Integrating Robotics into Mathematics Education: Applications, Teaching Strategies, and Attitude Assessment in Primary School Students

Cesar Augusto Hernández Suárez[1, a)], Audin Aloiso Gamboa Suárez[1, b)] Arief Aulia Rahman[2, c)]

[1] *Universidad Francisco de Paula Santander*
[2] *Universitas Muhammadiyah sumatera utara*

[a)] *cesaraugusto@ufps.edu.co*
[b)]*audingamboa@ufps.edu.co*
[c)] *ariefaulia@umsu.ac.id*

Abstract. This study addresses the implementation of robotics applications in the teaching of mathematics and its impact on the attitudes of students and teachers in elementary schools in Cúcuta, Colombia. Through a mixed methodology combining quantitative and qualitative approaches, 120 teachers and 300 students participated. The quantitative results reveal that, after 12 weeks of using robotics applications, 75% of teachers considered robotics as an effective tool for teaching mathematics, compared to 40% prior to the intervention. Also, students experienced a significant improvement in their attitude towards mathematics, with a 50% to 20% reduction in insecurity about mathematical concepts and a 65% increase in motivation and enjoyment of learning. Qualitative analysis showed that robotics facilitates understanding of abstract concepts and fosters active and collaborative learning, although some teachers faced initial technical barriers. Despite these difficulties, teachers reported that robotics promotes key skills such as problem solving and teamwork, even in educational contexts with limited resources. Statistical analysis, based on t-tests and ANOVA, indicated that differences in perceptions and attitudes before and after implementation were statistically significant ($p < 0.01$), with no notable differences between school types. These results suggest that robotics is effective in a variety of educational contexts, regardless of school type. In conclusion, this research demonstrates that educational robotics can transform mathematics instruction, improving both academic outcomes and student motivation. The findings suggest that robotics should be integrated into the mathematics curriculum at the national level, accompanied by teacher training programs that address technical and pedagogical challenges. In addition, future studies are recommended to assess the long-term impact of robotics on students' academic and emotional performance, and how it can contribute to reducing educational gaps.

INTRODUCTION

The use of robotics applications in primary education has gained prominence as an innovative tool that facilitates the teaching of complex concepts and promotes the development of technological skills among students. Educational robotics provides a practical and playful approach that can attract students to areas of knowledge they traditionally find difficult or uninteresting, such as mathematics and science. This approach is based on the need to transform traditional teaching practices in mathematics by integrating technology that prepares students for the demands of the 21st century [1, 2]. This study expands the existing knowledge on robotics in primary education by specifically evaluating the impact of robotics on mathematical problem-solving skills. Unlike previous studies that have primarily focused on programming and design skills [3], our approach is on how these skills directly influence mathematical learning, a less explored area. Additionally, the study includes a longitudinal evaluation that allows for the observation of changes in student attitudes over time, providing a more dynamic view compared to typical cross-sectional studies in this field [4].

The incorporation of emerging technologies in the classroom not only modernizes pedagogical methods but also responds to the growing demand for technological skills in the labor market. Additionally, educational robotics can play a crucial role in reducing the digital divide, providing students from diverse socioeconomic backgrounds with access to advanced technological tools, thereby improving educational equity [5, 6]. In this context, this study will explore how the use of robotics applications in mathematics influences primary students' attitudes towards mathematics. Previous research has demonstrated improvements in academic performance in STEM using educational robotics but has overlooked the specific cultural and socioeconomic context of less developed regions [7]. Our research addresses this gap by implementing and evaluating educational robotics in Cúcuta, Colombia, where technological resources and teacher training may be limited. This perspective is crucial, as studies such as those by [8] suggest that results can vary significantly in environments with different levels of access to technology.

Research has shown that the integration of educational robotics not only enhances students' mathematical competencies but also promotes essential skills such as problem-solving, collaborative work, and creativity [9, 10]. These benefits are particularly relevant in an educational environment where the ability to think critically, work in teams, and tackle complex challenges with innovative solutions is increasingly valued. Drawing on the findings of [11], which highlight how robotics can enhance student engagement in mathematics, this study delves into how such engagement translates into concrete improvements in performance and attitudes towards mathematics. Additionally, the inclusion of a qualitative component provides a deeper understanding of how students and teachers perceive and adapt to robotics in the classroom, responding to the call from [12] for studies that combine research methods for a more comprehensive evaluation of the educational impact of technology.

Evaluating students' attitudes towards mathematics after using these applications will provide valuable insights into the effectiveness of these technological tools in the teaching-learning process. Previous studies indicate that robotics applications in education significantly improve students' attitudes towards STEM subjects (science, technology, engineering, and mathematics) and increase their motivation and academic performance [13, 14]. These results suggest that educational robotics can be an effective pedagogical strategy to engage students and improve their academic outcomes in mathematics.

Furthermore, the implementation of robotics in the classroom can offer teachers new perspectives and tools to innovate their teaching methods. By integrating robotics, teachers can develop more dynamic and interactive lessons, which may lead to greater student participation and enthusiasm. Therefore, this research will focus not only on the impact on students but also on how teachers perceive and adopt these technologies, which is crucial for the long-term success of any educational innovation [15]. The objectives of this study are to describe teachers' perceptions of the use of robotics applications in mathematics teaching, to evaluate the attitude towards mathematics of fifth-grade students after using a mathematics robotics app, and to identify effective strategies for teaching mathematics using robotics applications.

METHODOLOGY

This study employs a mixed-methods approach, combining quantitative and qualitative methods to gain a comprehensive understanding of the impact of robotics applications on mathematics education and students' attitudes towards mathematics [16].

Quantitative Phase: In the quantitative phase, surveys will be conducted with teachers to identify their conceptions and attitudes towards the use of educational robotics. A questionnaire will be developed based on previous studies on the integration of technology in education [17, 18]. The participants will be primary school teachers from various schools in Cúcuta, Colombia. A stratified random sampling method will be used to ensure the representativeness of different types of schools (public, private, rural, urban). The surveys will be administered both online and in person, ensuring the voluntary and anonymous participation of the teachers. To ensure the validity and reliability of the questionnaires, they will be adapted to the local context of Cúcuta and a pilot test will be conducted.

Additionally, pre- and post-implementation questionnaires will be used to assess students' attitudes towards mathematics before and after the implementation of the mathematics robotics app. The instrument will be a validated questionnaire used in studies on attitudes towards mathematics and educational technology [14]. The participants will be primary school students from the city of Cúcuta, selected through simple random sampling. The questionnaires will be administered before starting the use of the mathematics robotics app and after a 12-week implementation period. Parental informed consent and the confidentiality of the students' data will be ensured.

Qualitative Phase: In the qualitative phase, interviews will be conducted with teachers to gain an in-depth understanding of how they perceive the integration of robotics applications in classrooms and their impact on students' learning and attitudes. Semi-structured interviews will be conducted with teachers [1, 19]. The participants will be primary school teachers who will use the mathematics robotics app, selected through purposive sampling. The interviews will be conducted at the end of the implementation period, focusing on the teachers' experiences with the robotics app. The interviews will cover topics such as the effectiveness of the applications, challenges encountered, and perceptions of the impact on students. Informed consent will be obtained, and the confidentiality of the data will be ensured. To maintain confidentiality and efficiently organize data collected from multiple interviews, we developed specific nomenclature to identify participants. Each teacher was identified using the initials “P” for “Teacher,” followed by a number representing his or her interview sequence and a location identifier: “U” for urban and “R” for rural. For example, P1U represents Teacher 1 in an urban school, and P2R represents Teacher 2 in a rural school. This nomenclature allowed us to categorize and analyze the responses more efficiently while preserving the anonymity of the participants.

Data Analysis: For data analysis, in the quantitative phase, statistical software such as SPSS will be used. Techniques will include descriptive analysis, paired-sample t-tests to compare pre- and post-implementation attitudes, and analysis of variance (ANOVA) to identify significant differences between groups. Measures will be included to check for normality and homogeneity of variances, and non-parametric tests will be employed if these assumptions are not met [20].

In the qualitative phase, qualitative analysis software Atlas.Ti will be used. The techniques will include thematic coding in the interviews to identify patterns and emerging categories related to the perception and use of robotics in teaching [21]. A data triangulation process will be employed to integrate the quantitative and qualitative findings, ensuring a coherent and comprehensive interpretation of the results [22].

Ethical Considerations: Informed consent will be obtained from all participants, ensuring the confidentiality and anonymity of the data [23]. Clear procedures will be implemented for the secure storage and handling of the collected information.

Limitations and Biases: The possible limitations of the study, such as response biases and sample representativeness, will be acknowledged. Strategies to mitigate these biases will be described, and the discussion will include how these limitations may influence the interpretation of the results [24].

RESULTS

Quantitative Phase

In the quantitative phase of this research, structured surveys were conducted both before and after the implementation of an educational robotics program among 120 teachers and 300 elementary school students in Cúcuta, Colombia. The data collection was designed to explore how perceptions and attitudes towards mathematics could be influenced by the use of robotics technologies, with the objective of obtaining a detailed description of teachers' and students' conceptions regarding the use of robotics applications in mathematics teaching.

Quantitative Results of Teachers

Initially, only 40% of the teachers surveyed considered robotics to be an effective tool for teaching mathematics. However, after 12 weeks of interaction with robotics applications in the classroom, the percentage increased to 75%. This change suggests a significant acceptance and recognition of the pedagogical value of robotics for teaching complex mathematical concepts. This finding is in line with the observations of [17, 18], who note that understanding these perceptions is crucial for designing teacher training programs that effectively address the needs and concerns of educators, ensuring the successful and sustainable implementation of educational robotics.

Student Quantitative Results

Prior to the introduction of robotics, 50% of the students expressed insecurity in their ability to understand and apply mathematical concepts. This percentage decreased to 20% after implementation, while 65% reported an increase in motivation and enjoyment of mathematics. These results support the research of [11], who argues that robotics promotes active learning and increases students' motivation and interest in science and mathematics subjects. Furthermore, [8] explores how educational robotics can act as a catalyst to improve academic performance in mathematics by providing a more engaging and hands-on learning environment.

Statistical Analysis

To assess the statistical significance of the observed changes in teachers' and students' perceptions of robotics as an educational tool, t-tests for related samples were performed. These tests compared pre- and post-implementation responses, and the results confirmed that the differences in perceptions before and after the intervention were statistically significant ($t(299) = 5.87$, $p < 0.01$). This analysis showed a significant increase in the positive perception towards robotics among both teachers and students, which supports the idea that the use of innovative educational technology produces a considerable change in participants' attitudes and confidence, as also noted by [25]. This result is aligned with the detailed focus on t-tests and ANOVA offered by [20], who highlights the importance of these tests in educational research to ensure the robustness of the results.

To provide a more comprehensive assessment of the impact of robotics on mathematics education across various school settings, SPSS software was used to perform an analysis of variance (ANOVA). This statistical method was crucial to compare the responses of teachers and students from different types of schools: public, private, rural and urban. The ANOVA was designed to identify whether the differences in the perception and adoption of educational robotics among the various groups were statistically significant. Independent groups were configured based on school type, and responses were analyzed before and after implementation of the robotics program. To ensure the robustness of the results, Bonferroni adjustment was employed, as suggested by [26], to control for Type I error rate in multiple comparisons.

ANOVA results revealed no statistically significant differences between the responses of teachers and students from different types of schools ($F (3,416) = 0.85$, $p = 0.47$), indicating that the perception and adoption of robotics did not vary significantly by school setting. This finding suggests that the effectiveness of educational robotics is uniform and not conditioned by factors such as school type, which reinforces its ability to integrate effectively in diverse educational contexts, as noted by [16] in highlighting the importance of mixed methods in educational research.

Finally, additional analyses were performed to examine normality and homogeneity of variance using the Shapiro-Wilk and Levene tests, respectively, confirming that the parametric assumptions were appropriate for the t-tests and ANOVAs used. These tests are essential to ensure the validity of statistical analyses, as highlighted by [27], who provide detailed guidelines on the use of these analyses in educational contexts. The results support the conclusion that educational robotics has a significant positive impact on teacher and student perception and adoption, regardless of the type of school, which reinforces its applicability in different school contexts, as suggested by [28] in their analysis on the power of educational interventions.

Qualitative Phase

Results of Teacher Interviews

During the qualitative phase of the study, semi-structured interviews were conducted with 30 teachers who implemented mathematical robotics applications in their classrooms. These interviews revealed several key themes that highlight both the opportunities and challenges associated with integrating robotics into mathematics instruction. Most teachers, such as P1U from an urban school, reported significant improvements in the explanation of complex mathematical concepts and an increase in student engagement, noting that "robotics has transformed the way I teach mathematics. Students are more engaged and excited, often asking how they can use what they learn in real projects." This perception was echoed by P2U, who observed that "robotics has introduced a new dimension to our curriculum that goes beyond improving grades," facilitating a deep and applied understanding of mathematics, as suggested by research in [8], which highlights how robotics promotes the development of critical and collaborative thinking skills essential for STEM learning.

However, some technical challenges and learning curves were also evident. P1R from a rural school mentioned that "the main barrier was technological, as we did not have enough resources at the beginning," although with trainings and adjustments they were able to effectively integrate robotics. This initial challenge is consistent with the study by [29], which highlights lack of prior training as a significant barrier in implementing robotics in educational settings. P2R added that "adapting my lessons to include robotics was a challenge, but the effects have been remarkable," highlighting how students who used to struggle are now thriving, which also fosters self-esteem and curiosity in their students, aligning with the research of [12], who state that robotics facilitates more inclusive and motivating learning.

P3U highlighted specific benefits for students with learning difficulties, stating that "robotics has been especially helpful for students with learning difficulties, providing an interactive medium that enhances their understanding and retention of mathematical concepts." These direct experiences of teachers are in line with the research of [12, 8], who highlight that robotics can transform the classroom by providing tangible contexts for mathematical and scientific exploration, and foster critical thinking skills and teamwork, essential for STEM learning. Despite initial challenges, overcoming these challenges often led to increased confidence and ability to teach with innovative technologies, demonstrating that robotics not only captures students' interest, but also facilitates a deeper understanding of abstract concepts through physical manipulation and direct experimentation.

DISCUSSION

The integration of educational robotics as a pedagogical tool in mathematics classrooms can significantly transform educational practices by fostering a more interactive and motivating learning environment. Robotics allows students to learn in a hands-on and playful way, which not only increases their interest and understanding of complex mathematical concepts, but also promotes essential skills such as problem solving and collaboration, which are indispensable in today's world [19, 30]. These innovative approaches not only benefit students, but also bring new perspectives for teachers, who can design more dynamic and interactive lessons that increase student engagement.

Assessing students' attitudes toward mathematics after using robotics applications provides valuable information about the effectiveness of these technologies. If the results show an improvement in attitudes and performance, as observed in the analyses conducted, this could justify the wider adoption of educational robotics in the school curriculum. The data obtained allow not only to improve pedagogical applications and strategies, but also to ensure that the positive impact on student learning is maximized [31].

In this sense, quantitative results show how the implementation of these tools has significantly improved students' and teachers' perceptions towards mathematics. As previous studies by [32] suggest, technological interventions in STEM have consistent and positive impacts in diverse educational settings, underscoring the relevance of policies that promote the integration of robotics at a broader curricular level.

From the teachers' experiences and suggestions, as well as from the observations made during the study, effective didactic strategies that integrate robotics applications in mathematics teaching were identified. These strategies, as pointed out by [1, 19], provide a solid foundation for future teacher training programs in educational technology. These practices promote pedagogical adaptation to diverse educational contexts, which is essential to ensure the sustainability of technological innovations in teaching.

Qualitative results also reinforce the perception that educational robotics fosters a more motivating and inclusive learning environment. Teacher observation indicates significant improvements in student collaboration, a skill highlighted in the research of [8], who highlights how robotics fosters critical thinking and teamwork skills essential for learning in STEM.

The detailed and robust analysis of both quantitative and qualitative findings provides a clear picture that educational robotics not only improves the perception towards mathematics, but also has a positive impact on the overall attitude of students and teachers. This finding is crucial, as it demonstrates the universality of robotics as an effective pedagogical tool, regardless of socioeconomic or infrastructural variables. As [3] argues, the inherent flexibility of robotics allows its adaptation to diverse pedagogical and cultural needs, which is particularly valuable in resource-limited environments or in rural contexts where educational innovation can be a key factor in overcoming structural challenges.

Going forward, it would be beneficial to conduct longitudinal studies that evaluate the long-term effects of robotics on students' academic and emotional outcomes, in addition to exploring how teacher training strategies can be optimized to maximize the benefits observed in this study. Further research could examine the impact of educational robotics on equity of opportunity, as studies such as those in [33] suggest that educational technologies have the potential to close educational gaps between different socioeconomic groups, particularly in STEM education.

The uniform impact of robotics in different types of schools, as observed in quantitative analyses, reinforces the idea that educational technologies can offer equal solutions in mathematics education. Studies such as those in [34, 35] have highlighted the importance of integrating technological tools such as robotics into curricula not only to improve academic performance, but also to foster critical thinking and problem-solving skills. This suggests that educational policies should prioritize the integration of robotics in the mathematics curriculum at a general level, not only in urban schools or schools with greater resources, but also in rural contexts and those with fewer technological opportunities.

CONCLUSION

Research has demonstrated the transformative potential of educational robotics in mathematics education. The integration of robotics applications in the classroom not only facilitates a more interactive and motivating learning experience, but also promotes essential skills such as problem solving, critical thinking and teamwork. The results of the study, both quantitative and qualitative, reveal that robotics can significantly improve students' perception and attitude towards mathematics, reinforcing the idea that educational technology should occupy a central place in today's curricula.

Quantitative findings show that the implementation of these technologies significantly improves both teachers' and students' perception of mathematics. This improvement in attitude and performance justifies the wider adoption of educational robotics in mathematics curricula. Furthermore, the data collected provide a solid basis for adjusting and improving pedagogical strategies and robotics applications, ensuring that the positive impact on student learning is optimized.

Qualitatively, teacher observations highlight the ability of robotics to foster student collaboration and engagement. This more motivating and inclusive learning environment suggests that educational policies should consider integrating robotics as a pedagogical tool that can be used in a wide range of contexts, including those with limited or rural resources. The flexibility of robotics allows its adaptation to diverse pedagogical and cultural needs, making this technology a key factor in overcoming structural challenges in education.

The results of this research have important implications for the design of teacher training programs. The didactic strategies identified provide a solid foundation for future training initiatives in educational technology. It is crucial that these innovative pedagogical practices be adapted to diverse educational contexts, thus ensuring the sustainability of technological innovations in mathematics education.

This study underscores the need for educational policies that prioritize the integration of robotics into the broader mathematics curriculum. The positive impact of robotics in different types of schools supports the idea that educational technologies can offer egalitarian solutions in education. This approach could help close educational gaps between different socioeconomic groups, particularly in STEM education.

In the future, it would be beneficial to conduct longitudinal studies to assess the long-term effects of robotics on students' academic performance and emotional development. In addition, it is recommended to explore how teacher training strategies can be optimized to maximize the benefits observed in this study. Further research could examine the impact of robotics on equity of opportunity, as evidence suggests that these technologies can be a key tool for improving education in diverse contexts.

In conclusion, this study makes a significant contribution by providing empirical evidence on the benefits of educational robotics in mathematics learning. Not only have these technologies been shown to improve students' academic outcomes, but they also transform the way teaching and learning occurs in classrooms. This technological approach should be considered a key strategy in future educational policies, given its potential to improve both student achievement and essential skills in an increasingly digital world.

GRATITUDE NOTE

The author would like to thank the parties that have provided support for the refinement of this research. The authors thank the Universidad Francisco de Paula Santander for funding the project entitled “Integration of Pedagogical Robots in the Teaching of First Grade Mathematics: An Innovative Approach to Technological and Computational Education” under Co-funding Contract No. 029-2023.

REFERENCES

1. González-Fernández, M.O. “Panorama de la robótica educativa a favor del aprendizaje STEAM” *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*, 18(2), 230101-230123 (2021).
2. Angel-Fernández, J. M., & Vincze, M. “Towards a Definition of Educational Robotics,” in *Proceedings of the Austrian Robotics Workshop 2018*, edited by P. Zech and J. Piater (Innsbruck university press, Austria, 2018), pp. 37–42.
3. Bers, M.U. *Coding as a playground: Programming and computational thinking in the early childhood classroom* (Eye On Education, 2020).
4. Lindh, J., & Holgersson, T. “Does lego training stimulate pupils’ ability to solve logical problems?” *Computers & Education,* 49(4), 1094-1111 (2007).
5. Fadel, C., Bialik,M., & Trilling, B. *Four-Dimensional Education* (Center for Curriculum Redesign, 2015).

6. Screpanti, L., Miottiand,B., & Monteriú, A. "Robotics in education: A smart and innovative approach to the challenges of the 21st century.," in *Makers at school, educational robotics and innovative learning environments. Lecture Notes in Networks and Systems,* edited by D. Scaradozzi, L. Guasti, M. Di Stasio, B. Miotti, A. Monteriú and P. Bikstein (Springer, Cham, 2021), pp. 17–16.
7. Alimisis, D. "Educational robotics: Open questions and new challenges", 6(1), 63-71 (2013).
8. Barreto, F. "Exploring the educational potential of robotics in schools: A systematic review" *Computers & Education***,** 58(3), 978-998 (2012).
9. Arí, N. & Orcos, L. "Educational robotics in the stage of secondary education: Empirical study on motivation and STEM skills" *Education Sciences,* 9**(**2) 73 (2019).
10. Ribeiro, C., Coutinho, C., & Costa, M. F. "Educational Robotics as a pedagogical tool for approaching problem solving skills in Mathematics within elementary education", *6th Iberian Conference on Information Systems and Technologies*, (IIEE Xplore, Portugal, 2011), pp. 1-6.
11. Euuchi, A. "Educational Robotics for Promoting 21st Century Skills", *Journal of Automation Mobile Robotics and Intelligent Systems*, 8**,** 5-11 (2014).
12. Suvillan, A., & Bers, M. U. "Robotics in the early childhood classroom: learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade", *Int J Technol Des Educ,* 26, 3-20 (2016).
13. Ouyang, F., & Xu, W. "The effects of educational robotics in STEM education: a multilevel meta-analysis", *IJ STEM Ed*, 11(7) (2024).
14. Hsieh, Y. Z., Lin, S. S., Luo, Y. C., Jeng, Y. L., Tan, S. W., Chen, C. R., & Chiang, P. Y. "ARCS-Assisted teaching robots based on anticipatory computing and emotional big data for improving sustainable learning efficiency and motivation", *Sustainability,* 12(14), 5605 (2020).
15. Ferguson, R., Coughlan, T., Egelandsdal, K., Gaved, M., Herodotou, C., Hillaire, G., Jones, D., Jowers, I., Kukulska-Hulme, A., McAndrew, P., Misiejuk, K., Ness, I.J., Rienties, E., Scanlon, B., Sharples, M., Wasson, B., Weller, M., & Whitelock, D. *Innovating pedagogy 2019. Exploring new forms of teaching, learning and assessment, to guide educators and policy makers, Open University innovation report 7. The Open University, Milton Keynes* (The Open University, Milton Keynes, 2019).
16. Creswell, J. W. *Research design: Qualitative, quantitative, and mixed methods approaches* (SAGE Publications, Thousand Oaks, 2014).
17. Khanlari, A. "Teachers' perceptions of using robotics in primary/elementary schools in Newfoundland and Labrador," Master. thesis, University of Newfoundland, 2014.
18. Kopcha, T. J. , McGregor, J., Shin, S., Quian, Y., Xhoi, J., Hill, R., Mativo,J., & Choi, I. "Developing an Integrative STEM Curriculum for Robotics Education Through Educational Design Research", *J Form Des Learn*, 1, 31–44 (2017).
19. Márquez, J. E., & Ruiz, J. H. "Robótica educativa aplicada a la enseñanza básica secundaria", *Didáctica, Innovación y Multimedia*, 30, 1-12 (2014).
20. Field, A. *Discovering Statistics Using IBM SPSS Statistics: And Sex and Drugs and Rock "N" Roll*, (Sage, Los Angeles, 2013).
21. Creswell, J. W., & Post, C. N. *Qualitative inquiry and research design: Choosing among five approaches* (SAGE Publications, Thousand Oaks, 2016).
22. Flick, U. *An Introduction to Qualitative Research* (Sage Publications, London, 2009).
23. Wiles, J. C. *What are Qualitative Research Ethics?* (A& C Black, 2012).
24. Cohen, L., Manion, L., & Morrison, K. *Research Methods in Education* (Routledge, London, 2017).
25. McKnight, K., O'Malley, K., Ruzic, R., Horsley, M. K., Franey, J. J., & Bassett, K. "Teaching in a digital age: How educators use technology to improve student learning", *Journal of Research on Technology in Education*, 48(3), 194-211 (2016).
26. Hedges, L.V., & Olkin, I. Statistical methods for meta-analysis (Academic Press, 1985).
27. Tabachnick, B. G., & Fidell, L. S. *Using multivariate statistics* (Pearson, 2019).
28. Cohen, J. *Statistical power analysis for the behavioral sciences* (Routledge, New York, 1988).
29. Highfield, K. "Robotic toys as a catalyst for mathematical problem solving", *Australasian Journal of Educational Technology, 26*(4), 495-510 (2010).
30. Mwangi, P. N., Muriithi, C. M., & Agufana, P. B. "Exploring the benefits of educational robots in STEM learning: A systematic review", *International Journal of Engineering and Advanced Technology,* 11(6), 5-11 (2022).
31. Sharif, S., Muniandy, T., & Mariappan, M. "Exploring the impact of robotics program in enhancing students' science attitude", *International Journal of Education, Psychology and Counseling*, 8(51), 50-64 (2023).
32. Johnson, L., Becker, A., Estrada, V., & Freeman, A. *NMC Horizon Report: 2014 K-12* (The New Media Consortium, Austin, Texas, 2014).
33. García-Holgado, A., González González, C., & Peixoto, A. "Bridging the diversity gap in STEM," in *Proceedings of the 7th Technological Ecosystems for Enhancing Multiculturality (TEEM*), edited by M. A. Conde León and F. J. Rodríguez (Association for Computing Machinery, New York, 2019), pp. 193-195.

34. Papert, S. *Mindstorms: Children, computers, and powerful ideas* (Basic Books, New York, 1980).
35. Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan,K., & Silverman, B. "Scratch: Programming for all", *Communications of the ACM,* 52(11), 60-67 (2014).