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Jose Carlos Sanchez Tapia

jsanchezt@ups.edu.ec

Universidad Politécnica Salesiana

Luis Alfredo Calle

Universidad Politécnica Salesiana

Fernando Moscoso

Universidad Politécnica Salesiana

Juan Cárdenas Tapia

Universidad Politécnica Salesiana

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Impact of Educational Robotics on Enhancing Fine Motor Skill Development in Adolescents

José Carlos Sánchez Tapia[1,*], Luis Alfredo Calle Arévalo[1], Victor Fernando Moscoso Merchan[1], and Juan Alcides Cárdenas Tapia[1]

[1]Research Group Learn to Learn (GIAA), Universidad Politécnica Salesiana, Cuenca, 010101, Azuay, Ecuador
[*]jsanchezt@ups.edu.ec

ABSTRACT

This study sought to evaluate the effect of robotics workshops, centered on hands-on assembly and block-based visual programming, on the fine motor skills of adolescents. A quasi-experimental pretest-postest design was employed involving 53 participants aged 12 to 17. Manual dexterity was evaluated before and after a two-week robotics-based educational intervention, consisting of structured robotics courses utilizing LEGO MINDSTORMS EV3 and VEX IQ kits, using the Purdue Pegboard Test. The results revealed a statistically significant improvement ($p < 0.005$) across the four test metrics: dominant hand, non-dominant hand, both hands, and assembly. The effect size was particularly substantial for bimanual coordination ($d = 0.71$). Furthermore, the analysis demonstrated that the improvement was consistent and independent of the participants' initial skill levels. It is concluded that participation in robotics workshops involving intensive manipulation of small components was associated with significant pre–post improvements in fine motor performance in this sample. Given the one-group pretest–posttest design, these findings should be interpreted as evidence consistent with a beneficial effect, while acknowledging potential threats to causal inference.

Introduction

While educational robotics has become a well-established tool within the STEAM approach for developing cognitive abilities, its impact on the psychomotor domain remains insufficiently quantified. The development of fine motor skills, which involve the precise coordination of small muscle groups in the hands and fingers, is a fundamental component of comprehensive psychomotor development[1]. Although their foundation is established during childhood[2], adolescence represents a critical stage for the refinement and automation of these skills, which are indispensable for an increasing range of complex tasks[3,4]. Robust scientific evidence demonstrates a significant positive correlation between fine motor proficiency and academic performance in key areas such as mathematics and literacy[5–7]. In an era dominated by digital interaction, which often favors repetitive gestures over tactile manipulation[8,9], ensuring that young people continue to develop robust manual dexterity remains a relevant pedagogical challenge. In this context, active methodologies such as the STEAM (Science, Technology, Engineering, Arts, and Mathematics) framework provide an ideal setting by promoting practical, tangible learning that inherently engages both cognition and physical action[10,11].

Within the STEAM ecosystem, educational robotics has emerged as a high-impact pedagogical instrument. Its value lies not only in introducing programming or electronics but also in its inherently constructivist and kinesthetic nature[12]. Robotic assembly requires students to interpret diagrams, select components, and manipulate them with precision—a process that fosters hand-eye coordination and bimanual dexterity. Despite these evident benefits, scientific literature has tended to focus on the cognitive outcomes of educational robotics, such as improvements in computational thinking, cognitive function, or problem-solving[13–15]. Consequently, there is a notable research gap regarding the rigorous quantification of its specific impact on the psychomotor domain. The potential of these activities as a direct training ground for manual dexterity has been largely overlooked, resulting in a lack of empirical evidence validating robotics workshops as an effective intervention for motor development[16].

The present study directly addresses this gap, with the primary objective of quantitatively evaluating the impact of a two-week educational robotics intervention on the fine motor skill development of students aged 12 to 17. To ensure objective and reliable measurements, a quasi-experimental pretest-postest research design was employed, utilizing the Purdue Pegboard Test as a standardized instrument[17]. It was hypothesized that active participation in the assembly tasks during the workshops would result in a statistically significant improvement across the four dimensions of manual dexterity assessed by the test: dominant hand, non-dominant hand, both hands simultaneously, and assembly.

Results

The data obtained through the Purdue Pegboard Test were analyzed to determine the efficacy and consistency of the intervention. The analysis begins with the descriptive statistics of the scores, summarized in Table 1. Overall, an increase in mean scores across all metrics is observed when comparing postest results with pretest values, suggesting a trend of performance improvement among participants following the intervention.

Metric	Phase	Mean $\pm$ SD	Minimum	Maximum
Dominant Hand	Pretest	12.87 ± 1.94	9.0	18.0
	Posttest	13.60 ± 2.14	9.0	20.0
Non-Dominant Hand	Pretest	12.11 ± 1.49	7.0	16.0
	Posttest	12.55 ± 1.68	7.0	18.0
Both Hands	Pretest	20.25 ± 2.92	12.0	26.0
	Posttest	21.92 ± 3.20	15.0	30.0
Assembly	Pretest	5.71 ± 1.64	3.0	13.0
	Posttest	6.17 ± 1.50	3.0	9.0

Table 1. Descriptive statistics for pretest and posttest scores (N=53). Data are presented as mean $\pm$ standard deviation (SD) alongside minimum and maximum values.

The results of the inferential analysis to determine the statistical significance and magnitude of these improvements are presented below.

Overall Efficacy of the Robotics Intervention

The primary analysis revealed a statistically significant increase in fine motor skill performance following participation in the workshops. Table 2 summarizes the results of the Wilcoxon Signed-Rank Test. Significant improvements ($p < 0.005$) were observed across the four evaluated metrics, with effect sizes ranging from medium to large for bimanual dexterity ($d = 0.71$) and medium for the dominant hand ($d = 0.51$).

Metric	W	p	Cohen's *d*	Effect Magnitude
Dominant Hand	29.00	< 0.001	0.51	Medium
Non-Dominant Hand	58.50	0.003	0.44	Small-Medium
Both Hands	41.50	< 0.001	0.71	Medium-Large
Assembly	47.50	0.001	0.30	Small

Table 2. Comparative analysis of pretest and postest scores. The W statistic corresponds to the Wilcoxon Signed-Rank Test.

Figure 1 visually corroborates these findings, showing a positive shift in the medians and the overall distribution of postest scores. An improvement in data consistency is noted, particularly for the dominant hand and assembly tasks, with a more pronounced effect in the "Both Hands" category. Regarding the "Non-Dominant Hand" metric, the graphical representation does not intuitively reflect the statistical significance detected by the Wilcoxon test; this divergence is attributed to the pronounced data dispersion within this subgroup.

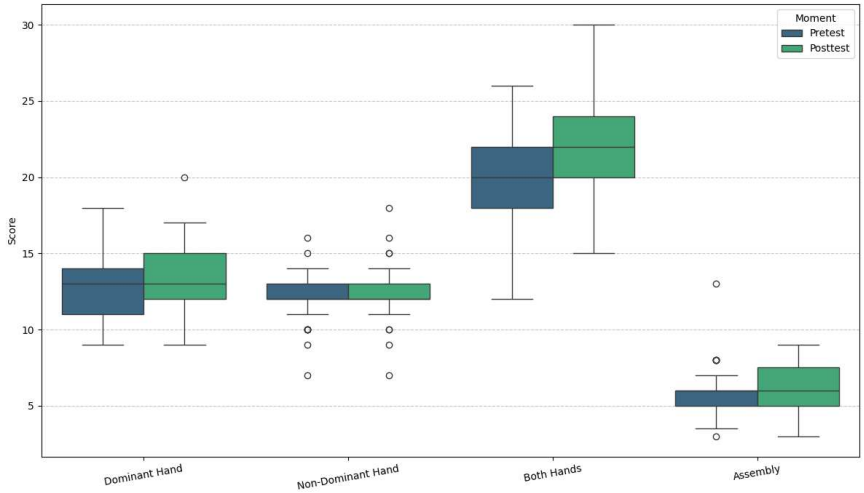


Figure 1. Box plots displaying the distribution of pretest (blue) and posttest (green) scores across the four Purdue Pegboard Test metrics. The data illustrate the overall shift in manual dexterity performance before and after the robotics intervention for **a** dominant hand, **b** non-dominant hand, **c** both hands, and **d** assembly tasks.

To analyze the distribution of the magnitude of this improvement, histograms of the score differences (Postest - Pretest) were generated. As illustrated in Figure 2, the improvement was notable and nearly unanimous for the "Both Hands" task, showing a clear positive skew in the distribution of differences. In contrast, the improvement was less significant for the "Non-Dominant Hand," where the distribution was centered near zero, indicating that individual gains and losses statistically offset each other. For the other two tasks, the graph confirms that while most students improved, the high data dispersion precludes concluding a significant gain at the group level.

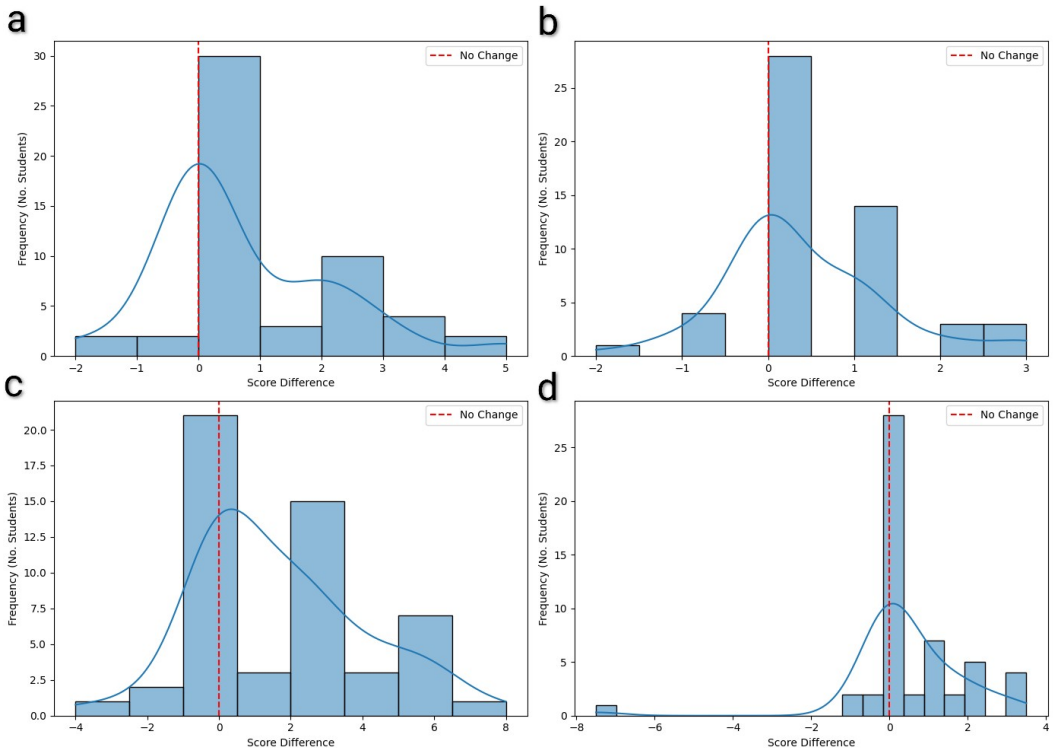


Figure 2. Histograms showing the distribution of score gains (posttest minus pretest) for the four Purdue Pegboard Test subtasks: **a** dominant hand, **b** non-dominant hand, **c** both hands, and **d** assembly. The vertical red dashed line represents zero change, while positive values on the x-axis indicate an improvement in dexterity.

Consistency of the Effect at Individual and Skill Levels

While the global analysis confirms that the intervention was effective on average, it is essential to examine the consistency of this effect. A positive average result could, theoretically, be driven by very large improvements in a small subgroup of participants, masking a lack of effect for the majority. Therefore, this section analyzes two key aspects of consistency: first, whether the improvement was a widespread phenomenon at the individual participant level and, second, whether the magnitude of the improvement was equitable across the entire spectrum of initial skill levels.

To determine if the observed improvement was a generalized phenomenon, individual participant changes were analyzed.

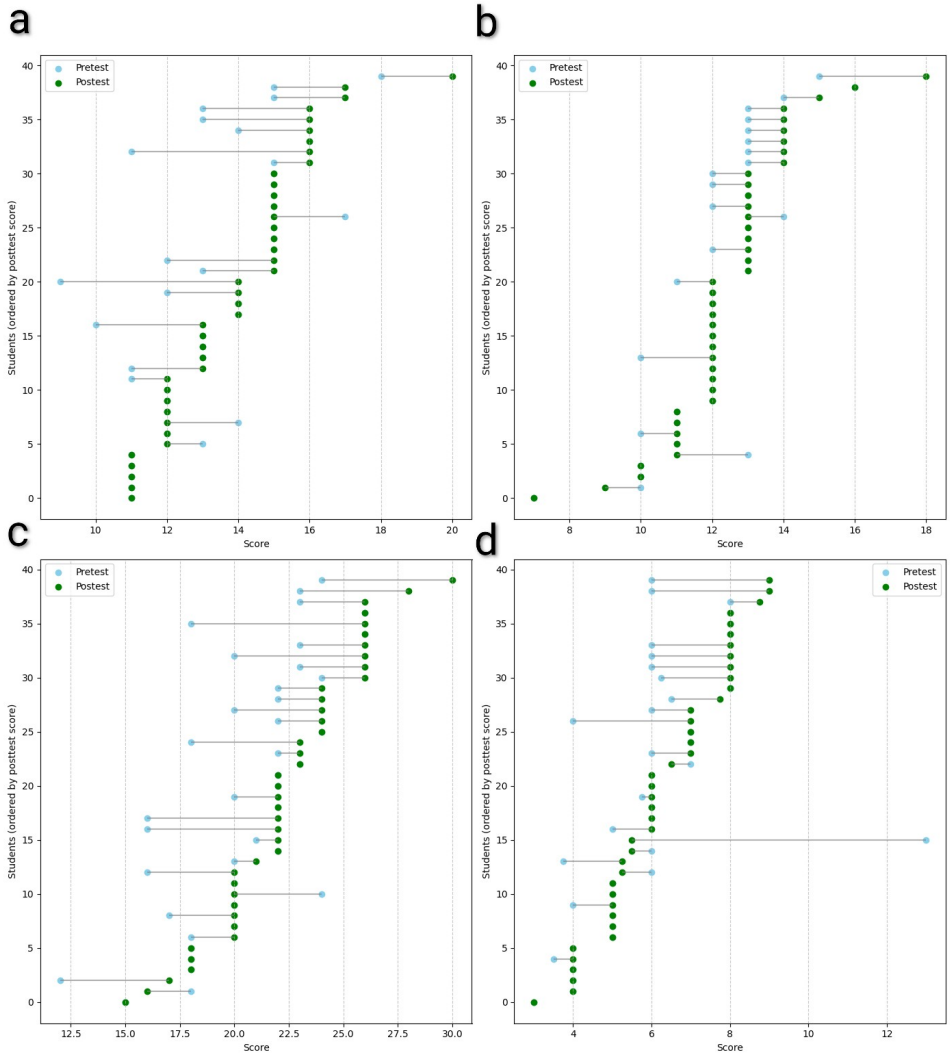


Figure 3. Dumbbell plots illustrating individual performance trajectories for a subsample of 40 students from pretest (light blue circles) to posttest (dark green circles). The panels represent the four Purdue Pegboard Test subtasks: **a** dominant hand, **b** non-dominant hand, **c** both hands, and **d** assembly. Participants are ordered on the y-axis according to their posttest scores, with the length and rightward direction of the connecting lines indicating the magnitude of individual dexterity improvement.

Figure 3 illustrates individual trajectories for a subsample of 40 participants, visually revealing a markedly positive and homogeneous effect in the "Both Hands" task. Conversely, performance in the "Non-Dominant Hand" is characterized by considerable response variability, with positive, negative, and null changes observed, explaining the absence of a defined group trend.

Additionally, it was investigated whether the magnitude of improvement was conditioned by the student's initial skill level. A linear regression analysis on the data from the Bland-Altman plot (Figure 4) revealed a fairly uniform distribution of scores, suggesting that the intervention benefited all skill levels equitably.

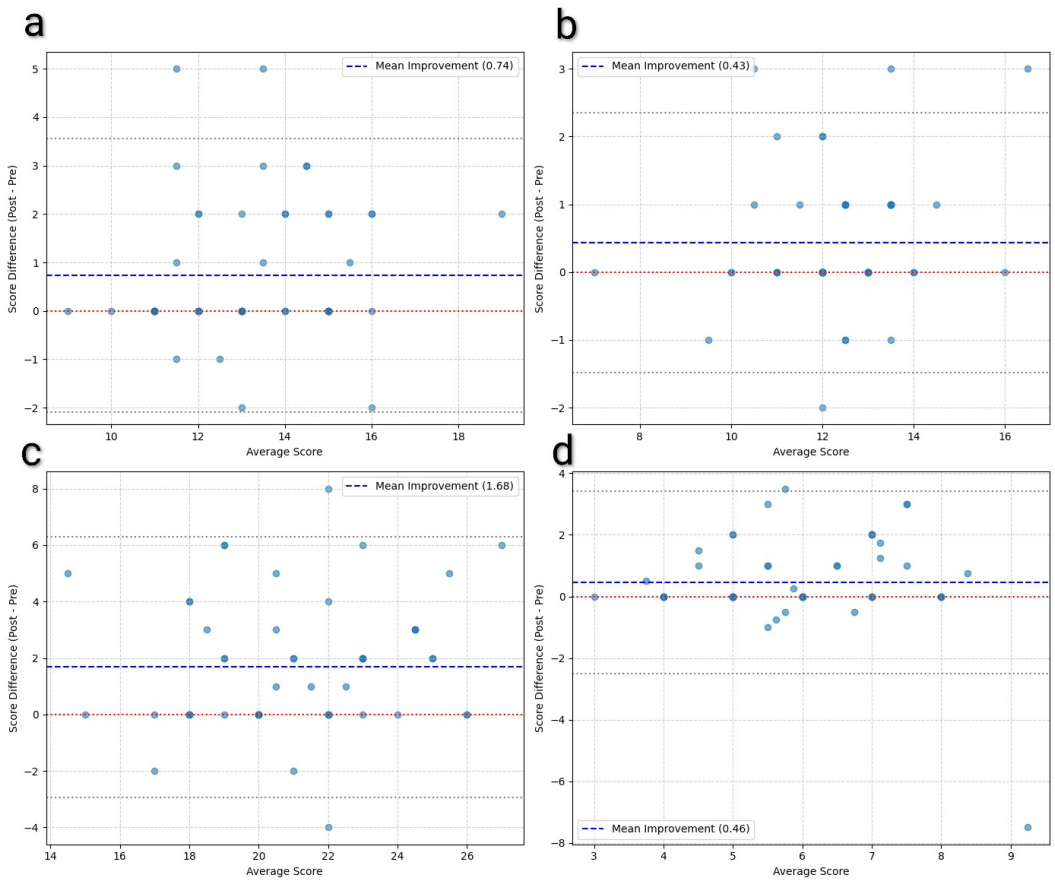


Figure 4. Bland-Altman plots assessing the relationship between mean scores and score differences for the four Purdue Pegboard Test subtasks. The panels correspond to **a** dominant hand, **b** non-dominant hand, **c** both hands, and **d** assembly. The x-axis displays the average of the pretest and posttest scores, while the y-axis shows the score difference (posttest minus pretest). The horizontal red dotted line indicates zero change, and the blue dashed line represents the mean improvement for each respective task.

Numerical analysis found no statistically significant correlation between a student's average score and their score gain across any of the four metrics ($p > 0.05$ in all cases). These results, detailed in Table 3, corroborate that the intervention was equitably effective, benefiting both students with low initial performance and those with greater baseline dexterity.

Metric	p-value	Significant Trend
Dominant Hand	0.293	No
Non-Dominant Hand	0.142	No
Both Hands	0.369	No
Assembly	0.430	No

Table 3. Results of the regression analysis to evaluate the dependence of improvement on the initial skill level.

Discussion

The results of this study robustly confirm the initial hypothesis: an educational robotics workshop centered on hands-on assembly serves as an effective intervention to significantly enhance fine motor skills in adolescents. The following discussion interprets the nature of these findings, situates them within the context of current scientific literature, and reflects on their implications and the future research avenues opened by this work.

The most pronounced improvement, in terms of both statistical significance and effect size ($d = 0.71$), was observed in bimanual dexterity. This finding is particularly insightful and can be directly attributed to the inherent nature of the workshop

activities. Construction with systems such as LEGO and VEX IQ necessitates constant bimanual coordination, where one hand stabilizes the structure while the other manipulates and connects components. This result validates the workshop not merely as a learning activity but as a functional training environment for motor coordination. Furthermore, a highly relevant outcome is the consistency of the effect; the analysis demonstrated that the improvement was equitable and independent of the participants' initial skill levels, underscoring the value of robotics as an inclusive pedagogical tool.

These findings contribute empirical evidence to an underexplored area. While numerous studies have focused on the cognitive benefits of robotics, this work quantifies its impact on the psychomotor domain. The results are consistent with literature establishing a strong link between motor competence and academic performance[5,6], suggesting that kinesthetic activities like robotics do not only teach technology but can also strengthen the fundamental skills underlying overall academic success. This study, therefore, positions robotics not just as a STEAM discipline, but as a tool for comprehensive development.

Moreover, the study's design strengthens the attribution of these results to the intervention. The fact that the workshops were conducted during the participants' school holiday period is a critical detail, as it minimized the influence of confounding variables, such as school assignments, that might have affected the students' motor development. By being immersed almost exclusively in workshop activities, the interpretation that the observed improvements are a direct consequence of intensive exposure to robotic prototype assembly is reinforced.

The practical implications of these findings for education are clear. This study demonstrates that integrating robotics into the curriculum can be an effective and engaging strategy not only for teaching technology but also for psychomotor development. Educators are encouraged to value and leverage the kinesthetic component of these activities. Future work could explore the long-term impact of these interventions and compare the effectiveness of different robotic platforms in developing specific motor sub-skills, thereby consolidating the role of robotics as a holistic educational tool.

The findings of this study transcend the technical mastery of robotics kits and have important socio-pedagogical implications in the digital age. In the current educational landscape, often dominated by touch-screen interactions, there is a growing concern regarding the "fine motor gap" in adolescents. Our results demonstrate that the tactile nature of robotics—manipulating small pins, gears, and sensors—provides a necessary "re-skilling" of the hands. From a constructionist perspective, this physical engagement is not merely a mechanical exercise; it is a cognitive anchor. The significant improvement in the 'Assembly' task suggests that students developed a higher level of visuospatial integration. Furthermore, the equitable nature of the gains observed across the group—regardless of whether students came from public or private backgrounds—indicates that educational robotics functions as a "pedagogical leveler." In a social context where access to specialized technical training varies, these 2-hour daily sessions provided a standardized platform for psychomotor development, ensuring that all students could achieve the manual proficiency required for future success in STEM-related fields.

In conclusion, active participation in robotic assembly tasks constitutes an effective method for achieving significant and measurable improvements in manual dexterity across multiple dimensions. While quantitative analysis demonstrated a statistically significant increase across all subtasks evaluated by the Purdue Pegboard Test, the effect magnitude varied. The kinesthetic nature of the workshops served as functional training, yet its impact was most pronounced in skills requiring bimanual cooperation and the use of the dominant hand, with the non-dominant hand exhibiting more modest gains. Despite these disparities, the overall benefit remained equitable and independent of the participants' initial skill levels. Ultimately, this work provides empirical evidence validating educational robotics not only as a tool for teaching STEAM concepts but also as an effective strategy for psychomotor development. These findings offer a robust justification for educators to integrate these technologies for their demonstrated benefit in strengthening fundamental motor competencies. In an educational landscape striving for comprehensive development, educational robotics emerges as a holistic pedagogical tool capable of meaningfully bridging abstract computational thinking with precise physical action.

Methods

The research followed a quasi-experimental pretest-postest design conducted across two educational robotics workshop models, each spanning a two-week duration. One workshop was centered on the LEGO MINDSTORMS EV3 education environment[18], while the other utilized the second-generation VEX IQ Classroom Bundle ecosystem[19]. Although each robotic platform possesses distinct characteristics, both workshops were guided by a shared pedagogical philosophy: hands-on, project-based learning aimed at fostering STEAM competencies. The intervention specifically focused on enhancing fine motor skills through a progressive learning framework, as illustrated in the diagram in Figure 5.

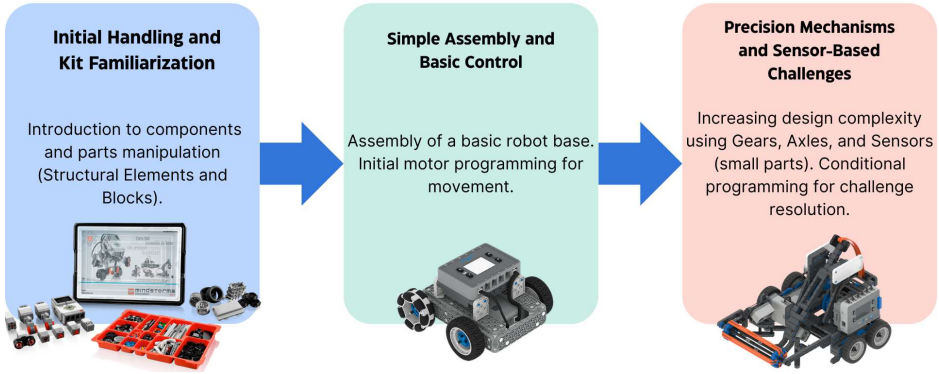


Figure 5. Schematic diagram illustrating the progression of activities and the specific fine motor skill focus throughout the two-week educational robotics workshops.

The pedagogical approach did not focus on increasing component volume but rather on gradually escalating the complexity of the mechanisms and programming logic. The initial phase began with the guided construction of a base robot using a manual and the mastery of the block-based visual programming environment, ensuring that all students shared a common technical baseline. From there, the methodology transitioned toward challenge-based learning: for subsequent projects, a specific objective was set, and students were required to apply their own design considerations and component selections to solve it, thereby fostering active participation and critical thinking.

Participants and Ethical Declarations

The study sample comprised a total of 53 students, aged 12 to 17, from various public and private educational institutions in Cuenca, Ecuador. The gender distribution consisted of 13 female and 40 male participants. Written informed consent was obtained from the parents or legal guardians of all students prior to the start of the pedagogical intervention, which took place during the participants school holiday period.

This research was conducted in accordance with the tenets of the Declaration of Helsinki. Ethical review and approval were explicitly waived for this study by the Universidad Politécnica Salesiana. This waiver was granted as the research was a retrospective analysis of anonymized pedagogical performance data, which had been routinely collected during the standard operation of the educational workshops. The study design and the use of the waiver are in alignment with the Organic Law on the Protection of Personal Data of Ecuador (Art. 7, paragraph 4) and the Universidad Politécnica Salesiana Policy for the Treatment, Protection, and Use of Personal Data and Information Classification (Resolution No. 128-104-2023-04-19), which classified this analysis as a minimal risk study involving only existing educational records.

Instrument: Purdue Pegboard Test

The Purdue Pegboard Test, a standardized and widely validated instrument for measuring manual dexterity, was utilized for the quantitative assessment of fine motor skills. Originally developed by Tiffin in 1948 to evaluate the dexterity of assembly line job candidates, its application has since expanded into fields such as rehabilitation, neuropsychological assessment, and occupational medicine, demonstrating its robustness and reliability over time[20–22].

The test is designed to measure fine motor coordination and gross manual dexterity through four timed subtasks:

1. **Dominant Hand:** Insertion of the maximum number of pegs into the board's holes using only the dominant hand for 30 seconds.
2. **Non-Dominant Hand:** Insertion of the maximum number of pegs into the board's holes using only the non-dominant hand for 30 seconds.
3. **Both Hands:** Insertion of the maximum number of pegs using both hands simultaneously and in a coordinated manner for 30 seconds.
4. **Assembly:** Construction of "assembly" sequences (peg, washer, collar, and washer) using both hands alternately for 60 seconds[17].

The score for each subtask corresponds to the number of elements correctly placed or assembled within the stipulated time. Its sensitivity in detecting changes in dexterity makes it an ideal instrument for the pretest-postest design of this study.

Procedure and Pedagogical Intervention

The intervention was grounded in the fusion of constructivism and kinesthetic learning. The construction process constitutes an intensive exercise in hand-eye coordination and dexterity, and this demand for precision is analogously reflected in the block-based visual programming.

Activities were presented as a series of challenges that prompted students to apply an iterative design cycle, as schematized in Figure 6. When faced with a prototype exhibiting suboptimal performance, students were required to make adjustments within a feedback loop. This continuous optimization process yields a dual outcome: constant physical manipulation refines motor skills, while code debugging fosters computational thinking.

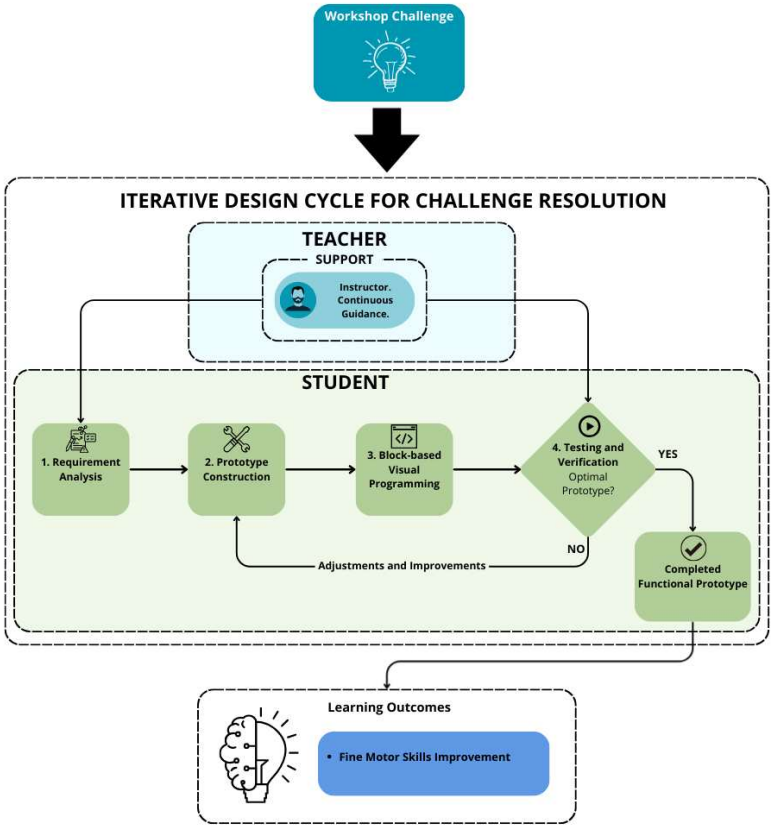


Figure 6. Flowchart outlining the iterative design cycle employed by students to resolve mechanical and programming challenges. The process highlights the continuous feedback loop between prototype construction, block-based visual programming, and performance testing.

The following sections detail the daily activities that implemented this methodological framework.

Workshop 1: LEGO MINDSTORMS EV3

This workshop focused on the LEGO MINDSTORMS EV3 ecosystem. Activities were designed to progressively increase in mechanical and logical complexity, as detailed in Table 4. The objective was for students to become familiar with a modular construction system requiring the precise connection of beams, pins, and gears.

Workshop 2: VEX IQ

The second workshop utilized the VEX IQ Classroom Bundle kit, which features a snap-fit construction system. This provided a stimulus for fine motor skills similar to LEGO, albeit requiring a different application of force and coordination. The progression of activities is summarized in Table 5.

Day	Main Topic	Activities and Fine Motor Skill Focus
Day 1	Introduction and Initial Construction	Kit introduction, parts sorting, and base robot assembly. **Motor focus:** Initial manipulation of 79 pieces, including 32 small components (pins and axles), for familiarization and basic dexterity.
Day 2	Basic Movement Programming	Completion of the base assembly and programming of basic movements (forward, backward, and turns). **Motor focus:** Assembly reinforcement, ensuring firm connections that require precision.
Day 3	Loops and Additional Actuators	Introduction to programming loops and mounting an additional medium motor onto the prototype. **Motor focus:** Integration of a new component, requiring dexterity to couple it with the existing structure.
Day 4	Creative Design: Dancing Robot	Commencement of free design and construction of a "dancing robot" using all available parts. **Motor focus:** Fostering creativity through free manipulation and experimentation with various mechanical joints.
Day 5	Conditionals and Gears	Completion of the dancing robot. Introduction to conditionals and reconstruction into a sumo robot, integrating a gear system. **Motor focus:** Precision assembly of axles and gears, manipulating a total of 96 pieces (39 small).
Day 6	Design for Competition	Completion of the sumo prototype with the addition of a front ramp. Commencement of competition programming. **Motor focus:** Coupling a new substructure (the ramp), requiring spatial planning and dexterity.
Day 7	RC and Autonomous Sumo Competition	Remote-controlled (RC) Sumo competition. Introduction to color and infrared sensors for autonomous sumo robot programming. **Motor focus:** Precise mounting and calibration of sensors onto the chassis.
Day 8	Advanced Programming	Finalization of programming and Autonomous Sumo competition. **Motor focus:** Fine adjustments to sensor mounting based on observed performance.
Day 9	Line Follower Robot	Assembly of a new line-follower robot prototype. **Motor focus:** Construction of a more compact and dense robot, handling 78 total pieces (44 of which were small), requiring high precision.
Day 10	Final Evaluation	Administration of the postest using the Purdue Pegboard Test to all participants.

Table 4. Daily activity plan for the LEGO MINDSTORMS EV3 workshop, detailing the progression of mechanical complexity and motor skill focus.

Data Analysis

Intervention data were digitized and anonymized. For each participant, a unique identifier, age, and scores obtained across the four Purdue Pegboard Test subtasks (dominant hand, non-dominant hand, both hands, and assembly) were recorded for both the pretest and postest phases.

A significance level (alpha) of $\alpha = 0.05$ was established for all hypothesis testing. The analysis plan was as follows:

- **Descriptive Statistics:** Measures of central tendency (mean, median) and dispersion (standard deviation) were calculated to characterize the sample and the score distributions in both measurement phases.
- **Pre-Post Improvement Analysis:** The selection of the appropriate statistical test was based on the distribution of differences between postest and pretest scores. Normality of these differences was assessed using the Shapiro-Wilk test, whose statistic W is defined as:

$$W = \frac{(\sum_{i=1}^{n} a_i x_{(i)})^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{1}$$

where $x_{(i)}$ are the sample order statistics, $\bar{x}$ is the mean, and the coefficients a_i are tabulated constants[23]. Since the results of this test indicated a deviation from normality ($p < 0.05$), a non-parametric test was utilized.

Day	Main Topic	Activities and Fine Motor Skill Focus
Day 1	Introduction and Base Construction	Kit introduction and commencement of base robot assembly. **Motor focus:** Initial manipulation of 106 components, including 76 small-scale parts.
Day 2	Movement Programming	Finalization of base assembly and initial movement calibration. **Motor focus:** Continuous practice and reinforcement of assembly.
Day 3	Programming Logic (Virtual)	Programming activities within the VEX VR environment to develop logic without manual motor demand.
Day 4	Sensor Integration	Mounting distance sensors onto the physical chassis and real-world testing. **Motor focus:** Precise attachment and wiring.
Day 5	End Effector Construction: Claw	Assembly of a mechanical claw mechanism. **Motor focus:** Construction of a complex subsystem involving 36 additional mobile components.
Day 6	Optimization and Application	Block sorting activity and trajectory optimization. **Motor focus:** Fine adjustments to claw tension and alignment.
Day 7	Final Project Initiation: Catapult	Introduction to binary concepts and start of the catapult robot assembly. **Motor focus:** Handling 411 total pieces.
Day 8	Advanced Construction	Continued assembly of the catapult mechanism. **Motor focus:** Intensive manipulation of 240 small components.
Day 9	Calibration and Testing	Finalization of construction and mechanical fine-tuning. **Motor focus:** Precision mechanical calibration.
Day 10	Competition and Evaluation	Internal catapult competition and administration of the Purdue Pegboard postest.

Table 5. Daily activity plan for the VEX IQ workshop, highlighting fine motor skill engagement through snap-fit assembly.

The comparison between scores was performed using the Wilcoxon Signed-Rank Test instead of the t-test due to the non-normality of the analyzed data. The test statistic W is calculated as the minimum of the sum of positive difference ranks (W^+) and the sum of negative difference ranks (W^-):

$$W = \min(W^+, W^-) \tag{2}$$

The **p-value** associated with this statistic is determined by comparing the observed W value with its theoretical probability distribution under the null hypothesis.

- **Effect Size Quantification:** To determine the practical magnitude of the improvement, Cohen's d for paired samples was calculated. The formula used was:

$$d = \frac{\bar{x}_{\text{diff}}}{s_{\text{diff}}} \tag{3}$$

where $\bar{x}_{\text{diff}}$ is the mean of the differences between postest and pretest scores, and s_{diff} is the standard deviation of those differences.

- **Trend Analysis (Bland-Altman):** To statistically verify the relationship between initial ability and the magnitude of improvement, a simple linear regression model was fitted. The model evaluates the slope (β_1) of the relationship between the difference in scores and their average:

$$(\text{Post} - \text{Pre}) = \beta_0 + \beta_1 \left(\frac{\text{Post} + \text{Pre}}{2} \right) + \varepsilon \tag{4}$$

The null hypothesis for this analysis is that no trend exists, i.e., $H_0 : \beta_1 = 0$[24].

Finally, for the primary analysis, data from participants in both workshops were pooled to increase statistical power and evaluate the overall effect of the intervention methodology.

Use of Artificial Intelligence

Artificial intelligence, specifically Large Language Models (LLMs), was utilized for the English translation, language refinement, and formatting of the manuscript to adhere to the journal's guidelines.

References

1. Suggate, S. P., Karle, V. L., Kipfelsberger, T. & Stoeger, H. The effect of fine motor skills, handwriting, and typing on reading development. *J. Exp. Child Psychol.* **232**, DOI: 10.1016/j.jecp.2023.105674 (2023).
2. Bukva, A. & Memisevic, H. Development of fine motor skills in elementary school students: Gender and age effects. *Multidiscip. Pristupi u Edukaciji i Rehabilitaciji* **6**, 14–22, DOI: 10.59519/mper6202 (2024).
3. Damme, T. V., Simons, J., Sabbe, B. & van West, D. Motor abilities of children and adolescents with a psychiatric condition: A systematic literature review. *World J. Psychiatry* **5**, 315, DOI: 10.5498/wjp.v5.i3.315 (2015).
4. Gokmen, G. Y., Yilmaz, F. N., Keskin, E., Kecelioglu, S. & Mutlu, E. K. Investigation of factors affecting motor competence in early adolescents. *Balikesir Heal. Sci. J.* DOI: 10.53424/balikesirsbd.1384674 (2023).
5. Wang, L. & Wang, L. Relationships between motor skills and academic achievement in school-aged children and adolescents: A systematic review. *Children* **11**, DOI: 10.3390/children11030336 (2024).
6. Li, Y., Wu, X., Ye, D., Zuo, J. & Liu, L. Research progress on the relationship between fine motor skills and academic ability in children: a systematic review and meta-analysis. *Front. Sports Active Living* **6**, DOI: 10.3389/fspor.2024.1386967 (2024).
7. Flores, P., Coelho, E., Mourao-Carvalhal, M. I. & Forte, P. Association between motor and math skills in preschool children with typical development: Systematic review. *Front. Psychol.* **14**, DOI: 10.3389/fpsyg.2023.1105391 (2023).
8. Petrigna, L. *et al.* Time spent on the smartphone does not relate to manual dexterity in young adults. *BMC Neurosci.* **22**, DOI: 10.1186/s12868-021-00639-y (2021).
9. Operto, F. F. *et al.* Digital devices use and fine motor skills in children between 3-6 years. *Children* **10**, DOI: 10.3390/children10060960 (2023).
10. Atikah, C. & Biru, L. T. Steam-based learning to enhance early childhood creativity. *Int. J. STEM Educ. for Sustain.* **4**, 164–175, DOI: 10.53889/ijses.v4i1.303 (2024).
11. Hsiao, H.-S., Chen, J.-C., Chen, J.-H., Chen, Y.-X. & Chung, G.-H. Incorporating the 6e model integrated with creative thinking strategies into steam education: Enhancing children's fine motor skills. *Early Child. Educ. J.* DOI: 10.1007/s10643-025-01981-0 (2025).
12. Huda, S., Zuhrie, M. S., Buditjahjanto, I. G. P. A. & Nurlaela, L. Implementation of educational robotic into teaching-learning process to enhance students skills in the science and technology. *J. Physics: Conf. Ser.* **1842**, DOI: 10.1088/1742-6596/1842/1/012062 (2021).
13. Fernandez-Batanero, J. M., Pinero-Virue, R., Rodriguez-Gonzalez, C. A. & Reyes-Rebollo, M. M. Educational robotics and attention to diversity: A case study. *Eur. J. Educ. Res.* **11**, 739–748, DOI: 10.12973/eu-jer.11.2.739 (2022).
14. Chandrashekhar, R. *et al.* The impact of cognition on motor learning and skill acquisition using a robot intervention in infants with cerebral palsy. *Front. Robotics AI* **9**, DOI: 10.3389/frobt.2022.805258 (2022).
15. Amri, S., Budiyanto, C. W., Fenyvesi, K., Yuana, R. A. & Widiastuti, I. Educational robotics: Evaluating the role of computational thinking in attaining 21st century skills. *Open Educ. Stud.* **4**, 322–338, DOI: 10.1515/edu-2022-0174 (2022).
16. Uslu, N. A., Yavuz, G. O. & Usluel, Y. K. A systematic review study on educational robotics and robots. *Interact. Learn. Environ.* **31**, 5874–5898, DOI: 10.1080/10494820.2021.2023890 (2023).
17. Mathiowetz, V., Rogers, S. L., Dowe-Keval, M., Donahoe, L. & Rennells, C. The purdue pegboard: norms for 14- to 19-year-olds. *The Am. journal occupational therapy* **40**, 174–179, DOI: 10.5014/ajot.40.3.174 (1986).
18. LEGO. Track3r gripp3r ev3rstorm. *LEGO Manuals* (2013).
19. VEX Robotics. Vex iq gen 2 kit contents. *VEX Robotics Documentation* (2021).
20. Lawson, I. Purdue pegboard test. *Occup. Medicine* **69**, 376–377, DOI: 10.1093/occmed/kqz044 (2019).
21. Irmak, A. Y. & Ketenciler, A. P. Purdue manual dexterity testing: Normative data from young people from turkey. *J. Hand Ther.* DOI: 10.1016/j.jht.2025.02.012 (2025).
22. Hockenberry, M. *et al.* Longitudinal evaluation of fine motor skills in children with leukemia. *J. Pediatr. Hematol.* **29**, 535–539, DOI: 10.1097/MPH.0b013e3180f61b92 (2007).
23. Rochon, J., Gondan, M. & Meinhard, K. To test or not to test: Preliminary assessment of normality when comparing two independent samples. *BMC Med. Res. Methodol.* 12–81, DOI: 10.1186/1471-2288-12-81 (2012).

24. Giavarina, D. Understanding bland altman analysis. *Biochem. Medica* **25**, 141–151, DOI: 10.11613/BM.2015.015 (2015).

25. Pitchford, N. J., Papini, C., Outhwaite, L. A. & Gulliford, A. Fine motor skills predict maths ability better than they predict reading ability in the early primary school years. *Front. Psychol.* **7**, DOI: 10.3389/fpsyg.2016.00783 (2016).

26. Jozsa, K., Oo, T. Z., Borbelyova, D. & Zentai, G. Exploring the growth and predictors of fine motor skills in young children aged 4-8 years. *Educ. Sci.* **13**, DOI: 10.3390/educsci13090939 (2023).

27. Cortes, R. A., Green, A. E., Barr, R. F. & Ryan, R. M. Fine motor skills during early childhood predict visuospatial deductive reasoning in adolescence. *Dev. psychology* DOI: 10.1037/dev0001354 (2022).

28. Zhang, T. *et al.* Higher fasting plasma glucose is associated with smaller striatal volume and poorer fine motor skills in a longitudinal cohort. *Psychiatry Res. Neuroimaging* **278**, 1–6, DOI: 10.1016/J.PSCYCHRESNS.2018.06.002 (2018).

29. Chen, C.-C. J. & Ringenbach, S. D. A pilot study for test-retest reliability of the purdue pegboard test in adolescents and young adults with down syndrome. *J. Mot. Learn. Dev.* **3**, 151–157, DOI: 10.1123/jmld.2015-0004 (2015).

30. Gardner, R. A. & Broman, M. The purdue pegboard: Normative data on 1334 school children. *J. Clin. Child Psychol.* **8**, 156–162, DOI: 10.1080/15374417909532912 (1979).

31. Havaei, N., Rezaei, M. & Rostami, H. R. Dexterity and two-point discrimination of the hand in school-aged children with dysgraphia. *Med. J. Islam. Repub. Iran* (2017).

32. Rodriguez-Guerrero, Y. I., Gil-Madrona, P., Leon, M. P. & Vasquez-Cruz, A. E. Relationship between fine/gross motor skills and language and math development in colombian caribbean children: A study in barranquilla. *Infant Child Dev.* **32**, DOI: 10.1002/icd.2430 (2023).

33. Mardani, S. & Budiarti, I. S. Professional competence of elementary school teachers in teaching mathematics by utilizing motor skills. *Sebelas Maret Univ. J.* **7**, 265–275 (2024).

34. Kalozi-Szabo, C., Mohai, K. & Cottini, M. Employing robotics in education to enhance cognitive development-a pilot study. *Sustain. (Switzerland)* **14**, DOI: 10.3390/su142315951 (2022).

35. D'Amico, A., Guastella, D. & Chella, A. A playful experiential learning system with educational robotics. *Front. Robotics AI* **7**, DOI: 10.3389/frobt.2020.00033 (2020).

36. Altiok, S. Effects of robotic coding on computational thinking skills of secondary school students. *Can. J. Learn. Technol.* **50** (2024).

37. D'Amico, A., Paci, G., di Domenico, L. & Geraci, A. Using educational robotics to support motor, cognitive, and social skills in a child with spinal muscular atrophy. a single-case study. *Comput. Hum. Behav. Artif. Humans* **5**, 100175, DOI: 10.1016/j.chbah.2025.100175 (2025).

38. Chao, F., Lin, H., Jiang, M. & Zhou, C. A developmental constraint driven approach to developmental robotic hand-eye coordination. *2012 IEEE Int. Conf. on Robotics Biomimetics* 1848–1853, DOI: 10.1109/ROBIO.2012.6491237 (2012).

39. Freeman, S. *et al.* Active learning increases student performance in science, engineering, and mathematics. *Proc. Natl. Acad. Sci. United States Am.* **111**, 8410–8415, DOI: 10.1073/pnas.1319030111 (2014).

40. Silva-Hormazabal, M. & Alsina, A. Exploring the impact of integrated steam education in early childhood and primary education teachers. *Educ. Sci.* **13**, DOI: 10.3390/educsci13080842 (2023).

41. Akcay, B., Kecelioglu, S., Ozen, M. S., Gokmen, G. Y. & Yuce, H. Effect of smartphone addiction level on manual and finger dexterity, hand grip strength, pinch grip strength, and thumb pressure pain threshold in university students. *Addicta: Turkish J. on Addict.* **10**, 158–164, DOI: 10.5152/ADDICTA.2023.23034 (2023).

42. Shi, P. & Feng, X. Motor skills and cognitive benefits in children and adolescents: Relationship, mechanism and perspectives. *Front. Psychol.* **13**, DOI: 10.3389/fpsyg.2022.1017825 (2022).

43. Sigirtmac, I. C. & Oksuz, C. Determination of the optimal cutoff values and validity of the purdue pegboard test. *Br. J. Occup. Ther.* **85**, 62–67, DOI: 10.1177/03080226211008046 (2022).

44. Chien, S.-Y., Wong, A. M., Wu, C.-Y. & Beckman, S. L. Interactive electronic pegboard for enhancing manual dexterity and cognitive abilities: Instrument usability study. *JMIR Hum. Factors* **11**, e56357, DOI: 10.2196/56357 (2024).

Data availability

The datasets generated and analyzed during the current study are not publicly available due to privacy restrictions concerning the adolescent participants and the institutional data protection policies of the Universidad Politécnica Salesiana, but are available from the corresponding author upon reasonable request.

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Author contributions

J.C.S.T. and L.A.C.A. conceived the study, the underlying idea, and designed the methodology. J.C.S.T. conducted the educational workshops, collected the data, performed the statistical analysis, and wrote the main manuscript text. J.C.S.T. and L.A.C.A. generated the figures. V.F.M.M. and J.A.C.T. contributed to the interpretation of the results and provided critical revisions. All authors reviewed the final manuscript.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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