ISSN: 1815-7696 | RNPS: 2057 | Mendive. Journal on Education. Vol. 24, e4445
Mautino Pérez, J. A.; Asís López, M. E.; Mendoza López, A. D. "Papy's minicomputer for learning basic mathematical operations with numbering systems".
https://mendive.upr.edu.cu/index.php/MendiveUPR/article/view/4445

2026

Original article

Papy's minicomputer for learning basic mathematical operations with numbering systems

Minicomputador de Papy en el aprendizaje de operaciones matemáticas básicas con sistemas de numeración

Minicomputador de Papy na aprendizagem de operações matemáticas básicas com sistemas de numeração

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Received: 16/09/2025
Accepted: 28/06/2026

ABSTRACT

Contemporary education demands the incorporation of innovative teaching strategies that promote meaningful learning of mathematics. In this context, the Papy's minicomputer is presented as a pedagogical tool with the potential to strengthen the understanding of basic mathematical operations and number systems. The objective of this study was to analyze the effect of using the Papy's minicomputer on the development of the competency "Solves quantity problems in basic mathematical operations with number systems" in secondary school students. The research adopted a quantitative approach, with a quasi-experimental, explanatory design, and included an experimental group and a control group. Data collection involved assessment instruments

administered before and after the pedagogical intervention, as well as performance records and the rating scale established in the National Curriculum for Basic Education. The validity of the instrument was confirmed through expert judgment, and its reliability was verified through an adequate internal consistency coefficient. Data analysis was performed using descriptive and inferential statistical procedures. The results showed a significant improvement in the learning level of the students who participated in the Papy's minicomputer experience, as well as relevant progress in all dimensions of the assessed competency. In conclusion, the application of the Papy's minicomputer contributes significantly to strengthening the learning of basic mathematical operations with number systems in secondary school students.

Keywords: Papy's minicomputer; mathematics learning; number systems; secondary education.

RESUMEN

La educación contemporánea exige la incorporación de estrategias didácticas innovadoras que favorezcan el aprendizaje significativo de las matemáticas. En este contexto, el minicomputador de Papy se plantea como una herramienta pedagógica con potencial para fortalecer la comprensión de las operaciones matemáticas básicas y los sistemas de numeración. El objetivo del estudio fue analizar el efecto de la aplicación del minicomputador de Papy en el desarrollo de la competencia "Resuelve problemas de cantidad en operaciones matemáticas básicas con sistemas de numeración", en estudiantes de Educación Secundaria. La investigación adoptó un enfoque cuantitativo, con un diseño cuasiexperimental de tipo explicativo, y consideró un grupo experimental y un grupo de control. Para la recolección de la información se emplearon instrumentos de evaluación aplicados antes y después de la intervención pedagógica, así como registros de desempeño y la escala de calificación establecida en el Currículo Nacional de la Educación Básica. La validez del instrumento fue confirmada mediante juicio de expertos y su confiabilidad se comprobó a través de un coeficiente de consistencia interna adecuado. El análisis de los datos se realizó mediante procedimientos de estadística descriptiva e inferencial. Los resultados evidenciaron una mejora significativa en el nivel de aprendizaje de los estudiantes que participaron en la experiencia con el minicomputador de Papy, así como avances relevantes en todas las dimensiones de la competencia evaluada. En conclusión, la aplicación del minicomputador de Papy contribuye de manera significativa al fortalecimiento del aprendizaje de las operaciones matemáticas básicas con sistemas de numeración en estudiantes de Educación Secundaria.

Palabras clave: minicomputador de Papy; aprendizaje de las matemáticas; sistemas de numeración; educación secundaria.

RESUMO

A educação contemporânea exige a incorporação de estratégias didáticas inovadoras que favoreçam a aprendizagem significativa da matemática. Nesse contexto, o minicomputador de Papy apresenta-se como uma ferramenta pedagógica com potencial para fortalecer a compreensão das operações matemáticas básicas e dos sistemas de numeração. O objetivo do estudo foi analisar o efeito da aplicação do minicomputador de Papy no desenvolvimento da competência "Resolver problemas de quantidade em operações matemáticas básicas com sistemas de numeração", em estudantes do Ensino Secundário. A pesquisa adotou uma abordagem quantitativa, com um delineamento quase-experimental de caráter explicativo, considerando um grupo experimental e um grupo de controle. Para a coleta de dados, foram utilizados instrumentos de avaliação aplicados antes e depois da intervenção pedagógica, bem como registros de desempenho e a escala de classificação estabelecida no Currículo Nacional da Educação Básica. A validade do instrumento foi confirmada por meio de julgamento de especialistas, e sua confiabilidade foi comprovada por meio de um coeficiente de consistência interna adequado. A análise dos dados foi realizada utilizando procedimentos de estatística descritiva e inferencial. Os resultados evidenciaram uma melhoria significativa no nível de aprendizagem dos estudantes que participaram da experiência com o minicomputador de Papy, bem como avanços relevantes em todas as dimensões da competência avaliada. Em conclusão, a aplicação do minicomputador de Papy contribui de maneira significativa para o fortalecimento da aprendizagem das operações matemáticas básicas com sistemas de numeração em estudantes do Ensino Secundário.

Palavras-chave: minicomputador de Papy; aprendizagem da matemática; sistemas de numeração; ensino secundário.

INTRODUCTION

Mathematics education at the secondary level faces significant challenges in the contemporary digital age. Research demonstrates that there is a considerable gap between traditional teaching methodologies and the learning needs of 21st century students (Meuleners *et al.*, 2024). Studies reveal that students frequently experience difficulties understanding abstract mathematical concepts, especially in areas such as integers, where most struggle to apply rules of signs (Ismail *et al.*, 2023). This problem is exacerbated by high failure rates in mathematics, demonstrating the urgent need for innovative pedagogical approaches (Cóndor-Herrera & Ramos-Galarza, 2021).

In this regard, the integration of technological tools into mathematics education has emerged as a promising solution. Research indicates that digital tools can significantly improve student performance when carefully implemented (Ismail *et al.*, 2023), and that ICT-based learning has a moderate positive effect ($g=0.527$; $p<0.05$) on students' numeracy (Ariani *et al.*, 2024). However, challenges remain in the effective implementation of these technologies, including a lack of adequate infrastructure and insufficient teacher training (Agyei *et al.*, 2024).

On the other hand, Georges Papy, a Belgian mathematician and educator, became the architect and undisputed leader of modern mathematics reform in Belgium during the 1960s. Papy designed and carried out bold experiments, developed new programs and teaching materials, and engaged mathematics teachers through large-scale in-service education programs (De Bock & Vanpaemel, 2019).

Papy's minicomputer is a physical device that represents numerical values using tokens and boards, facilitating the understanding of arithmetic operations and the structure of the number system. It is based on direct manipulation, allowing students to visualize and experiment with concepts such as addition, subtraction, and grouping of numbers (Papy, 1974; Lamon & Threadgill, 1975).

Similarly, studies show that digital tools are used more often in high-quality biology classes than in mathematics (Meuleners *et al.*, 2024). Furthermore, mathematics teachers often use calculators as a simple substitute or complement in their classrooms (Agyei *et al.*, 2024). This trend raises the possibility of exploring how classic pedagogical tools, such as the Papy's minicomputer, can be adapted to or complement current digital technologies.

Furthermore, prior observations and interviews with teachers and students revealed that the traditional teaching model limits the achievement of meaningful learning, leading to boredom, demotivation, and fatigue. In contrast, Papy's minicomputer promotes dynamic and playful learning, thanks to its design based on colored squares that correspond to Cuisenaire rods (numbered 1, 2, 4, and 8, representing the binary system). This structure encourages "learning by doing" through hands-on manipulation and play.

In this context, the objective of this study is to determine if the application of the Papy's minicomputer improves the learning level of the competence "Solves quantity problems in basic mathematical operations with number systems" in first year of secondary school students.

MATERIALS AND METHODS

This research was framed within a quantitative approach and, according to its level or scope, was explanatory in nature, with a quasi-experimental design. This type of study seeks to identify the causal effect or impact of an intervention (treatment) under real-world conditions, when it is not possible or ethical to randomly assign participants to groups. That is, it attempts to estimate what change can be attributed to the intervention, even though the assignment was not random (Harris *et al.*, 2006). It also aims to explain why a phenomenon occurs and under what conditions it manifests, with the purpose of applying an independent variable that contributes to modifying said phenomenon (Hernández Sampieri *et al.*, 2014). The quasi-experimental design employed was a pretest-posttest design, in which subjects were not randomly assigned to groups, but rather the groups were already formed beforehand.

The unit of analysis in this study was the student. The population consisted of 34 first-year secondary school students, distributed between the Mariano Melgar Valdiviezo-Cajay Educational Institution (19 students) and the Nuestra Señora de Guadalupe de Huamparán Educational Institution (15 students). The sample was a census, with the students from the Mariano Melgar Valdiviezo Educational Institution serving as the experimental group and those from the Nuestra Señora de Guadalupe Educational Institution as the control group.

The following instruments were used for data collection: an evaluation record, the National Curriculum for Basic Education (CNEB) rating scale, and a questionnaire administered in the pretest and posttest. This questionnaire was designed to assess the learning level of the competency "Solves

quantity problems in basic mathematical operations with number systems", and its dimensions: "Translates quantities into numerical expressions", "Communicates understanding of numbers and operations", "Uses estimation and calculation strategies and procedures" and "Arguments statements about numerical relationships and operations".

The instrument's content validity was determined through consultation with a panel of three experts, yielding an average agreement rate of 93.33%, indicating high validity. Regarding reliability, a pilot test was conducted, followed by a final test using the Kuder-Richardson KR-20 split-half reliability coefficient. The resulting value was 0.859, demonstrating a strong correlation and unidimensionality of the items, and confirming their applicability.

The data processing and statistical analysis plan included descriptive and inferential statistics. The descriptive section presented frequency distribution tables for both groups (control and experimental) in the pretest and posttest, including arithmetic means and standard deviations. For the inferential section, given that the data were normally distributed, the paired-samples t-test was used (pretest and posttest for each group). All analyses were performed with a significance level of 5% ($p<0.05$).

Ethical observation

During the execution of the investigation, the physical and mental well-being of the participants was ensured; informed consent was obtained prior to participation; the use and handling of information strictly respected copyright and intellectual property, properly citing the sources; the methodology and results were based on reliable and verifiable data.

RESULTS

Following the fieldwork and the application of Papy's minicomputer to the experimental group, the following results are presented:

Table 1. Pretest scores for the learning level of the competency "Solves quantity problems in basic mathematical operations with number systems"

Scores	Groups	
	Control (%)	Experimental (%)
5	1(6,7)	-
6	1(6,7)	-
7	640.0)	1(5,3)
8	1(6,7)	1(5,3)
9	2(13,3)	1(5,3)
10	1(6,7)	2(10,5)
11	2(13,3)	5(26,3)
12	-	3(15,8)
13	1(6,7)	4(21,1)
15	-	1(5,3)
16	-	1(5,3)
Total	15 (100)	19 (100)
Arithmetic mean	8,267	11,474
Standard deviation	2,187	2,195

The data in table 1 show the results obtained in the pretest for both the control and experimental groups, in relation to the overall objective. The mean scores were 8.267 for the control group and 11.474 for the experimental group.

Table 2. Pretest scores of learning level in basic mathematical operations with number systems in the dimension "Translates quantities to numerical expressions"

Scores	Groups	
	Control (%)	Experimental (%)
1	4(26,7)	1(5,3)
2	4(26,7)	8(42,1)
3	6(40,0)	4(21,1)
4	1(6,7)	5(26,3)

5	-	1(5,3)
Total	15 (100)	19 (100)
Arithmetic mean	2,267	2,842
Standard deviation	0.961	1,068

Table 2 presents the results for the "Translates quantities into numerical expressions" dimension in first-year secondary school students in the pretest, for both the control and experimental groups. The arithmetic means of the data are 2.267 for the control group and 2.842 for the experimental group.

Table 3. Pretest scores on the level of learning in basic mathematical operations with number systems in the dimension "Communicates their understanding of numbers and operations"

Scores	**Groups**	
	Control (%)	**Experimental (%)**
2	6(40,0)	2(10,5)
3	6(40,0)	4(21,1)
4	2(13,3)	9(47,4)
5	-	4(21,1)
7	1(6,7)	-
Total	15 (100)	19 (100)
Arithmetic mean	3,000	3,790
Standard deviation	1,309	0.918

The data in table 3 show the results obtained in the pretest, for both the control and experimental groups, in relation to specific objective 2. It can be seen that the arithmetic means of the data are 3.0 for the control group and 3.79 for the experimental group.

Table 4. Pretest scores of learning level in basic mathematical operations with number systems in the dimension "Uses estimation and calculation strategies and procedures"

Scores	Groups	
	Control (%)	Experimental (%)
1	7(46,7)	4(21,1)
2	7(46,7)	5(26,3)
3	1(6,7)	5(26,3)
4	-	4(21,1)
5	-	1(5,3)
Total	15 (100)	19 (100)
Arithmetic mean	1,600	2,632
Standard deviation	0.632	1,212

The data in table 4 show the results obtained in the pretest, both from the control and experimental groups, in relation to specific objective 3, and it can be seen that the arithmetic means of the data are 1.60 for the control group and 2.632 for the experimental group.

Table 5. Pretest scores on the level of learning in basic mathematical operations with number systems in the dimension "Arguments statements about numerical relationships and operations"

Scores	Groups	
	Control (%)	Experimental (%)
0	1(6,7)	-
1	9(60,0)	3(15,8)
2	3(20,0)	11(57,9)
3	2(13,3)	4(21,1)
5	-	1(5,3)
Total	15 (100)	19 (100)
Arithmetic mean	1,400	2,211
Standard deviation	0.828	0.918

The data in table 5 show the results obtained in the pretest, both for the control and experimental groups, in relation to specific objective 4. It can be seen that the arithmetic means of the data are 1.40 for the control group and 2.211 for the experimental group.

Table 6. Posttest scores for the learning level of the competency "Solves quantity problems in basic mathematical operations with number systems"

Scores	Groups	
	Control (%)	Experimental (%)
5	2(13,3)	-
6	2(13,3)	-
7	3(20,0)	-
8	3(20,0)	-
10	1(6,7)	-
11	1(6,7)	-
12	1(6,7)	-
15	1(6,7)	-
17	1(6,7)	-
23	-	1(5,3)
25	-	1(5,3)
27	-	1(5,3)
28	-	6(31,6)
29	-	3(15,8)
30	-	1(5,3)
31	-	3(15,8)
33	-	1(5,3)
35	-	1(5,3)
36	-	1(5,3)
Total	15 (100)	19 (100)
Arithmetic mean	8,800	29,316
Standard deviation	3,570	3,110

The data in table 6 show the results obtained in the posttest for both the control and experimental groups, in relation to the general objective, and it can be seen that the arithmetic means of the data are 8.80 for the control group and 29.316 for the experimental group.

Table 7. Posttest scores on the level of learning in basic mathematical operations with number systems in the dimension "Translates quantities to numerical expressions"

Scores	Groups	
	Control (%)	Experimental (%)
1	6(40,0)	-
2	4(26,7)	-
3	4(26,7)	1(5,3)
4	1(6,7)	1(5,3)
6	-	1(5,3)
7	-	3(15,8)
8	-	7(36,8)
9	-	6(31,6)
Total	15 (100)	19 (100)
Arithmetic mean	2,000	7,579
Standard deviation	1,000	1,677

The data in table 7 show the results obtained in the posttest of the control and experimental groups, in relation to specific objective 1. It can be seen that the arithmetic means of the data are 2.00 for the control group and 7.579 for the experimental group.

Table 8. Posttest scores on the level of learning in basic mathematical operations with number systems in the dimension "Communicates their understanding of numbers and operations"

Scores	Groups	
	Control (%)	Experimental (%)
1	4(26,7)	
2	4(26,7)	
3	2(13,3)	
4	3(20,0)	

6	-	2(10,5)
7	2(13,3)	3(15,8)
8	-	3(15,8)
9	-	6(31,6)
10	-	4(21,1)
11	-	1(5,3)
Total	15 (100)	19 (100)
Arithmetic mean	2,933	8,526
Standard deviation	1,981	1,429

The data in table 8 show the results obtained in the posttest, both for the control and experimental groups, in relation to specific objective 2. It can be seen that the arithmetic means of the data are 2,933 for the control group and 8,526 for the experimental group.

Table 9. Posttest scores on the level of learning in basic mathematical operations with number systems in the dimension "Uses estimation and calculation strategies and procedures"

Scores	**Groups**	
	Control (%)	**Experimental (%)**
1	7(46,7)	-
2	5(33,3)	-
3	2(13,3)	-
4	1(6,7)	-
5	-	4(21,1)
6	-	3(15,8)
7	-	8(42,1)
8	-	2(10,5)
9	-	1(5,3)
10	-	1(5,3)
Total	15 (100)	19(100)
Arithmetic mean	1,800	6,790
Standard deviation	0.941	1,357

The data in table 9 show the results obtained in the posttest, both for the control and experimental groups, in relation to specific objective 3. It can be seen that the arithmetic means of the data are 1.80 for the control group and 6.790 for the experimental group.

Table 10. Posttest scores on the level of learning in basic mathematical operations with number systems in the dimension "Arguments statements about numerical relationships and operations"

Scores	Groups	
	Control (%)	Experimental (%)
1	5(33,3)	-
2	6(40,0)	-
3	2(13,3)	-
4	2(13,3)	2(10,5)
5	-	5(26,3)
6	-	2(10,5)
7	-	5(26,3)
8	-	4(21,1)
10	-	1(5,3)
Total	15 (100)	19 (100)
Arithmetic mean	2,067	6,421
Standard deviation	1,033	1,610

The data in table 10 show the results obtained in the posttest of the control and experimental groups, in relation to specific objective 4. It can be seen that the arithmetic means of the data are 2,067 for the control group and 6,421 for the experimental group.

Table 11. Related samples t-test

Groups	Related differences		t-test for equality of means		
	Average	Standard deviation	t	gl.	p-value
Experimental	17.84	3.96	19.56	18	**0.0001**
Control	0.53	4.82	0.43	14	**0.675**

Note: Prepared based on data from tables 1 and 6

Decision rule: reject the null hypothesis if the p-value is less than 0.05 ($p<0.05$), which is equivalent to a significance level of $\alpha=0.05$.

Interpretation: the results in table 11 indicate that, in the control group, where the Papy's minicomputer strategy was not applied to the learning of the competency "Solves quantity problems in basic mathematical operations with number systems", no statistically significant differences ($p=0.675$; $p>0.05$) were found between the pretest and posttest. However, in the experimental group, where the Papy's minicomputer strategy was applied to the learning of the same competency, statistically significant differences ($p=0.0001$; $p<0.05$) were observed between the pretest and posttest. Therefore, the application of the Papy's minicomputer significantly improves the learning level of the competency "Solves quantity problems in basic mathematical operations with number systems" in first-year secondary school students at the Mariano Melgar Valdiviezo Educational Institution, Cajay, 2023.

DISCUSSION

The results of this study show that the implementation of the Papy's minicomputer had a significant effect on the learning of basic mathematical operations with number systems in first-year secondary school students. The mean difference between the pretest and posttest in the experimental group was 17.84 points, with a p-value of 0.0001, while the control group showed no significant changes ($p = 0.675$). These results are supported by the findings in table 11, indicating a statistically robust improvement thanks to the use of the Papy's minicomputer. They also align with previous studies on the positive impact of manipulatives in mathematics education. For example, Kontas (2016) reported that secondary school students who used manipulatives improved significantly in both academic performance and attitude toward mathematics compared to a control group. Similarly, Enríquez (2019) also found a positive impact of the Papy's minicomputer on mathematical performance.

Furthermore, meta-analyses and longitudinal studies highlight that the use of physical tools increases performance in mathematics when implemented over a prolonged period, especially when teachers receive adequate training in their use (Kablan, 2016). However, brief or poorly trained use does not produce significant effects, which underscores the importance of lesson planning.

The pretest results (Table 1) show that, before the intervention with the Papy's minicomputer, both groups exhibited low levels of learning in the competency "Solves quantity problems in basic

mathematical operations with number systems". The arithmetic mean obtained by the control group was 8.267, while the experimental group scored 11.474. Although the experimental group showed a slight initial advantage, the difference is not significant enough to be attributed to a variable other than the intervention, considering that both groups shared similar socio-educational conditions. These initial results coincide with previous studies that have identified deficiencies in the understanding of number systems in traditional school contexts. Ismail *et al.* (2023) point out that the teaching of integers and basic operations, when delivered using conventional methodologies, generates confusion among students due to the abstract nature of the concepts and the lack of manipulative resources that facilitate their understanding. Along these lines, Meuleners *et al.* (2024) argue that the integration of digital technologies and concrete tools in mathematics teaching remains limited, which perpetuates low levels of performance in basic operations, especially in student populations from rural contexts or with infrastructure limitations.

Consequently, the slight difference in means favoring the experimental group (11.474 versus 8.267) could be explained by factors such as the students' initial disposition toward mathematics or their prior experience with manipulatives in earlier stages. However, studies such as that by Cóndor-Herrera y Ramos-Galarza (2021) show that, without appropriate pedagogical intervention, initial performance differences tend to remain stable or decrease as the complexity of the topics increases.

Similarly, Herrera Villamizar *et al.* (2012) highlight that the lack of teaching strategies focused on the concrete manipulation of objects and the visual representation of quantities limits the development of fundamental numerical skills. This reinforces the need to implement tools such as Papy's minicomputer to facilitate students' transition from concrete to abstract thinking.

Therefore, the incorporation of Papy's minicomputer not only improved performance in basic operations, but also fostered the development of communication, reasoning, and mathematical argumentation skills, establishing itself as an effective teaching strategy in mathematics education.

In turn, the consistency of the results across the different dimensions and the contrast with the control group reinforce the validity of the intervention using Papy's minicomputer. The ability of this tool to facilitate the understanding of number systems and basic operations, by allowing the concrete manipulation of abstract concepts, emerges as a key factor in improving learning. Limitations of the study include the sample size and the specificity of the geographic context, which could affect the generalizability of the results. However, the findings provide a solid foundation for future research

on the implementation of Papy's minicomputer in other educational contexts and with broader populations. In summary, this study underscores the importance of integrating innovative teaching tools to enhance mathematics learning, contributing to closing the achievement gap and fostering a more dynamic and effective approach to teaching.

Finally, the observed effectiveness of Papy's minicomputer can be explained by its active learning approach, since the use of physical objects allows students to experiment with quantities, construct manipulable knowledge, and articulate representations at the enactive, iconic, and symbolic levels, thus fostering the development of more robust cognitive processes. However, some students may initially resist or perceive the manipulatives as a crutch rather than a conceptual tool, especially when faced with tasks of greater cognitive complexity (Quane, 2024). Overall, the results demonstrate that the application of Papy's minicomputer significantly improves the learning level of basic mathematical operations with number systems in first-year secondary school students by facilitating the understanding of abstract numerical concepts through concrete manipulation. This provides evidence of its effectiveness as a teaching resource in rural contexts and establishes it as a viable alternative for strengthening mathematics instruction at the primary levels.

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Conflict of interest

Authors declare no conflict of interests.

Authors' contribution

The authors participated in the design and writing of the article, in the search and analysis of the information contained in the consulted bibliography.

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