent reviews, studies into the impact of the Montessori Education method on development and learning are rare, and for the most part, conducted in the United States (Lillard, 2012; Marshall, 2017). Among the few existing studies, some show the results of the Montessori method to be superior to other methods (e.g. Besançon & Lubart, 2008; Denervaud et al., 2020; Lillard et al., 2017; Lillard & Else-Quest, 2006; Reed, 2008). Others show similar or even unfavorable results of the method compared to other methods (e.g. Ansari & Winsler, 2014; Lopata et al., 2005). These contradictory results could be due to two categories of limitations, the first being methodological limitations such as variations in the quality of implementing the Montessori method, the absence of "active control groups" (i.e., benefiting also from an different type of intervention than the experimental group), or inadequate sample sizes, or the second category relating to Montessori's conception of development, such as ignoring the role of language (Gentaz & Richard, 2022).

Our research team investigated the impact of the Montessori method during the preschool years (3 to 6 years old), as defined by the French system. In a previous article (Courtier et al., 2021), we focused on evaluating executive control (such as inhibition and flexibility), social competencies (such as understanding the knowledge, beliefs, and desires of the other) and academic achievements (especially in language and mathematics). In this article, we review the results concerning academic achievement only in mathematics. Our study used a cross-sectional design and random assignment of children, with a sample of public-school students aged 5-6 from disadvantaged backgrounds. We compared the mathematical performance of preschoolers who had received 3 years of Montessori pedagogy with those of students who had not, using two tests: a psychometric test, and a test specific to the study, developed by our team and based on a didactic theoretical framework. This test enables a detailed assessment of the skills mobilized when the preschooler constructs the concept of number.

1. Theoretical Background

1.1. Montessori Method

The Montessori Method of education was developed during the first half of the 20th century by an Italian doctor, Maria Montessori. She first became interested in the role of sensorimotor education in the development of children with intellectual disabilities. Eventually she began working with underprivileged children with typical development. In 1907, she set up her own preschool classroom in Rome and applied her teaching methods; it became her laboratory, where she established the basics of the Montessori Method (Montessori, 2015, 2016). From her observations, Maria Montessori defined and proposed her guiding principles for child development, which she used as a basis for her philosophy and educational method.

Her first principle claimed that children are born with an "absorbent mind" (Montessori, 2015, p. 48), and a motivation to learn. Second, she posited that the child passes through "sensitive periods", during which they are particularly receptive to understanding specific learning domains easily and rapidly. Finally, she asserted that

2023 Swiss Journal of Educational Research 45 (3), 307-319

DOI 10.24452/sjer.45.3.7 ISSN 2624-8492
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not all children progress at the same speed through these sensitive periods, therefore each child must be allowed to activate their sensitive period at the most appropriate time for them.

In the classroom, these principles translate into various specifications concerning the environment available to the children and the role of the teacher. First, classrooms have mixed age groups; for example, in the preschool environment, children range from 3 to 6 years old. Second, children move from one self-chosen activity to another, they choose how long they spend on each activity, who they would like to work with, and where they would like to work. A child can repeat each activity as many times as they wish during the three years of Montessori Education. Third, the material has some specifications; materials automatically provide feedback, and only one set of each activity is available per classroom. The materials are laid out on small shelves in the classroom, organized according to level of difficulty and grouped by educational domain. These domains include practical life, sensorial, language, mathematical, geography, biology, music and visual arts (Montessori, 1934a, 1934b). Fourth, the role of the educator is to present each activity to the children and ensure that the students choose activities of an appropriate level of difficulty. Finally, the activities are presented almost exclusively in small groups or one-on-one.

1.2. Studies Investigating the Impact of the Montessori Method on Learning Mathematics in Kindergarten

The effects of Montessori pedagogy on child development may be contradictory or moderate, but Demangeon's recent meta-analysis of 33 studies (Demangeon et al., 2023) shows that, in terms of academic success, this pedagogy appears to produce significant and positive effects. Only a few studies have specifically compared the mathematical advancement of children in Montessori programs with children in conventional educational programs in preschool, and their results showed mixed outcomes (e.g., Laski et al., 2016; Lillard & Else-Quest, 2006; Mix et al., 2017; Reed, 2008; Wexley et al., 1974). As our study focuses on math and preschool, we present a few studies on the impact of Montessori pedagogy on success in math before 2nd grade, and try to highlight their limitations.

In 1974, Wexley and colleagues compared children aged 3 to 5 from disadvantaged backgrounds in a Montessori program with children in a conventional day care program. They used a matched pairs design, considering age, sex, race, socio-economic status, number of parents in the home, and number of years spent in an educational context. These groups were also compared to two control groups (one group of children from an advantaged background and the other from a disadvantaged background) who were not enrolled in any program. Cognitive development was evaluated using the Weschler Preschool and Primary Scale of Intelligence (WPPSI) (Weschler, 1967) and other cognitive tests. This study showed that the students enrolled in the Montessori program had better results in arithmetic than the control group (not enrolled in any program) from a disadvantaged background. However, the Montessori group was no different from the children in the daycare program, or the control group (not enrolled in any program) from an advantaged background.

In 2006, Lillard & Else-Quest conducted an evaluation of the Montessori Method by using a lottery-based allocation system. All parents who participated in this lottery were interested in enrolling their child in a Montessori program. The families not drawn from the lottery were enrolled in other education systems and assigned to a control group. In total, American children of 5 years old– and 12 years old – were compared on a series of cognitive measures. For the measure of mathematics knowledge, the group used the Applied Problems subtest from Woodcock-Johnson III (Woodcock et al., 2001). They observed a significant difference in favor of the Montessori group for the 5-year-old children, but not the 12-year-olds.

In 2008, Reed compared understanding of calculation and place-value concepts among children in 1st grade through 3rd grade enrolled in Montessori schools and conventional schools. The students in the Montessori classrooms performed better than the students in the conventional classrooms on the two tasks concerning place-values of a digit. This was particularly true for the 1st grade group, where 71% of Montessori classroom students succeeded in one of the tasks, as compared to 13% of conventional classroom students. In the addition tasks, presented by line to the students, the students in the Montessori program used more sophisticated techniques. No significant difference was found for the addition tasks completed in columns. The author interpreted the results as demonstrating a superior utilization of the principles of order of operations among the students enrolled in Montessori programs.

More recently, Lillard (2012) conducted a study on children aged 3-6, questioning the importance of Montessori implementation fidelity. In this research, she observed the impact of pedagogy on various skills; in terms of mathematics, she showed that children from high fidelity schools perform better than those from lower fidelity schools (offering materials other than those promoted by the Montessori pedagogy). In this study, however, it is worth noting that the sample sizes were quite small and there was no randomization of children.

Laski et al. (2016) obtained similar results in a longitudinal study investigating understanding of place-values and arithmetic in 150 children enrolled in Montessori and non-Montessori educational contexts. The children were tested (time point 1) at the end of kindergarten for a first cohort, and at the end of 1st grade for a second cohort. The same students were tested again two years later (time point 2), either in 2nd grade for the first cohort, or 3rd grade for the second cohort. At time point 1, the students were tested on their understanding of the place-value system and on their performance of calculating addition problems. At time point 2, they were evaluated on their performance of resolving comparison problems in symbolic writing and various math problems. The authors found that at time point 1, the children in Montessori programs had better results on the task evaluating understanding of the place-value system, but no differences were visible two years later.

Mix et al. (2017) evaluated students aged 5 and 7 enrolled in Montessori or conventional programs from the age of 3. There were no significant differences between these two groups on the decimal numeral system or division at the age of 5. However, the students enrolled in the Montessori program fared better than the students in the conventional group at the age of 7. No differences were found between the groups at age 5 or 7 in a number line estimation task (i.e., ability to place numbers on a physical line). It should be noted that the teachers in the Montessori group had been trained by the AMI (Association Montessori Internationale).

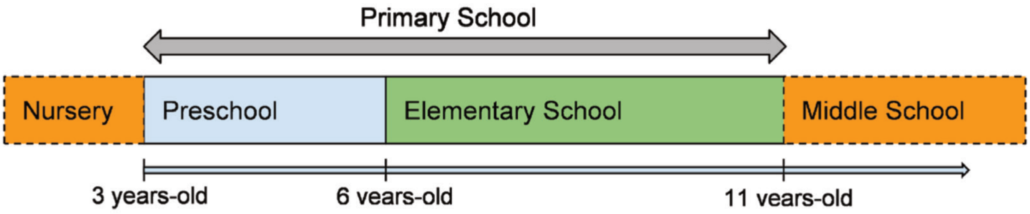
Finally, Denervaud et al. (2020) evaluated scholastic development in a cross-sectional study of kindergarten. They showed that Montessori kindergarteners outperformed children from traditional schools in academic outcomes. A single competence was used to assess the numeracy skills of kindergarteners, solving 10 arithmetic word problems. In terms of these skills, the Montessori Education groups produced positive results. One of the limitations of this study is that the Montessori classes were all in private schools, whereas the traditional schools were public.

In conclusion, these studies seem to indicate that compared to conventional methods of education, the Montessori Method generally leads to better performance in tests of certain mathematical competencies in primary school. However, these results should be interpreted with caution. There have been few studies, all of which have multiple methodological limitations. For example, the assignment to experimental and control groups in most of these studies was not randomized (except for Lillard & Else-Quest, 2006). Even in this study, all parents were supportive of their children's enrollment in the Montessori system, which limits the external validity of the study to the general population of public school students. Some of the papers cited give no information about how well the schools included in the studies adhered to the principles of the Montessori method (Laski et al., 2016; Reed, 2008). Furthermore, some studies tend to overgeneralize the results of tests that measured a limited range of mathematical competencies (Denervaud et al., 2020). Finally, apart from Denervaud's research, all these studies were conducted in one world region only, namely the United States. Therefore, in the following section, since our study was conducted in France, we will specify the unique characteristics of early childhood education in France.

1.3. French school system

In France, primary school (for 3- to 10-year-olds) includes the stages of preschool (for 3- to 6-year-olds) and elementary school (for 6- to 10-year-olds) (Figure 1). Preschool, as understood in France, is free, attended by nearly all children from the age of 3, and has recently become mandatory as of the 2019 school year. In other words, all children in France between the age of 3 and 6 years old are expected to attend school. Preschool (ages 3-6) is therefore an integral part of the education system in France: teachers working in preschools have received the same training as teachers at elementary level. A preschool teacher teaches all disciplines of study and is responsible for a single class consisting, on average, of 25 students. This class may include multiple levels or groups. Every teacher refers to the educational program, which is set by a board of academics, researchers, education specialists, and elected representatives of the country and wider society (Ministère de l'Éducation Nationale et de la Jeunesse [MEN], 2023).

Figure 1
Primary School in France



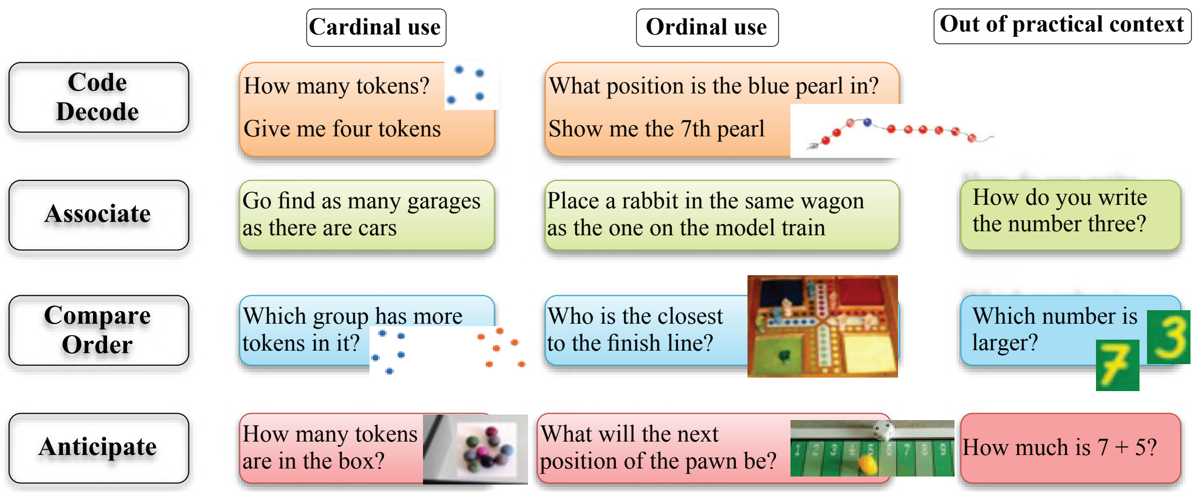
This compulsory “preschool” - equivalent to pre-school, pre-kindergarten and kindergarten in the United States, and reception and year 1 in the United Kingdom - is a characteristic of the French system. The French government, bolstered by low rankings of French students in international assessments such as the PIRLS and the PISA, is prioritizing school attendance in preschool years as essential for student achievement. These aspects of the French system - mandatory school attendance at the age of 3, the same training program for preschool and elementary school teachers, and the existence of an educational program establishing nationwide expectations of students – mean that our research group can study children as young as 3 years old in a classroom setting. Indeed, since children in other countries rarely attend school from the age of 3, it is quite rare for educational research to be carried out in real-life learning conditions.

1.4. Teaching numbers in France

During the preschool years in the French public school system, the objective of the mathematics curriculum is for each child to understand that a number can express both a quantity of a set and a rank in a list. Learning numbers is based on understanding quantity, both written and spoken codification, oral number sequencing, and counting (MEN, 2023). The French mathematics curriculum is based on research in mathematics education and recommends a balance between a concrete approach with manipulative and conceptual understanding of numbers. It is similar to the Common Core State Standards for Mathematics (CCSSM) in early childhood in the US, which are based on a “balanced approach that includes both understanding and fluency and generally moves in each math domain from meaning making and supporting understanding of concepts to a focus on practice to gain fluency to prepare for the next level of conceptual learning” (Clements et al., 2019, p. 13). Like CCSSM in early childhood, learning numbers in French preschool precedes the introduction of the decimal number system. Students are not given learning activities centered on place value; the topics of grouping and exchange, recognizing the connection between the position of a digit, and the number of groupings are first tackled in elementary school, not preschool (Margolinas & Wozniak, 2014). No time is dedicated at this stage to mathematical operations.

In a didactic study, Croset and Gardes (2020, 2020) mapped the early understanding of numbers. This study is based on various research results in math education (Fayol & Seron, 2005; Fischer, 1990; Fuson, 1988; Margolinas & Wozniak, 2012, 2014). Eleven types of tasks were identified to test the different areas of knowledge necessary for early understanding of numbers. These task types were categorized into three groups based on the use of the number in the given setting; the use can be cardinal, meaning the number is used as a measure of quantity, ordinal, meaning the number is used as a measure of position, or the number can be used out of a practical context (i.e., without support of magnitude). For each type of use, tasks can require coding or decoding actions (Fayol & Seron, 2005), association of numbers, comparison of numbers, or anticipation of the result of an action. Examples are given in Figure 2. These eleven types of tasks characterize the mathematical field we consider in this study, henceforth referred to as *‘number construction’*. We will use this conceptual framework to describe what we have assessed as competencies in this study. The advantage of this framework - over that of the National Research Council (2009) or the National Council of Teachers of Mathematics (2023) - is that it is adapted to the French school system and, by virtue of its construction, gives a complete overview of the skills involved in learning the concept of number.

Figure 2
Map of number construction development in preschool (Croset & Gardes, 2020)



2. Present study

In summary, various features distinguish our study from previous studies in this field. First, the present study was conducted in a French public school, in a disadvantaged area. Second, students enrolled in the study followed the same type of education for three years, both in the Montessori classrooms as well as the conventional classrooms. Children were assigned to one of these classrooms on entering school at age 3. All children included in the analyses of this article followed the same pedagogical approach during the three years of schooling, and their teachers were trained to teach the entire age range, from 3- to 6-years-old. In studies on monitoring learning achievement, there is generally some attrition of students (moving, absence during assessments (see below), etc.). For this reason, we collected data on 3 cohorts of students; each cohort followed the same pedagogy for 3 years and was tested at the end of this period, in June 2017, 2018, and 2019 respectively. Third, the control group and the experimental group were in the same school and the group assignment was randomized. Finally, the educational and didactic competencies and perspectives of the research team allowed us to clearly outline the specific tasks used to understand the concept of numbers in each pedagogical approach. In this article, we aim to closely analyze what skills are learned, and to investigate the following research question: Are there differences between the Montessori and conventional teaching methods concerning the completion of each type of task described in Figure 2?

3. Method

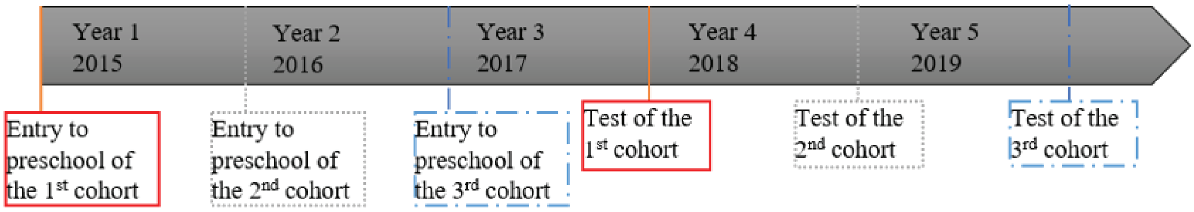
3.1. Participants and procedure

We evaluated 131 French preschoolers enrolled at the same public school: 53 children were taught according to the Montessori method (27 girls), and 78 children in a control group (40 girls) were taught with the conventional method used in French public schools. Three cohorts of students were tested in June 2017, 2018, and 2019 respectively. The data were collected over 5 years to increase the number of participants in the same school (see Figure 3). The experiment was approved by the local school board and conducted in accordance with the ethical standards established by the Declaration of Helsinki.

Initially, 160 students were eligible to be included in the study. Of these 160 students, 29 were excluded because parental consent was not given (n = 10), they changed education program (n =12), were not fluent in French (n = 3), had a diagnosed disability (n = 3) or were related to a staff member (n = 1). All the children retained for the study followed three years of the same type of education, either Montessori or conventional. Furthermore, of the 131 students who remained, two students were excluded from certain tasks because of absence or refusal to complete the task.

Figure 3

Chronology of the study



The school is in a disadvantaged area (the school comes under the French 'Reinforced Priority Education Network') and has multiple classrooms of children aged 3 to 6. There are two types of classrooms in the same school: multi-age Montessori classrooms (3-, 4- and 5-year-olds), and conventional classrooms with maximum of one or two age groups (3- and 4-year-olds or 4- and 5-year-olds).

Some teachers already occupied their post in the school at the start of the research, and therefore stayed for the five years of the experiment, while others were in the post for just one year. Also, some teachers worked in their classrooms full-time, and others part-time (so that some classes, whether Montessori or conventional, had two teachers each week). In addition, three teachers were on maternity leave over the course of the project and were therefore replaced for part of the year. None of the teachers in the Montessori classrooms were trained in an AMI (Association Montessori Internationale) center at the beginning of the experiment. They held a degree from a conventional teacher's college (minimum requirement in France), and initially were largely self-trained in Montessori Education only. By the end of the study, however, one teacher in the Montessori-public group had completed AMI training.

To ensure that our findings would be reproducible and generalizable to other contexts, we quantified the fidelity of implementation of the Montessori pedagogy in the preschool of our study using a scale based on the characteristics and activities of both Montessori and conventional classrooms (see Courtier et al., 2021). Overall, the Montessori group scored relatively high on the characteristics (above 80% fidelity) and activities scales (above 86% fidelity), whereas the conventional classrooms scored relatively low (above 20% fidelity on characteristics and above 5% fidelity on activities scales). For information, an accredited Montessori School obtains 92% on characteristics and 83% on activities scales. We therefore obtained a high fidelity of the implementation, and ensured that the two groups were very different from the point of view of applied pedagogy.

The teachers randomly assigned the children to their classrooms on enrollment in the school. The students were tested individually at the end of preschool, after three years of one type of education (conventional vs. Montessori). At the time of testing, students in the Montessori classes were on average 5.94 years old (SD = 0.28), while students in the conventional classes were on average 5.98 years old (SD = 0.29). The ages of the two groups did not differ significantly, $t(129) = -0.65$; $p = 0.52$. For more information, see Courtier et al. (2021).

3.2. Measures

The students were evaluated with the Woodcock-Johnson III (WJ-III) Applied Problems sub-test (Woodcock et al., 2001). This subtest was translated by our team into French. The test consists of 63 items of increasing difficulty; one point was awarded for each item successfully solved therefore the score could range from 0 to 63. After six consecutive errors, the test was stopped. This test was chosen because of its use in prior studies, especially Lillard & Else-Quest (2006), Lillard (2012) and Lillard et al. (2017). The accompanying manual states that the test is a measure of quantitative reasoning, or mathematical knowledge and competencies (Woodcock et al., 2001). However, matching items on the test to the concepts on the map in the theoretical background of this paper (Figure 2) allows us to determine that the first 30 items of the test only evaluate coding/decoding (11 tasks) and additive problem solving (11 tasks). There are no items which test comparing numbers, ordinal use of numbers, or construction of an equivalent collection. This test does not consider the complexity inherent in mathematical skills, as described in Figure 2. This ties in with the results of Peteers (2020) who analyzed this and other tests designed to evaluate basic mathematics skills with various theoretical frameworks, such as Zareki-R (Dellatolas & Von Aster, 2005) and Tedi-Math (Van Nieuwenhoven et al., 2001). Using didactical analysis criteria, the authors highlight the shortcomings of numerical cognition tests in relation to what is taught and knowledge of mathematics education.

Therefore, in addition to this test, we created the Mathematical Didactic Diagnosis Test (Appendix 1), based on the map of the development of number construction in preschool (Figure 2) to evaluate the expectations of a French public preschool. The first task, essential for counting, asks the student to recite their numbers as far as they can (T1). This task is a continuous variable, as compared to the other tasks presented below. Seven other types of tasks were chosen from the eleven presented in Figure 2. Tasks related to comparisons and anticipation of positions, or calculation of numbers out of context were not retained for the assessment because they fell outside the expectations of the program of national education in France. The tasks included in this assessment are concrete, using tokens that the children can manipulate themselves. We present the tasks below, showing in brackets their connection with the elements presented in Figure 2 (see appendix 1 for details).

Determine the cardinal (number of elements) of a set (T2)

Construct a set with a given cardinal (T3) [Code/Decode, cardinal use]

Solve simple arithmetical problems (addition or subtraction of an element from a set) (T4) [Anticipate, cardinal use]

Construct a set of the same number of elements as another set (T5) [Associate, cardinal use]

Compare the cardinal of two sets (T6) [Compare, cardinal use]

Name written numbers (T7) [Code/Decode, use numbers out of context]

Identify the rank of a given element in a list (T8) [Code/Decode, ordinal use]

Identify a ra*nk in a list and reproduce it in another list (T9) [Associate, ordinal use]*

For tasks T2, T3, T4, T5, T6, and T9, we proposed varying subtasks of increasing difficulty. For example, in task T2, the children first identify the cardinal of a set of 3 tokens, then 7 and finally 11. At the end of these subtasks, a child's score can range from 0 to 3, based on their success in identifying the cardinals. The score is then averaged to achieve a minimum score of 0 and a maximum score of 1. In total, the children were tested on 33 subtasks divided into 8 tasks, giving them a total score between 0 and 8.

Children were tested individually in a quiet room at their preschool. The tests were administered by different testers (graduate students, research assistants, and undergraduate students) over five sessions of approximately 15 to 20 minutes. The order of sessions was randomized on a child-to-child basis. No feedback was given to children during testing, and children, teachers, and parents were not informed of the results for the duration of the study. Teachers and parents were unaware of the test content until data collection had been completed.

3.3. Analyses

The data were analyzed using both frequentist and Bayesian inference tests. First, we compared the total scores on the two tests (Applied Problems and Mathematical Didactic Diagnosis Test) and on each of the tasks in the Mathematical Didactic Diagnosis Test using frequentist independent t-tests or Chi squared tests. We used a significance threshold of $p = .05$. The effect size was quantified using Cohen's d.

However, since frequentist statistical methods do not allow us to invalidate the presence of a difference between the two groups of students when the effect is not significant, we also completed the analyses using Bayesian statistical methods. These allowed us to evaluate the measure of strength of evidence using the Bayes factor (BF) in favor of the alternative hypothesis of a difference between these groups (H1), as compared to the null hypothesis of an absence of a difference between the groups (H0) for each test.

We used Jeffreys (1961) guidelines for interpreting BFs: a $BF < 3$ is considered anecdotal evidence, a $3 < BF < 10$ is considered substantial evidence, a $10 < BF < 30$ is considered strong evidence, a $30 < BF < 100$ is considered very strong evidence, and finally, anything above 100 ($100 < BF$) is considered extremely strong evidence. The BF is indicative of the likelihood that the data are more probable under the alternative hypothesis than the null hypothesis (i.e., BF10), or under the null hypothesis than the alternative hypothesis (i.e., BF01). Given the contrasting information found in the literature on the impact of the Montessori Method, these Bayesian tests were completed using default priors. The analyses were performed with Jamovi software (Jamovi Project, 2019).

4. Results

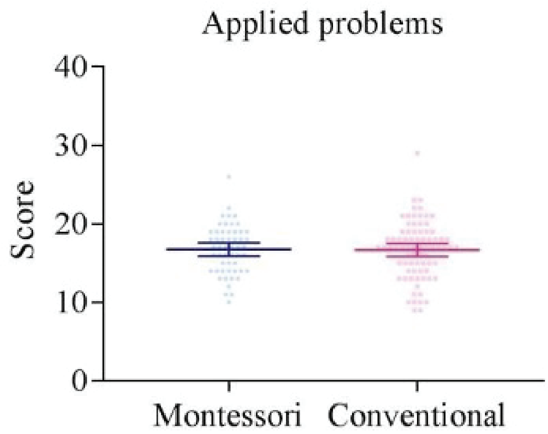
4.1. Applied Problems test

53 students in Montessori classrooms and 77 students in conventional classrooms were tested with the WJ-III Applied Problems subtest. The students in the Montessori classroom had a mean score of 16.74 (SD = 3.14)

and the students in the conventional classroom had a mean score of 16.66 (SD = 3.67). A Student's t-test showed substantial evidence for the null hypothesis, t(128) = 0.12, p = 0.91, d = 0.02, BF01 = 5.26 (Figure 4).

Figure 4

Score out of 63 on the Applied Problems test by pedagogical method



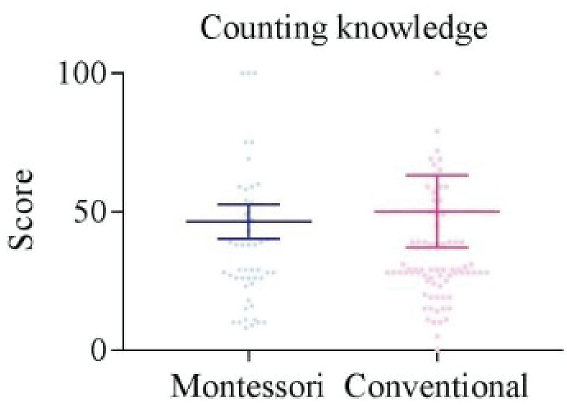
4.2. Mathematical Didactic Diagnosis Test

52 students in Montessori classrooms and 76 students in conventional classrooms were tested with the Mathematical Didactic Diagnosis Test. Of the 131 students who remained, two were excluded from this Didactic Test because of absence or refusal to complete the task. The counting knowledge score (T1, continuous variable) was dissociated from the quantitative knowledge score (T2-T9) to facilitate interpretation.

Regarding the first task (T1), which evaluated the stable capacity to count, the mean was 46.38 (SD = 44.73) for students in the Montessori classroom and 50.08 (SD = 113.84) for students in the conventional classroom. A Student's t-test showed substantial evidence for the null hypothesis t(126) = -0.22, p = 0.82, d = -0.04, BF01 = 5 (Figure 5).

Figure 5

Score of counting knowledge by pedagogical method.[1]



[1] Six data points greater than 100 do not appear on the figure to ensure it remains legible. The data points are at 102, 201, and 256 in the Montessori group, and 121, 201, and 999 in the Conventional group.

The Montessori group obtained a total mean score of 5.82 (SD=1.17) out of 8 for tasks 2 through 9, while the conventional group obtained a total mean score of 6.08 (SD=1.11) out of 8. A Student's t-test showed anecdotal evidence for the null hypothesis, t(126) = -1.27, p = 0.21, d = -0.23, BF01 = 2.5.

Since the results of T2 through T9 contributed individually to the total score reported above, the individual results for each of these tasks are reported below (Table 1).

Table 1

Results by task on the Mathematical Didactic Diagnosis Test

Task	Mean		Hypothesis test	BF
	Montessori	Conventional		
T2	0.79 (0.27)	0.78 (0.26)	t(126) = 0.30, p = 0.77 , d = 0.05	BF01=5
T3	0.84 (0.29)	0.87 (0.26)	t(126) = -0.78, p = 0.44, d = -0.14	BF01=4
T4	0.73 (0.29)	0.71 (0.29)	t(126) = 0.32,p = 0.75, d = 0.06	BF01=5
T5	0.26 (0.36)	0.35 (0.38)	t(126) = -1.32, p = 0.19, d = -0.24	BF01=2,38
T6	0.95 (0.15)	0.97 (0.12)	t(126) = -0.62, p = 0.53, d = -0.11	BF01=4,35
T7	0.98 (0.12)	0.97 (0.10)	t(126) = 0.51,p = 0.61, d = 0.09	BF01=4,55
T8	81%	86%	χ^2(1 ; N = 128) = 0.51, p = 0.48	BF01=2,44
T9	0.46 (0.33)	0.57 (0.31)	t(126) = -1.92, p = 0.06 , d = -0.35	BF10=1.01

In conclusion, the Student's t-tests and the Chi squared test indicated substantial evidence for the null hypothesis between the means for tasks 2, 3, 4, 6, and 7. Meanwhile, t-tests and Chi squared tests for tasks 5, 8, and 9 did not allow us to draw conclusions about the presence or absence of a significant difference between the means of the two groups (they showed anecdotal evidence for the null or alternative hypothesis).

5. Discussion

This study shows that there is no evidence of a difference in mathematics test performance at the end of the preschool years between the groups of students who were taught using the Montessori Method compared with conventional pedagogical methods. These results are consistent with the results of Ansari & Winsler (2014) who tested a large sample of pre-schoolers from low-income backgrounds on cognitive tasks such as counting. The same is true of the study by Lopata et al. (2005) on a large sample of children which shows no significant difference in favor of Montessori pedagogy on mathematical skills.

These results were obtained with an experimental protocol, with the presence of a control group. First, we have a randomized group distribution, without any parental intervention. The parents chose the school for its location, and not for its pedagogical practices. In addition, children were randomly assigned to one of the pedagogies. In Lillard & Else-Quest's study (2006), parents entered their children in a lottery for their children to attend a Montessori school. The parents were therefore clearly invested in school choice for their child, and most likely in their child's education in general as well. Thus, parental involvement could explain the difference in results between the Montessori students from this study as opposed to our study. Secondly, interventions into real-life learning context inevitably raise questions about the fidelity of implementation of educational programs (Fixsen, 2005). Lillard (2012) outlined that implementation could vary greatly from one class to another. In our study, we quantified the fidelity of implementation of the Montessori pedagogy as described above. Since the experiment was conducted in the same school, contamination effects could have occurred. This was not the case: Montessori classrooms were still far more faithful to Montessori Education than the conventional classrooms, which scored very low on our fidelity scale. Both groups (Montessori vs. conventional) seem to be therefore quite distinct. Third, we carried out didactic analysis on the mathematical skills expected by the French school system. Studies comparing the skills of students in Montessori and conventional education do not always consider this complexity inherent in mathematical abilities. For instance, in their longitudinal study, Lillard et al. (2017) showed a global improvement in learning: '[The results] show significantly greater growth in academic achievement across preschool for children enrolled in Montessori preschool [...] than waitlisted controls.' (p. 9-16). However, the authors grouped the results of the language tests (vocabulary and reading) and mathematics (problem solving and calculations) in the same measure, under academic competencies'. In our study, we have chosen to use a test that, according to our theoretical framework, exhaustively assesses the skillset involved in number construction.

To summarize, with a randomized distribution of participants, an accurate implementation of Montessori pedagogy, and a didactical analysis of the skills involved, we found that the Montessori method in public preschool leads to gains in math skills that are similar to a conventional preschool curriculum.

Nevertheless, our study has limits. First, teachers were not randomly assigned to the test conditions. This might have introduced some bias. The sample size was also constrained by the number of children attending the schools for the duration of the study. This influences the generalizability of results. Secondly, only one teacher in the Montessori group completed Association Montessori Internationale (AMI) training and the others were self-trained in Montessori Education. This may have had an impact on the results. Even if the implementation of the pedagogy seems correct, the training of teachers could be improved. A third limit could be related to the evaluated content. In our study, we chose to use a test that, according to our theoretical framework, exhaustively assesses the skillset involved in number construction. However, the two mathematical evaluations we used do not provide any information on certain skills targeted by the Montessori method, such as understanding the decimal system or calculations. As mentioned, recent studies (Laski et al., 2016; Mix et al., 2017) have shown that students in Montessori classrooms show higher success rates than students from conventional classrooms on tasks evaluating understanding of the decimal system.

In future, studies with larger sample sizes, randomized selection of participants, high rigor for implementation of the Montessori program, and didactic approaches towards mathematical abilities are necessary to further explore this question and confirm these preliminary results on precise mathematical performance.

6. Conclusion

The goal of the study presented here was to evaluate the impact of the Montessori Method on mathematical competencies in a disadvantaged preschool. Specifically, we focused on the competencies necessary to understand number construction as defined by Croset & Gardes (2019, 2020). The methodology was a randomized, cross-sectional study of a sample of children enrolled in the same school for three years. We showed that the students in a Montessori classroom exhibit no differences in performance compared with students in a conventional classroom in the Applied Problems sub-test of Woodcock-Johnson III, with a substantial level of evidence. Similar results were obtained in a test made up of nine tasks that allow for the evaluation of a range of crucial competencies in number construction. At a time when both critics and committed supporters of the Montessori educational approach are working to determine the true effectiveness of its methods, and the French government is in the process of reviewing teaching objectives in mathematics (Villani & Torossian, 2018), an analysis of this kind appears particularly pertinent and timely.

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Keywords: Early numerical abilities; Montessori education; didactical analysis; preschool; disadvantaged area

Auswirkungen der Montessori-Pädagogik auf das frühe Zahlenlernen in Französischen Vorschulen

Zusammenfassung

Es gibt nur wenige Untersuchungen über die Auswirkungen der Montessori-Pädagogik auf Lernergebnisse, insbesondere in Frankreich. Wir stellen eine randomisierte kontrollierte Querschnittsstudie vor, welche das frühe Zahlenlernen bei französischen Vorschulkindern, die drei Jahre lang eine Montessori-Pädagogik durchlaufen haben, mit der von Kindern vergleicht, die eine "konventionelle" Pädagogik durchlaufen haben. 131 Kinder (5-6 Jahre) wurden mit dem Untertest "Applied problems" des Woodcock-Johnson-III-Tests (WJ-III) und mit einem in der Mathematikdidaktik entwickelten Test beurteilt. Die Schülerinnen und Schüler, die nach der Montessori-Pädagogik unterrichtet wurden, erzielten in Mathematik vergleichbare Ergebnisse wie die Schülerinnen und Schüler des "herkömmlichen" Lehrplans.

Schlagworte: Frühe numerische Fähigkeiten; Montessori-Pädagogik; didaktische Analyse; Kindergarten; benachteiligtes Umfeld

Impact de la pédagogie Montessori sur l'aptitude numérique précoce à l'école maternelle française

Résumé

Il existe peu de recherches de l'impact de la pédagogie Montessori sur les apprentissages, en particulier en France. Nous présentons une étude transversale contrôlée randomisée qui vise à comparer le développement du concept de nombre chez des enfants de maternelle française ayant suivi pendant 3 ans une pédagogie Montessori à celui d'enfants ayant suivi une pédagogie « conventionnelle ». 131 enfants français de grande section (5-6 ans) d'une même école publique ont été évalués avec le sous-test « Applied problems » du test Woodcock-Johnson III (WJ-III) et avec un test conçu en didactique des mathématiques. Les élèves ayant suivi la pédagogie Montessori obtiennent des résultats comparables à ceux du programme « conventionnel » en mathématiques.

Mots-clés : Aptitudes numériques précoces ; pédagogie Montessori ; analyse didactique ; école maternelle ; milieu défavorisé

L'impatto della pedagogia Montessori sull'apprendimento precoce dei numeri nelle scuole materne francesi

Riassunto

Esistono poche ricerche sull'impatto della pedagogia Montessori sull'apprendimento, soprattutto in Francia. In questo articolo, presentiamo uno studio trasversale, randomizzato e controllato che mira a confrontare lo sviluppo dell'apprendimento precoce dei numeri in bambini in età prescolare provenienti da un'educazione Montessori e da un'educazione "convenzionale" in Francia. Nell'ambito dello studio, sono stati valutati 131 bambini in età prescolare (5-6 anni) iscritti alla medesima scuola pubblica che hanno seguito l'educazione montessoriana o quella convenzionale per tre anni. I bambini sono stati valutati sia con il sottotest Woodcock-Johnson III (WJ-III) sui problemi applicati, sia con un test progettato da ricercatori nel campo dell'educazione matematica. I bambini che hanno seguito la pedagogia Montessori hanno ottenuto risultati paragonabili a quelli che hanno frequentato il programma «convenzionale» in matematica.

Parole chiave: Abilità numeriche precoci; pedagogia montessori; analisi didattica; scuola dell'infanzia; ambiente svantaggiato

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Appendix 1

Description of the Mathematical Didactic Diagnosis Test

	Skill	Description	Items	Maximum score
T1	Counting Knowledge	The child was asked to count as high as possible. She/he was asked to do the task twice.		Highest number reached
T2	Code. Determine the cardinal of a set ("How many" task)	The child was asked to count and say how many elements there were.	3, 7, 11	3
T3	Decode. Construct a set with a given cardinal ("Give n" task)	The child was asked to put an amount of tokens into a cup.	5, 12	2
T4	Arithmetical trans-formations problem-solving	The child was presented X arithmetical problems that involve transformation (i.e., "There are *x* tokens in my hand. If I add *y* tokens, how many tokens will there be?" or "There are *x* tokens in my hand. If I take away *y* tokens, how many tokens will there be?")	3 + 1 = ?, 3 + 2 = ?, 3 - 1 = ?, 3 - 2 = ?, 6 + 1 = ?, 6 + 2 = ?, 6 - 1 = ?, 6 - 2 = ?)	8
T5	Construct a set of the same number of elements as another set	The child was asked to match a set of the same number of elements as another set (i.e., "In one trip, get just enough red tokens to put on top of the blue tokens. You must take that many and you can't go back for more").	5, 12	2
T6	Compare the cardinal of two sets	The child was asked to compare the cardinal of two sets (i.e., "Which pile has the most tokens?")	(2 vs. 3, 8 vs. 9)	2
T7	Name written numbers	The child was presented 9 flashcards with numbers on them. (i.e., "What number is this?")	1, 3, 2, 5, 4, 6, 8, 9, 7	9
T8	Identify the rank of a given element in a list	The child was presented seven tokens.	1st, last, 3rd	3
T9	Reproduce a rank of a given element in a list in another list	The child was asked to match a rank of a list with another list (i.e., "Here's a model train with wagons. There is a token in a wagon. Now I hide this model train. Here's another train. Can you place the token in the same place as the one in the model train?").	3, 7, 13	3