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# Evaluation of a Computer-based Learning Program for Students with Mathematical Learning Difficulties

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*A study was conducted in 2021 in Switzerland (Canton of Vaud) to evaluate two computer-based learning programs *Calcularis*<sup>1</sup> and *Matheros*<sup>2</sup> to help students improve their performance in calculation. *Calcularis* was especially designed to support students with mathematical learning difficulties. Then, our study focuses on the evaluation of the effect of *Calcularis* on the mathematical learning skills for students with mathematical learning difficulties in ordinary school context. We observed that *Calcularis* could allow a better progression compared to *Matheros* in calculation, number-line estimation task for students with mathematical learning difficulties.*

*Keywords: Mathematical learning difficulties, computer-based education, primary school, calculation.*

## Context of the study

Following the results of the PISA and TIMSS, some governments place the teaching of mathematics at the heart of their educational policy. This is for example the case of the canton of Vaud in Switzerland, which has set up a “mathematical mission” in 2018-2019 in order to improve the knowledge and skills in mathematics of elementary school students. One of the recommendations of this mission (Dias, 2019) is to propose a computer-based learning program to improve the performance of elementary school students in calculation. In order to choose this computer-based program, a study, led by the DGEO<sup>1</sup>, was conducted to specifically compare two programs: *Calcularis*<sup>2</sup> and *Matheros*<sup>3</sup>. These programs were chosen by the DGEO because already used in some schools in the canton during the Covid-19 pandemic. One difference between these two programs is that *Calcularis* was designed for students with mathematical learning difficulties (MLD). This paper is focused on evaluating this computer-based program for students with and without MLD.

## State of art

### Mathematical learning difficulties

For several years, research on mathematical learning difficulties has been developing both in cognitive neuroscience and in mathematics education. Two recent literature reviews (Deruaz et al., 2020; Lewis & Fisher, 2016) report on the following issues in this fields of research: heterogeneity

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<sup>1</sup> DGEO (Direction Générale de l'Enseignement Obligatoire) General management of compulsory school.

<sup>2</sup> <https://dybuster.com/fr/calcularis/>

<sup>3</sup> <https://matheros.fr/>

of definitions and characterizations (e.g., mathematical learning disabilities, dyscalculia, mathematical learning difficulties), a diversity of explanatory models, a variety of identification and support tools, a non-consideration from a didactical point of view.

Within the research group “Riteam” (<http://riteam.ch/fr/>), we are specifically interested in examining the mathematical learning difficulties in the school context and through didactical filters. That seems necessary and complementary to current studies, rather conducted out of class and within cognitive psychology. The aim is to take a more focused look at the teaching and learning processes.

According to Scherer and colleagues (2016), our prior research highlighted the need, for research in mathematics education, to broaden the definition of mathematical learning difficulties used most widely in cognitive sciences. However, in the school context, it is necessary to also consider students with difficulties that are not identified by a medical diagnosis. Thus, in mathematics education, research focuses on students with clinically diagnosed disorders, but also on students with severe difficulties in mathematics, identified by teachers (Deruaz et al., 2020). We also noted that research in mathematics education focuses more on interventions with students with mathematical learning difficulties. These are mostly case studies, outside the school context, evaluating the impact of a remediation intervention on a specific mathematical content. These interventions focus more on teaching strategies than on students' cognitive abilities. Among these teaching strategies, some are mediated by digital technology.

### **Computer-based intervention for students with mathematical learning difficulties**

In 2006, Wilson and colleagues proposed a pioneering study in the design and evaluation of a digital tool for remediation (Wilson et al., 2006). They evaluated the impact of an adaptive digital game (Number Race) on the mathematical learning of students with dyscalculia. Their results show positive effects on student performance in basic mathematical tasks such as subitizing, non-symbolic comparison, number comparison, and subtraction (of two one-digit numbers). However, these effects do not generalize to counting or other arithmetic tasks (two-digit addition or subtraction). Regarding the *Calcularis* program, several studies have evaluated its impact on the mathematical performance of students with or without mathematical learning difficulties (Käser et al., 2013; Kucian et al., 2011; Rauscher et al., 2016). Kucian and colleagues (2011) conducted an initial evaluation of the *Calcularis* program for a group of students with mathematical learning difficulties. The results indicate that training with *Calcularis* leads to improved spatial representation of numbers and modulation of neuronal activation, both of which facilitate the processing of numerical tasks. More recently, Rauscher and colleagues (2016) conducted a study with control groups. Their results show significant progress of the *Calcularis* group compared to the control group, especially with regard to subtractions and spatial representation of numbers. In addition, five months after the end of the use of the application, their level of performance was stable. The authors conclude that *Calcularis* not only leads to short-term improvement, but also allows students to use these improvements to succeed in the long term.

To conclude, current research on mathematical learning difficulties in mathematics education focuses mainly on case studies evaluating the impact of a remediation intervention on specific mathematical

content with students with mathematical learning difficulties. These interventions are often based on digital tools. Several meta-analyses have examined the effects of these interventions with digital tools and reveal positive effects (Kulik, 1994; Li & Ma, 2010). In particular, Li and Ma (2010) highlight their contributions to students with special educational needs in primary school. With regard to the *Calcularis* program, current studies highlight its impact on improving the spatial representation of numbers and solving simple subtractions in primary school students, with or without mathematical learning difficulties.

### **The current study**

The current study aims to contribute to the evaluation of *Calcularis* on the performance of elementary school students with and without mathematical learning difficulties. Indeed, the aim is to evaluate *Calcularis* as a computer-based learning program for students with difficulties, in ordinary classrooms in the Vaud school context. The research question focuses on the impact of *Calcularis* on the learning progress of students with or without difficulties. For that, we compare the use of *Calcularis* to another computer-based program (*Matheros*).

### **Materials and Method**

#### **Computer-based learning program: *Calcularis* and *Matheros***

*Calcularis* 2.0 is a highly adaptative computer-based training program (von Aster et al., 2016). *Calcularis* is based on theoretical neurocognitive foundations of numerical cognition, such as the triple-code model (Dehaene, 1992), the four-step developmental model (von Aster and Shavel, 2007) and further theoretical advancements (Kucian and Kaufmann, 2009). *Calcularis* has been designed according to insights on the typical and atypical development of mathematical abilities (Käser, 2013). The program aims to automatize the different number representations, to supports the formation and access to mental number line and to train arithmetic operations as well as arithmetic fact knowledge in expanding number ranges from 0-10 until 0-1,000 (Kohn et al., 2020). *Matheros* is one of the digital tools offered by the Monecole.fr site created in 2011 by L.Walter, a teacher and digital trainer in France. *Matheros* allows students to progress in mental calculation according to the principle of belts (as in martial arts) of skills (Monecole, 2021).

#### **Sample**

Our sample is composed of seven classes of third grade and eight classes of fourth grade (aged 8-9 years) in the canton of Vaud. This comprised 15 teachers and 260 students. The classes have been choice by the DGEO. There are 143 students in the *Calcularis* group (classes using the *Calcularis* program) and 117 students in the control group (classes using *Matheros* program). Students with MLD were defined as those whose score in two out of three tasks (see below) was situated in the bottom 20% for a given grade. This resulted in 18 students (10 in *Calcularis* group and 8 in *Matheros* group) in the third grade and 12 students (8 in *Calcularis* group and 4 in *Matheros* group) in the fourth grade.

## Measures

We used three tasks to assess students' performance in mathematics.

*Numeracy Fluency*: we assessed the numeracy fluency with the subtest 6 of the Woodcock-Johnson Test III (Woodcock, McGrew, & Mather, 2001).

*Number line estimation*: we assessed the spatial representation of numbers with a number line estimation task, adapted to the subtest of the Zareki (Dellatolas & Von Aster, 2006).

*Calculation*: we assessed the calculations (with multi-digit numbers) with a task designed by our team to evaluate the expectations of the curriculum in the third and fourth grades. This task aligned with the swiss curriculum has four categories: addition, subtraction, multiplication and half/double. For example, in third grade:  $87+9=$ ;  $4 \times 3=$ ;  $140-52=$ ; double of 55; and in fourth grade:  $254+2005+17=$ ;  $1060-69=$ ; half of 120. Each category is declined according to the different variables (e.g., for the addition: number of terms of the addition, size of the numbers at stake; presence of retention or not; possibility of complement to the top ten/hundred; associativity; commutativity; special procedure (+9)). Students can put the operation on the sheet if they want.

## Procedure

The procedure was carried out in four stages. The first step refers to the pre-tests: teachers administered the three mathematical tasks to all their students in their own classrooms. The second step concerns the use of computer-based learning programs: for six weeks, teachers proposed to their students to use *Calcularis* (in *Calcularis* group) or *Matheros* (in control group) at least two times 20 minutes per week, individually, in class or at home. The logbooks kept by the teachers during the study attest to the achievement of this weekly time by the students. The third step is related to the post-tests: teachers administered the (same) mathematical tasks one week after the computer-based learning programs were completed. The fourth step refers to the delayed post-tests: teachers administered the (same) mathematical tasks again, 4.5 months after the computer-based learning programs were discontinued.

## Results

### Results for all students

In this part, the effect of using *Calcularis* on the three tasks (numeracy fluency, number-line estimation, and calculation) will be evaluated and compared to the effect of using *Matheros*, and the evaluation will be carried out for all students.

#### *Pre-tests*

In order to examine whether there was a group difference in the pre-tests, we carried out a one-way ANOVA<sup>4</sup> on the pre-test score for the three tasks and the two grades separately. The results showed that in the third grade, compared to *Matheros* group, *Calcularis* group had significantly higher score in calculation test (18.0 vs 16.0,  $F(1, 120) = 4.82$ ,  $\eta^2p = .04$ ,  $p = .03$ ) and marginally lower score in

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<sup>4</sup> Analysis of variance (ANOVA) is an analysis tool.

fluency (37.8 vs 42.4,  $F(1, 120) = 3.74$ ,  $\eta^2p = .03$ ,  $p = .06$ ) test. In the fourth grade, *Calcularis* group had significantly lower score than *Matheros* group in fluency test (53.6 vs 58.5,  $F(1, 134) = 4.03$ ,  $\eta^2p = .03$ ,  $p = .047$ ). For the other tasks (number line tasks in third grade and fourth grade and calculation task in fourth grade), there are not significant differences between the two groups.

*Post-tests and delayed post-tests*

In order to examine the effect of group and pre-test score on the scores of post-tests and delayed post-tests, we ran a multiple linear regression for the three tasks and the two grades separately. Our analysis, that are presented in Table 1, revealed that in general, there was a significant effect of pre-test score on post-test and delayed post-test scores. The exceptions were found for number-line task during post-test for *Calcularis* group in the third grade and for *Matheros* group in the fourth grade. Furthermore, in the post-test, *Calcularis* had an advantage over *Matheros* in the third grade for calculation task ( $t(114) = 2.88$ ,  $p = .005$ ) but a disadvantage for number-line task ( $t(102) = -2.44$ ,  $p = .02$ ). In the delayed post-test, in the fourth grade, there was a difference to the disadvantage of *Calcularis* for fluency task ( $t(126) = -3.06$ ,  $p = .003$ ).

**Table 1. The slopes of post-test and delayed post-test as a function of pre-test**

Grade	Task	Group	Post-test		Delayed post-test	
			Slope	<i>p</i>	Slope	<i>p</i>
3rd	Calculation	Calcularis	0.80	< .001	0.60	< .001
		Matheros	0.48	< .001	0.55	< .001
	Number line	Calcularis	0.05	ns	0.18	.06
		Matheros	0.42	< .001	0.21	.051
	Fluency	Calcularis	0.85	< .001	0.89	< .001
		Matheros	0.65	< .001	0.75	< .001
4th	Calculation	Calcularis	0.70	< .001	0.53	< .001
		Matheros	0.75	< .001	0.29	.03
	Number line	Calcularis	0.09	.003	0.22	.03
		Matheros	0.19	ns	0.43	.002
	Fluency	Calcularis	0.84	< .001	0.78	< .001
		Matheros	0.92	< .001	1.19	< .001

Note. ns: non-significant differences

**Analyses for students with mathematical learning difficulties**

In this part, the effect of using *Calcularis* on the three tasks (fluency, number-line estimation, and calculation) will be evaluated and compared to the effect of using *Matheros*, but the evaluation will be carried out only for students with MLD. The performance of students with MLD was evaluated in the term of predicted and real observed scores of both post-test and delayed post-test. To obtain the predicted scores, we ran a multiple linear regression based on the scores of the students who were not categorized as students with MLD. The obtained slopes for a given tasks and a given grade were then used to calculate the predicted scores of students with MLD. These predicted scores were then compared to the observed scores of these students by means of a one-sample t-test.

The results for students with MLD are presented in Table 2. In the phase of post-test, there was no difference between the observed and predicted scores, except for calculation task in *Matheros* group

of the third grade, in which the observed score was significantly lower than the predicted score. In fact, the gap obtained in this group was significantly larger than in *Calcularis* group ( $t(16) = 2.11$ ,  $p = .051$ ). In the phase of delayed post-test, the observed score in the *Matheros* group of the third grade was significantly lower than the predicted score for calculation and number-line tasks. Again, these gaps were significantly larger than in *Calcularis* group ( $t(16) = 2.93$ ,  $p = .01$  for calculation and  $t(15) = 3.22$ ,  $p = .006$  for number-line task).

**Table 2. The difference between observed and predicted scores of post-test and delayed post-test for students with MLD**

Grade	Task	Group	Post-test		Delayed post-test	
			Difference	<i>p</i>	Difference	<i>p</i>
3rd	Calculation	Calcularis	-0.72	ns	0.66	ns
		Matheros	-3.82	.03	-6.16	.02
	Number line	Calcularis	-0.24	ns	0.95	ns
		Matheros	-1.43	ns	-1.41	.02
	Fluency	Calcularis	-0.54	ns	0.47	ns
		Matheros	7.33	ns	7.99	ns
4th	Calculation	Calcularis	1.16	ns	-0.47	ns
		Matheros	-1.94	ns	-0.25	ns
	Number line	Calcularis	-0.22	ns	-1.56	ns
		Matheros	1.41	Ns	0.30	ns
	Fluency	Calcularis	0.77	Ns	-3.67	ns
		Matheros	-7.87	Ns	-4.86	ns

*Note.* Positive differences imply higher observed score than predicted score. ns: non-significant differences.

## Discussion

Concerning the impact of *Calcularis* on the learning progress of student with and without difficulties, our results show that *Calcularis* allows all students to progress in calculation and numeracy fluency significantly after a 6-week use (post-test) and at a deadline of 4.5 months (delayed post-test). For the spatial number representation, the results are more nuanced. *Calcularis* allows fourth grade students to progress significantly but not for third grade students. Concerning the comparison between *Calcularis* and the other computer-based program, *Calcularis* is more efficient than the other computer-based learning program (*Matheros*) for third grade calculation. On the other hand, the other computer-based learning program (*Matheros*) seems more efficient in third grade. Concerning the students with MLD in the *Calcularis* group, they progress more than students with MLD in the Control group for the calculation in third grade. We also see better efficiency for third grade students on the number line estimation task.

These results obtained for students with MLD can be explained by two reasons. First, the specific design of *Calcularis* is based on theoretical neurocognitive foundations of numerical cognition (Kohn et al., 2020). Initially, the aim and conception of *Calcularis* is to support students with MLD. In *Calcularis*, the use of machine learning make takes more progressive being slightly challenging and thus may foster the development of new skills (Kohn et al., 2020). This technology is another major

difference with the other computer-based learning program *Matheros*. In contrary, *Matheros* offers a linear path, without the possibility of playing on the difficulty of the proposed calculations. It is possible to change the time given to perform the calculations but the teachers in our control group did not use it. Secondly, the finding that *Calcularis* allows third graders to make more progress in numeracy, especially for students with MLD, is consistent with our didactical analysis of the content of this computer-based learning program. Indeed, by comparing the contents of this program with the curriculum, we have highlighted a more appropriate calibration of *Calcularis* for third grade students, in particular due to machine learning.

The results obtained for students with MLD confirm the results of previous studies in numeracy fluency and number line test (Käser et al., 2013, Kohn et al., 2020, Rauscher, 2016). Rauscher (2016) demonstrates that *Calcularis* can be used effectively to support children in their numerical development and to enhance subtraction and spatial number representation. Käser (2013) found significant results in subtraction for students who used *Calcularis* for 6-8 weeks. This involved subtraction of two single-digit numbers, to be performed mentally. As far as we know, studies concerning posed calculations (with multi-digit numbers) are not very frequent. Therefore, our study provides new results on the effectiveness of *Calcularis* in improving numerical skills in students with MLD in the school context.

In sum, our findings are in line with previous research however they provide a complement because the study was conducted in ordinary classes. *Calcularis* seems particularly interesting as a computer-based learning programs to help students with MLD. In future research, we will analyze the data collected in the application (game duration, skills acquired, number of exercises performed correctly, etc.) to see if the application could be used as a tool for identifying students with MLD by teachers.

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