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The Impact of Educational Robotics on Cognitive Outcomes in Primary Students: A Meta-Analysis of Recent Studies

Meruyert Mukhasheva*
Zhetysu State University named after I. Zhansugurov, KAZAKHSTAN

Kalibek Ybyraimzhanov
Zhetysu State University named after I. Zhansugurov, KAZAKHSTAN

Khapiza Naubaeva
Zhetysu State University named after I. Zhansugurov, KAZAKHSTAN

Assem Mamekova
Zhetysu State University named after I. Zhansugurov, KAZAKHSTAN

Bibigul Almukhambetova
Zhetysu State University named after I. Zhansugurov, KAZAKHSTAN

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Abstract: In recent years, educational robotics has gained ground in educational policy around the world, and primary education is no exception. However, there has not yet been a thorough synthesis of methodologically appropriate empirical research on the effects of robotics upon cognitive performance among primary school students, which this paper attempted to do. Following literature screening, a total of eight studies published between 2018 and 2022 with a sample size of 567 children met inclusion criteria and were meta-analyzed. Resultantly, a medium aggregate effect size in favor of robotics experiments emerged (standardized mean difference of .641), which was significantly higher compared to non-robotics learning (p <.01). No between-study heterogeneity was detected. Subgroup analysis revealed a slightly larger overall effect for interventions on first- to third-graders rather than those in grades 4-6. Additionally, the analysis indicates that in order to enhance cognitive abilities in primary students, robotics interventions should be no longer than four weeks and involve robot construction. Based on the findings, implications, and suggestions are outlined for future research and practice.

Keywords: *Cognitive outcomes, educational robotics, elementary education, meta-analysis, primary students.*

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Introduction

These days, juveniles almost all over the globe are being raised in a technologically saturated environment (Corcoran et al., 2022; Singh et al., 2022). With the advancement of artificial intelligence education (Bellas & Sousa, 2023), new cultural and social landscapes require advancements in science education (Deepa et al., 2022; Lupion-Cobos et al., 2022). Technology has become an indispensable aspect of our daily lives, and electronic devices, such as smartphones, tablets, and computers, are widely available and frequently used by children. Simultaneously, there is a growing demand for a workforce that understands the latest technologies such as robots, smartphones, and augmented reality (Li, 2022). Consequently, national educational programs and private initiatives prioritize Science, Technology, Engineering, and Mathematics (STEM) literacy, with a focus on coding and computational thinking (Bers et al., 2019).

However, to be effective, teaching needs to be revised and it should embody new forms of competency learning, so that students do not memorize rotely, but can instead digest concepts through the usage of state-of-art technologies (Campos & Munoz, 2023). A practical way to make learning content go hand-in-hand with technology within educational settings is educational robotics (Castro et al., 2022). Over the past few years, the use of educational robotics has gained momentum in educational policies worldwide, including primary education (Madariaga et al., 2023; Yu et al., 2023). Robotics is a science field that involves the creation of robots, i.e., machines capable of movement and performing tasks. In turn, educational robotics is a specific branch of robotics that focuses on using robots and robot assembly kits in an educational context to teach a variety of subjects. This is achieved through pedagogical activities that encourage the development of higher-order thinking skills and absorption of concepts from other disciplines in students by having them construct and program robots (Kert et al., 2020; Lopez-Belmonte et al., 2021). By utilizing age-appropriate robotics kits,

* **Corresponding author:**
Meruyert Mukhasheva, Zhetysu State University named after I. Zhansugurov, Kazakhstan. ✉ mrmksh@hotmail.com

educators can introduce basic coding and computational thinking concepts to early learners (Chalmers, 2018). As regards programming, Jdeed et al. (2020) classify robots suitable for elementary level children into three categories: (i) robots like BeeBots with only buttons or symbols for programming, (ii) robots with a block-based programming language suitable for acquiring basic coding concepts, and (iii) robots programmed with a limited number of text commands.

The application of educational robotics in classrooms has become crescively popular due to its ability to offer flexible and innovative teaching approaches that can be adapted to various educational topics. By manipulating robots, students are empowered to design and amend solutions while also analyzing problems across different areas of education (Stein et al., 2023). Such praxis offers students an engaging and technology-driven learning experience gained from both physical and mental activities, making it entertaining and educationally effective.

The most crucial aspect of robotics is providing students with the chance to engage with tangible objects, as opposed to abstract concepts (Amri et al., 2022). This is because abstract content can sometimes make the educational goals unclear in learners' minds. When learning objectives lack practical applications, it can lead to a negative impact on students' motivation to learn. Students are more likely to be enthusiastic about their studies when they can work with objects that enable them to influence their environment and apply theoretical knowledge to create real-world change (Darmawansah et al., 2023; Kert et al., 2020).

Spurring student interest can facilitate the blossoming of such valuable skills as problem-solving, teamwork, and creativity amongst learners. Additionally, educational robotics can equip students with "learning by doing" experiences that might further be translated into actions in real-life situations (Souza et al., 2022). Educational robotics, in particular, is designed to cultivate computational thinking (Chevalier et al., 2020) referred to as formulating the solution to an issue in a way that can be processed by machines or humans (Kert et al., 2020). As Budiyanto et al. (2022) underline, educational robotics infused into the teaching and learning process can be transformative, as it helps address classroom diversity and keeps learners engaged and motivated. Thus, educational robotics is not simply a set of pedagogical activities but rather a holistic tool that integrates technology, pedagogy, and curricular content. According to Toh et al. (2016), skills that can be attained as a result of educational robotics can be roughly divided into language, conceptual, social (collaborative), and cognitive skills. The present analysis is focused on cognitive domain outcomes (such as computational thinking level) that primary school children gained from educational robotics interventions.

Research Rationale, Aim, and Questions

As previously mentioned, the use of educational robotics has become more prominent in the field of education. This trend is transforming the educational landscape, necessitating more study to better comprehend the potential of robot-based learning. Following this need, there have been a growing number of studies that have examined the influence of educational robotics on a range of skills in school students (Malinverni et al., 2021). However, research on primary students' acquisition of thinking skills through robotics activities is still an emerging and highly fragmented field, and extant works aimed at systematizing data on the topic, to the best of our knowledge, have failed to provide a clear answer to the question of whether the adoption of robotics activities in teaching primary school students is effective for their cognitive abilities. Moreover, those integrative papers often do not ensure the relevance and quality of reviewed articles. Particularly, the meta-analytic review by Athanasiou et al. (2019) includes ineligible studies like Li et al. (2016) in which schoolchildren were just engaged in activities with Lego bricks rather than robotics. A recent meta-analysis by Sapounidis et al. (2023) conflates educational robotics in elementary settings with other STEM interventions. Despite multiple research efforts that have been put forth to date, there appears to have been little consideration devoted to the comprehensiveness of available research in this domain. Against this background, the current investigation attempts to help bridge the gap in the cumulated research corpus by integrating the empirical evidence on the topic. Overall, the central aim of this meta-analysis was to answer the following research questions:

Research question 1. What is the pooled mean effect size for educational robotics interventions on primary students' post-test cognitive outcomes as compared to non-robotics conditions?

Research question 2. Does the effect of educational robotics on primary students' cognitive performance depend on study length, educational level, and whether the study entails constructing robots?

Methodology

A meta-analysis is a statistical analysis technique that implies amalgamating multiple findings from empirical studies on a particular topic to engender a combined effect measure, which can enable researchers to address specific questions, reconcile disagreements that may arise from discrepant evidence, and draw more meaningful conclusions (Wang et al., 2022).

Eligibility Criteria

The selection of studies for this meta-analysis was guided by a number of eligibility criteria. To be included in the analysis, a study had to:

1. Report robotics activities integrated into classroom or extra-school learning for advancing primary school (grades 1-6) students' cognitive domain abilities and skills in regular education settings.

2. Employ physical robots/robotics kits exactly as a subject of manipulation (programming, construction, and so forth);

3. Focus exactly on the robotics-based intervention as the explanatory variable influencing the measured outcome rather than other factors in parallel with the robotic activity, e.g., a mentoring program like in Cervera et al. (2020).

4. Provide clear and specific research questions or hypotheses relevant to the impact of educational robotics on cognitive outcomes in primary students.

5. Adopt experimental or quasi-experimental (no random assignment) research design with pretest and posttest measures and at least one control group in which similar content was delivered through the conventional teaching methods.

6. Provide a quantitative measure of the intervention effect sufficient to compute the effect size.

7. Be published as a peer-reviewed scientific journal article between 2010 and 2022.

The timeline of our search was since 2010, as research has been conducted on the incorporation of robots in education over the last quarter century (Chalmers et al., 2022), but it hardly was until the 2010s that technology reached the point where robots could actually be introduced into the curriculum in a meaningful and interesting way. Furthermore, the ACM Digital Library (dl.acm.org) charts a surge in publications on educational robotics beginning around 2010 and peaking in 2021. No language restriction was applied.

The following records were excluded from further consideration:

1. Studies employing social robots.

2. Studies employing software instead of physical robotics environments.

3. Studies in which robots served purely auxiliary functions, such as a pencil stand, like in Kim and Lee (2016).

4. Conference materials, book chapters, theoretical studies, etc.

5. Studies conducted in special education settings, i.e., those involving learners with special needs such as children with autism spectrum disorder.

Literature Screening

Based on the above criteria, two authors independently screened the titles, abstracts, and full texts of papers that could potentially be relevant. Disagreements were resolved either through discussion or with the intervention of a third reviewer acting as an arbitrator. The following bibliographic databases were searched for eligible studies: Springer Link, Cunningham Library, Science Direct, ACM Digital Library, and Google Scholar. Search strings included combinations of the terms "robot", "robotics", "education", "school", "primary", and "elementary" as main keywords. Additionally, reference lists of the included studies and previous reviews were manually searched to obtain studies that might be eligible. Our search strategy identified 1,268 documents from online databases. It was originally planned to also include the gray literature (dissertations and reports) in the meta-analysis to cover unpublished results and acquire a more comprehensive evidence base as broadly recommended (Marks-Anglin & Chen, 2020), but searches in ProQuest and Open Grey did not yield acceptable records.

Initially, 1,268 records were retrieved through keywords, and 226 papers appeared to meet the inclusion criteria, but most of them were excluded after the full-text screening to give a total of nine studies regarded as eligible. However, among these, the study by Chou (2018) reported an effect size in the experimental group which was twice larger compared to the control group, so this paper had to be removed from further analysis as an outlier. The flowchart of step-by-step article selection is depicted in Figure 1. Therefore, eight studies were included in the final analysis.

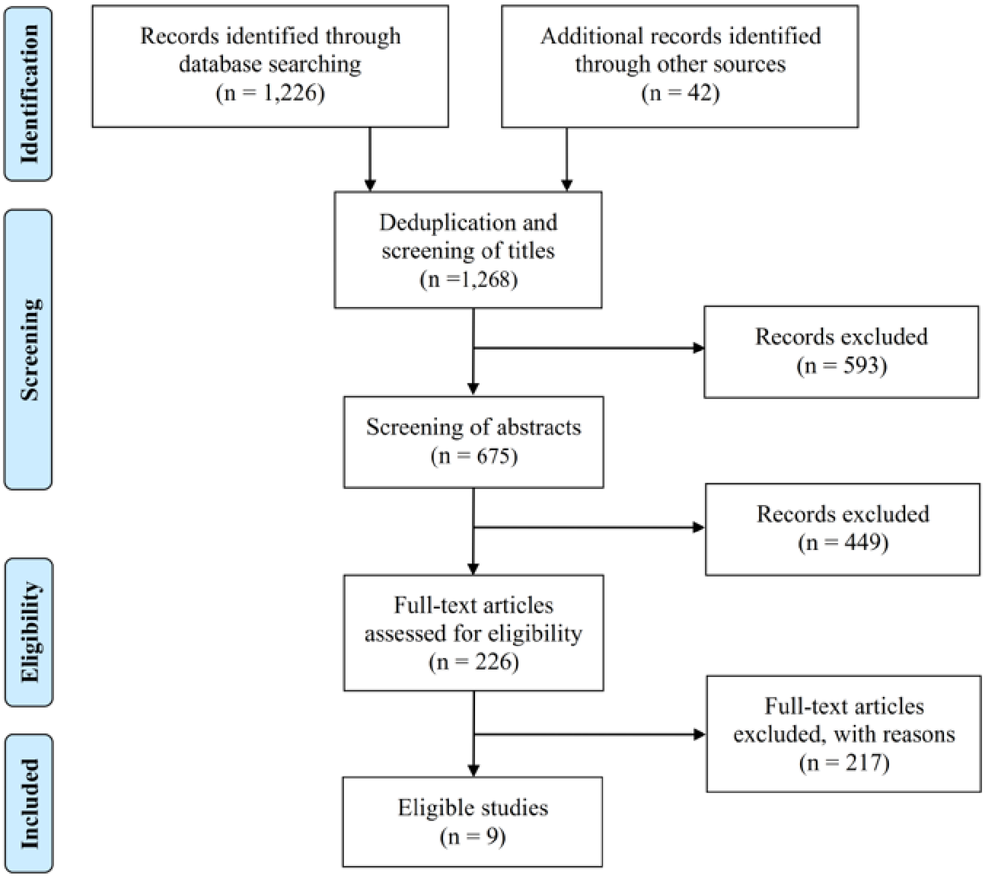

Figure 1. Flowchart of Identified, Included, and Excluded Studies

Statistics

For this meta-analysis, we employed a fixed-effects model since it is reportedly relevant when there are few studies to meta-analyze (Heyward et al., 2020). Effect sizes were expressed as standardized mean difference (SMD) and 95% confidence interval (CI). The summarized effect size was construed as small (.2), medium (.5), or large (.8) (Peterson & Foley, 2021). Z-statistics were utilized to appraise the overall effect. To verify the presence of highly influential studies that could exaggerate the summary effect size, sensitivity analysis was applied using the leave-one-out technique, that is the combined effect size was iteratively estimated exclusive of one study eliminated from the dataset (Alqahtani et al., 2022; Sothivannan et al., 2022). Inter-study heterogeneity was evaluated using the tau^2 index and the Chi-square test, with the degree of heterogeneity across studies quantified by the I^2 statistic interpreted as mild (I^2 <30%), moderate (I^2 = 31-50%), or high (I^2 >50%) (Higgins & Thompson, 2002).

To further test the robustness of the results, three pre-planned subgroup analyses were conducted in which the included studies were divided into (i) those in which participants were lower primary level students (grades 1-3) and those involving upper primary level students (grades 4-6), (ii) those focused on algorithmic activities (encoding the robot's movement path and the like) and those in which the experimental procedures also assumed constructing robots, and (iii) those in which the experimental period lasted up to four weeks and those in which it exceeded four weeks. As such, it was sought *inter alia* to see how these potential confounders could alter the aggregate proportion.

Publication bias (i.e., whether the available publications on the subject are skewed toward the preferred results) was examined using Meta-Essentials spreadsheets (Suurmond et al., 2017) where Egger's linear regression test along with Begg and Mazumdar's rank correlation test were performed (p <.05 is indicative of publication bias), plus a funnel plot was generated and visually inspected (imputed data points would indicate publication bias). The rest of the analyses were run in corresponding R libraries including Metafor (Beheshti et al., 2020; Viechtbauer, 2010; Wallace et al., 2012). For all analyses, the statistical level of significance was set up at p <.05.

Results

Search Results

Table 1 contains basic descriptive information about them. Although the search time span was from 2010 to 2022, it eventually ranged from 2018 to 2022.

Table 1. Characteristics of Studies Included in The Meta-Analysis

Study	Intervention	Response variables of interest
Caballero-Gonzalez and Garcia-Valcarcel (2020)	Bee-Bot movement sequence programming	Computational thinking
Caballero-Gonzalez and Munoz-Repiso (2020)	Bee-Bot movement sequence programming	Computational thinking
Chiazzese et al. (2019)	Activities on LEGO WeDo construction set	Computational thinking
Diago et al. (2022)	Tangible programming on Bee-Bot	Computational thinking and mental rotation
Hsiao et al. (2022)	Activities on Crab Robot	Robotics knowledge and skills and computational thinking
La Paglia et al. (2018)	Activities on LEGO Mindstorms robotic kit	Planning and problem solving
Saez Lopez et al. (2019)	Robotics and visual block programming on mBot board	Math and Science knowledge
Saez Lopez et al. (2021)	Robotics and visual block programming on mBot board	Computational thinking

Overall Effect Size

Pooling the impacts of educational robotics on learner cognitive outcomes revealed a medium positive effect in favor of intervention groups (SMD = .641, 95% CI [.462, .821], $p < .01$). A forest plot of the weighted mean outcome variable can be seen in Figure 2. Individual effect sizes (SMDs and their Cis) are represented by the black squares and horizontal lines, respectively. The square size is proportional to the fixed effects weight for each study. The dashed line and the center of the black diamond stand for the combined effect size. The diamond width indicates the overall pooled 95% CI. Although bull eyeing of individual effect sizes on the forest plot does not produce a smooth line, no evidence of heterogeneity between the studies was revealed.

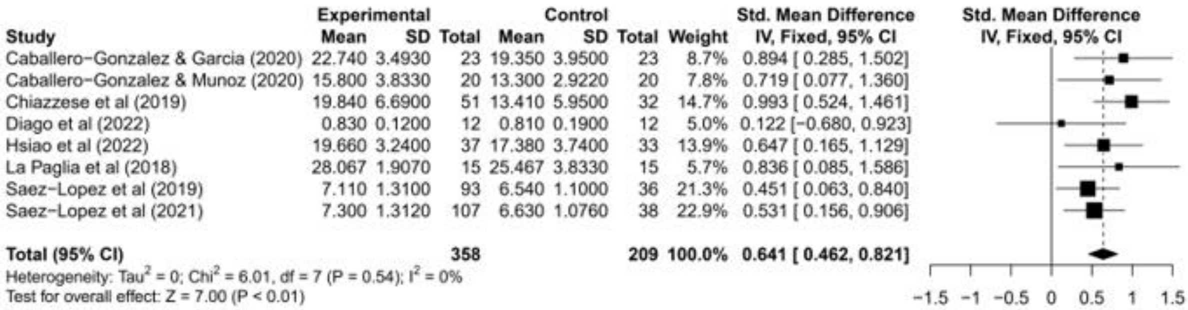

Figure 2. Forest Plot Showing the Overall Effect of Robotics on Cognitive Outcomes in Primary Students as Compared to Conventional Instruction.

Publication Bias and Sensitivity Analysis

The visual inspection of the funnel plot (Figure 3), Begg and Mazumdar test ($p = .805$), as well as Egger test ($p = .104$) point to the lack of publication bias for the meta-analysis. The leave-one-out plot (Figure 4) depicts the results of sensitivity analysis. Each black square with a horizontal line there indicates the combined effect size and its 95% CI excluding the corresponding study. It follows from Figure 4 that the overall effectiveness of the robotics interventions was at least .581 after consecutive deletion of individual studies and re-calculation of the effect magnitude. Therefore, it is safe to state that none of the primary studies had a drastic influence on the pooled effect estimate.

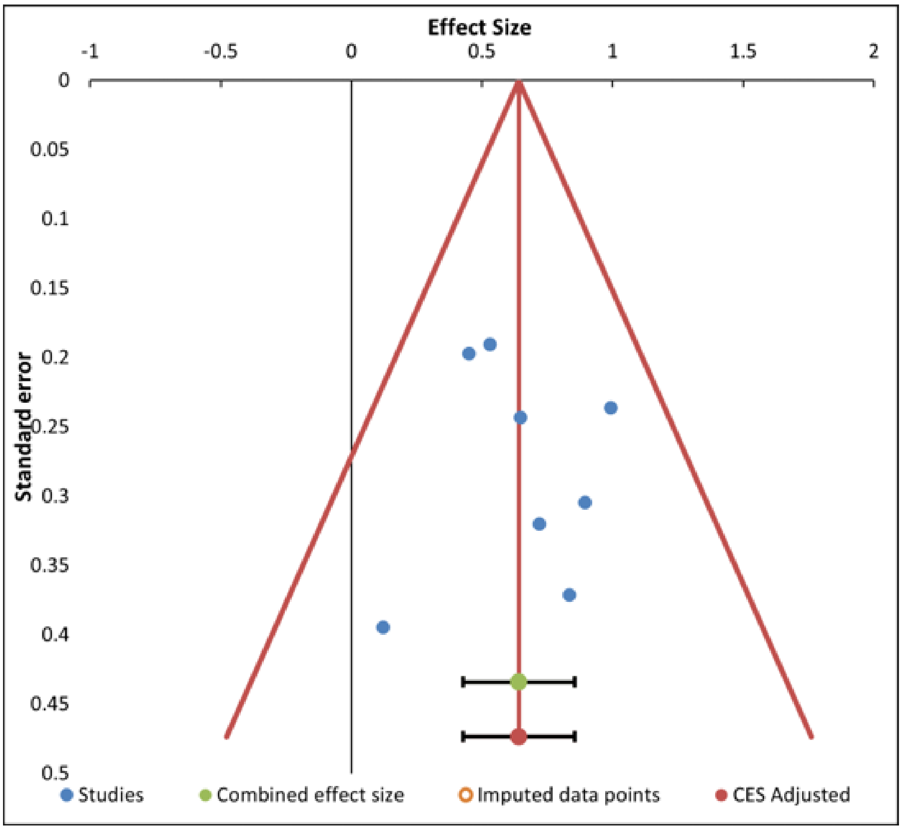

Figure 3. Funnel Plot of Studies Reporting the Impact of Educational Robotics on Primary Students' Cognitive Outcomes. CES = Combined Effect Size

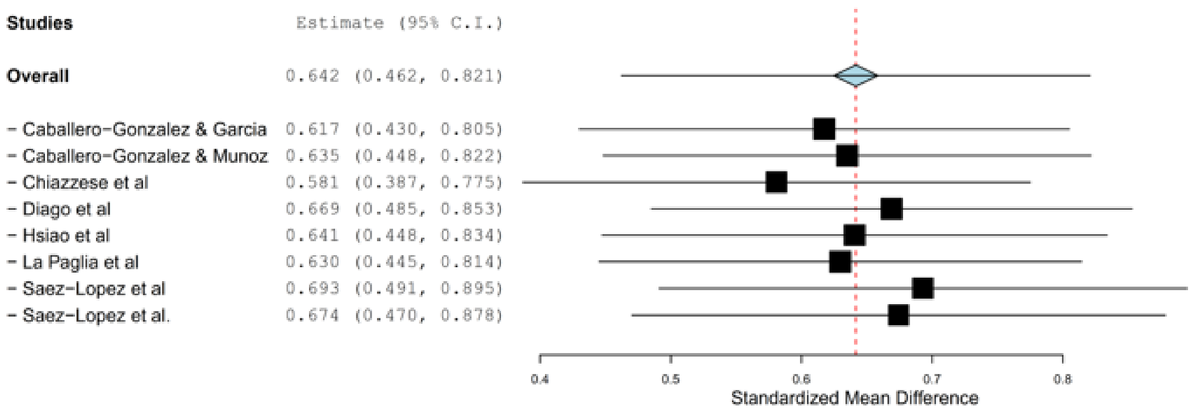

Figure 4. Leave-One-Out Forest Plot of Studies Reporting the Impact of Educational Robotics on Primary Students' Cognitive Outcomes

Subgroup Analysis

On average, robotics had an effect size close to large within the category of lower primary level (SMD = .789; 95% CI [.491, 1.087], *p* <.01), while the studies conducted on upper primary education students resulted in a medium overall effect on their cognitive outcomes (SMD = .557; 95% CI [.332, .782], *p* <.01) (Figure 5). Similarly, interventions assuming learners involved in robot construction exerted a large combined effect on the response variable (SMD = .827; 95% CI [.520, 1.133], *p* <.01), whereas the impact was medium for the subgroup of studies in which participants were not asked to construct robots (SMD = .544; 95% CI [.323, .766], *p* <.01) (Figure 6). As illustrated in Figure 7, the effect of educational robotics on the elementary students' performance was higher in experiments conducted within four weeks (SMD = .771; 95% CI [.367, 1.175], *p* <.01) as opposed to those lasting more than four weeks (SMD = .609; 95% CI [.409, .809], *p* <.01). Here we emphasize however that only two articles were included in the short-lasting subgroup.

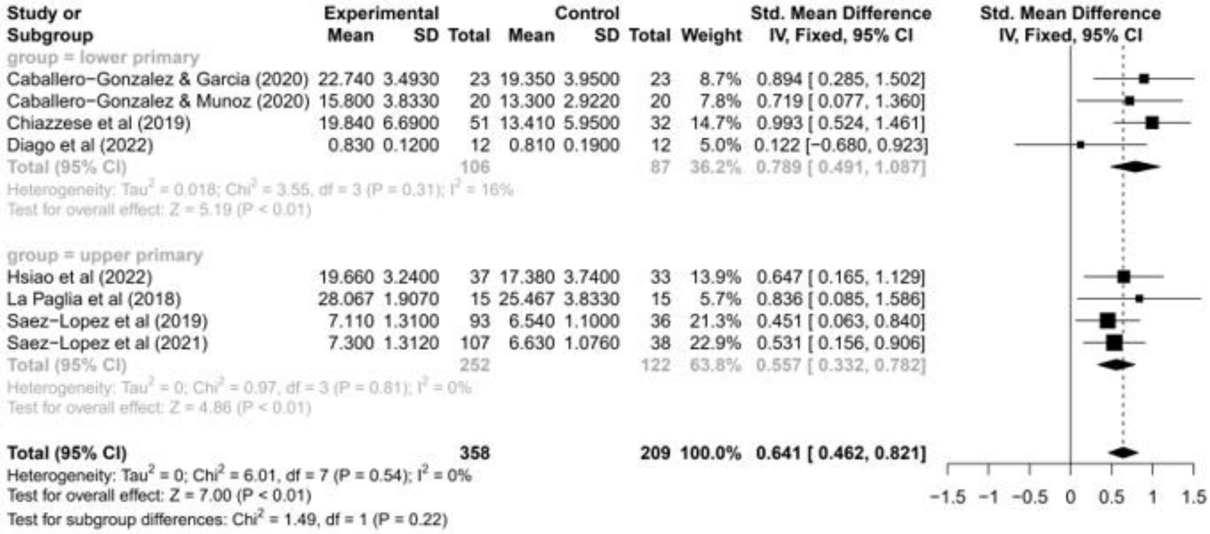

Figure 5. The Impact of Educational Robotics on Primary Students' Cognitive Outcomes Across Educational Levels

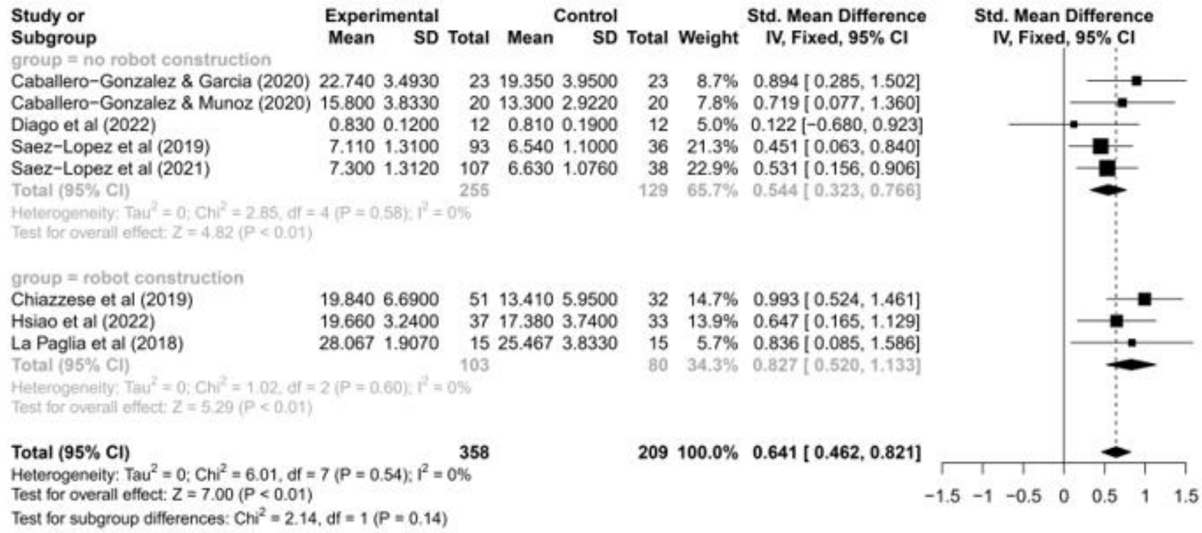

Figure 6. The Impact of Educational Robotics on Primary Students' Cognitive Outcomes Across Intervention Approaches

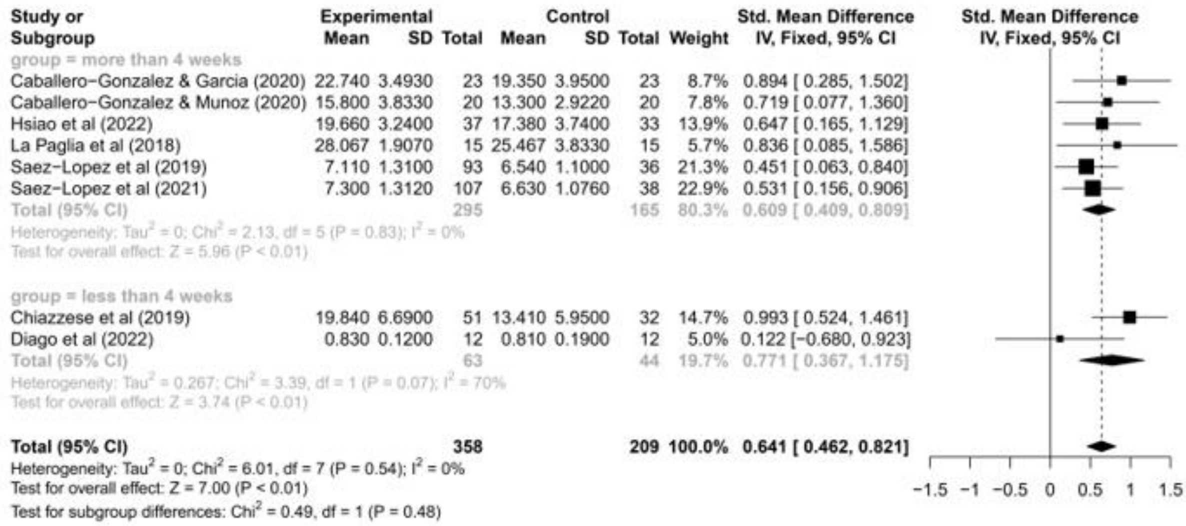

Figure 7. The Impact of Educational Robotics on Primary Students' Cognitive Outcomes Across Experimental Periods

Discussion

The major objective of this research was to explore the pooled learning gain of educational robotics for primary students in comparison to non-robotics conditions. The results of eight relevant studies were extracted and quantitatively synthesized. The first research question raised for this meta-analysis was whether robotics activities exerted a better effect on primary students' cognitive performance when compared to non-robotics instructional methods. The obtained findings suggest that overall, educational robotics had a medium positive effect on cognitive domain learning outcomes, and this effect significantly outmatched no-experiment conditions. These results diverge from findings in the meta-analysis of the impacts of robotics on students' computational thinking (Zhang et al., 2021), in which a subgroup analysis revealed a low summary effect size (SMD = .27, 95% CI [.08, .45]) for a subset of elementary school students, represented by seven studies. The meta-analysis by Athanasiou et al. (2019) covered a broader range of learning performance indicators, and the primary school segment there (six studies) yielded an aggregate SMD of as much as 1.05 (95% CI [.30, 1.81]), but this likewise differs from what we found. However, one should note that in both of the above meta-analyses, the summary estimate was compromised by the heterogeneity of the data, unlike in the present investigation, which underlines its contribution to research. Systematic reviews addressing the area of educational robotics also do not bring clarity to the subject and tend to span K-12 as a whole. Some of them infer the effectiveness of robotics for enhancing learning based merely on summary data about whether the author(s) of the included study thought the robot-based treatment was beneficial for participants (e.g., Kubilinskiene et al., 2017), while some systematic reviews did not contemplate such a variable as learning performance at all (Jung & Won, 2018). Therefore, it is rather difficult to say whether our results are congruous with the existing literature. Hopefully, the findings of this meta-analysis could have practical implications by providing stakeholders, such as teachers and school administrators, with at least some weighted evidence regarding the effectiveness of robot-based activities. This could assist them in making more informed decisions about whether to invest resources in this solution or not.

Despite the lack of heterogeneity between the included studies, the second research question of this synthesis research was whether the overall effect size varied by characteristics of interventions and participants. The current meta-analysis presumably adds to the research in the way that it appears to be the first to employ this moderator variable. Based on the results, we can say that in the domain where the experiments entailed constructing robots, the cumulative output was higher than in the subgroup where the robotics did not include these manipulations. As some evidence proves, LEGO-type robot kits can be quite successful even among kindergarteners (Kazakoff et al., 2013). Low-complexity building work aligns perfectly with children's natural interest in play and creating (Lindsay et al., 2017), so robotics construction sets have even been used as behavioral therapy (Narzisi et al., 2021). Incentivizing this propensity motivates young learners to actively discover and construct knowledge (Marouani, 2022). Hence, not incorporating such a cardinal component into a robotics program might well have decreased students' engagement in the process. Besides, the educational value of construction practice lies in the idea that future generations should aspire to produce technologies rather than solely consuming them (Fortunati et al., 2022).

As for the teaching experiment period, the subgroup analysis showed no remarkable difference between the overall effect size in the subgroup where the activities lasted less than four weeks and the one where they were longer than four weeks. This stands in contrast to the findings of Athanasiou et al. (2019) in which studies with an experimental period of 1-6 months were twice more effective relative to those less than a month in duration. By the same token, the meta-analysis by Zhang and Zhu (2022) concludes that "different course periods of educational robotic teaching all had a positive effect on learning, but would notably decrease as the course period extends." Nonetheless, our results to some degree accord with the findings from Zhang et al. (2021) which reports that the overall effect size for the pool of interventions that lasted no more than four weeks was slightly higher (SMD = .35, 95% CI [.15, .55]) as opposed to 4–11 weeks long (SMD = .28, 95% CI [.10, .47]). One obvious explanation for this is that as time passes, students' enthusiasm dwindles and they become less eager to learn. This is in harmony with common scientific observations in the literature (Hanus & Fox, 2015; Rasmitadila et al., 2020).

Judging by the combined SMD in the lower primary school subgroup, robotics classes were more effective for them in terms of cognitive achievement than for students in grades 4-6. It might be that the experimental equipment in the former subset was more developmentally appropriate than in the latter. Either way, this question demands further scrutiny. At this point, to our knowledge, no other meta-analysis of robotics research on schoolchildren has yet considered primary grade level as a possible effect modifier. Altogether, this subgroup analysis provides new evidence that may give an impulse to further in-depth investigations into the factors that determine the effectiveness of robotics in early education, which could aid educational decisions.

Conclusion

In sum, this meta-analytic investigation suggests a medium-sized benefit from educational robotics in promoting primary students' cognitive performance. The results of subgroup analysis indicate that robotics activities had a slightly greater effect on first to third graders as compared to children in grades 4-6. Moreover, this analysis shows that when the goal is to improve cognitive abilities, robotics activities for early schoolers should encompass building robots and be no longer than four weeks. Since this synthesis includes as few as eight effect sizes, the findings should be interpreted carefully. Nevertheless, the strength of our meta-analysis is that it does not suffer from the between-study heterogeneity found in previous meta-analyses on the topic, not many of which though have been conducted so far. The fact that the earliest data in this study start from 2018 underscores the inchoate state of the research on the subject. Future studies will provide further clarity on the topic as more robust empirical data on robot-based learning becomes available. This research enriched the theoretical basis of educational robotics and hopefully may provide additional reference and guidance for primary education practitioners and researchers.

Recommendations

By today, there are already lots of playthings on the market elaborated to familiarize children with the basics of robotics and programming, such as Thymio, Plobot, and Dr. Wagon (see, for example, Yu & Roque, 2019). However, there are virtually no reliable experimental studies on the use of these devices. We can recommend experimentally integrating these tools into elementary curriculum courses while applying quantitative analyses of the results to generate insights into the effectiveness of robotics for primary school students.

In their systematic review of studies on educational robotics, Anwar et al. (2019) remark that experimenters in this field typically administer post-tests right after an intervention, whereas researchers could determine if there are lasting effects by conducting longitudinal studies. In our opinion, longitudinal studies in this sector are unlikely to be feasible, but a follow-up would indeed be useful.

The combined effect size reported here stems from a meticulous examination of data from scientific publications, so the primary studies selected for this meta-analysis can later be subsumed into a larger-scale integration as a sound basis.

Limitations

We recognize some limitations of our meta-analysis. First, this study focused entirely on cognitive outcomes and so other categories of impact on participants are overlooked, which may distort the interpretation of the results reported herein. Second, the total number of includable studies was low, which makes substantial conclusions impossible. This paucity of adequate publications could be blamed on the fact that the scope of our paper is narrowed to robotics and elementary education. However, in the systematic literature review by Tselegkaridis and Sapounidis (2022), which covered both educational robotics and STEM research, 24 of the 36 included studies are non-experimental. Plus, in the recent systematic review on artificial intelligence, robotics, and blockchain in higher education (Chaka, 2023), only 10 articles on robotics were found pertinent after a rigorous literature screening.

Ethics Statements

This research does not need ethical approval.

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Conflict of Interest

The authors report no actual or potential conflicts of interest.

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Authorship Contribution Statement

Mukhasheva: Conceptualization, editing, literature search. Ybyraimzhanov: Supervision, drafting manuscript. Naubaeva: Design, writing, editing. Mamekova: Literature search, statistical analysis. Almukhambetova: Data interpretation, writing.

References

Alqahtani, J. S., Aldhahir, A. M., Al Ghamdi, S. S., Al Bahrani, S., Al Draiwiesh, I. A., Alqarni, A. A., Latief, K., Raya, R. P., & Oyelade, T. (2022). Inhaled nitric oxide for clinical management of COVID-19: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health*, *19*(19), Article 12803. https://doi.org/10.3390/ijerph191912803

Amri, S., Budiyanto, C. W., Fenyvesi, K., Yuana, R. A., & Widiastuti, I. (2022). Educational robotics: Evaluating the role of computational thinking in attaining 21st century skills. *Open Education Studies*, *4*(1), 322–338. https://doi.org/10.1515/edu-2022-0174

Anwar, S., Bascou, N. A., Menekse, M., & Kardgar, A. (2019). A systematic review of studies on educational robotics. *Journal of Pre-College Engineering Education Research*, *9*(2), Article 2. https://doi.org/10.7771/2157-9288.1223

Athanasiou, L., Mikropoulos, T. A., & Mavridis, D. (2019). Robotics interventions for improving educational outcomes - a meta-analysis. In M. A. Tsitouridou, J. Diniz, & T. Mikropoulos (Eds.), Technology and innovation in learning, teaching and education (Vol. 993, pp. 91-102). Springer. https://doi.org/10.1007/978-3-030-20954-4_7

Beheshti, A., Chavanon, M. -L., & Christiansen, H. (2020). Emotion dysregulation in adults with attention deficit hyperactivity disorder: A meta-analysis. *BMC Psychiatry*, *20*, Article 120. https://doi.org/10.1186/s12888-020-2442-7

Bellas, F., & Sousa, A. (2023). Editorial: Computational intelligence advances in educational robotics. *Frontiers in Robotics and Al*, *10*, Article 1150409. https://doi.org/10.3389/frobt.2023.1150409

Bers, M. U., Gonzalez-Gonzalez, C., & Armas–Torres, M. B. (2019). Coding as a playground: Promoting positive learning experiences in childhood classrooms. *Computers & Education*, *138*, 130–145. https://doi.org/10.1016/j.compedu.2019.04.013

Budiyanto, C. W., Fenyvesi, K., Lathifah, A., & Yuana, R. A. (2022). Computational thinking development: Benefiting from educational robotics in STEM teaching. *European Journal of Educational Research*, *11*(4), 1997-2012. https://doi.org/10.12973/eu-jer.11.4.1997

Caballero-Gonzalez, Y. A., & Garcia-Valcarcel, A. (2020). Aprender con robotica en Educacion Primaria? Un medio de estimular el pensamiento computacional [Learning with robotics in primary education? A means of stimulating computational thinking]. *Education in the Knowledge Society*, *21*, Article 10. https://doi.org/10.14201/eks.21443

Caballero-Gonzalez, Y. -A., & Munoz-Repiso, A. G. -V. (2020). Fortaleciendo el pensamiento computacional y habilidades sociales mediante actividades de aprendizaje con robotica educativa en niveles escolares iniciales [Strengthening computational thinking and social skills through learning activities with educational robotics in early school level]. *Pixel-Bit, Revista de Medios y Educacion*, (58), 117-142. https://doi.org/10.12795/pixelbit.75059

Campos, V. M., & Munoz, F. J. R. (2023). Design and piloting of a proposal for intervention with educational robotics for the development of lexical relationships in early childhood education. *Smart Learning Environments*, *10*, Article 6. https://doi.org/10.1186/s40561-023-00226-0

Castro, A., Medina, J., Aguilera, C. A., Ramirez, M., & Aguilera, C. (2022). Robotics education in STEM units: Breaking down barriers in rural multigrade schools. *Sensors*, *23*(1), Article 387. https://doi.org/10.3390/s23010387

Cervera, N., Diago, P. D., Orcos, L., & Yanez, D. F. (2020). The acquisition of computational thinking through mentoring: An exploratory study. *Education Sciences*, *10*(8), Article 202. https://doi.org/10.3390/educsci10080202

Chaka, C. (2023). Fourth industrial revolution—a review of applications, prospects, and challenges for artificial intelligence, robotics and blockchain in higher education. *Research and Practice in Technology Enhanced Learning*, *18*, Article 002. https://doi.org/10.58459/rptel.2023.18002

Chalmers, C. (2018). Robotics and computational thinking in primary school. *International Journal of Child-Computer Interaction*, *17*, 93–100. https://doi.org/10.1016/j.ijcci.2018.06.005

Chalmers, C., Keane, T., Boden, M., & Williams, M. (2022). Humanoid robots go to school. *Education and Information Technologies*, *27*, 7563–7581. https://doi.org/10.1007/s10639-022-10913-z

Chevalier, M., Giang, C., Piatti, A., & Mondada, F. (2020). Fostering computational thinking through educational robotics: A model for creative computational problem solving. *International Journal of STEM Education*, *7*, Article 39. https://doi.org/10.1186/s40594-020-00238-z

Chiazzese, G., Arrigo, M., Chifari, A., Lonati, V., & Tosto, C. (2019). Educational robotics in primary school: Measuring the development of computational thinking skills with the Bebras tasks. *Informatics*, *6*(4), Article 43. https://doi.org/10.3390/informatics6040043

Chou, P. N. (2018). Skill development and knowledge acquisition cultivated by maker education: Evidence from arduino-based educational robotics. *EURASIA Journal of Mathematics, Science and Technology Education*, *14*(10), Article em1600. https://doi.org/10.29333/ejmste/93483

Corcoran, E., Gabrielli, J., Wisniewski, P., Little, T. D., & Doty, J. (2022). A measurement model of media parenting: Differences across parent and child reports and youth age and sex. *Journal of Psychopathology and Behavioral Assessment*, *44*, 898–912. https://doi.org/10.1007/s10862-022-09962-y

Darmawansah, D., Hwang, G. -J., Chen, M. -R. A., & Liang, J. -C. (2023). Trends and research foci of robotics-based STEM education: A systematic review from diverse angles based on the technology-based learning model. *International Journal of STEM Education*, *10*, Article 12. https://doi.org/10.1186/s40594-023-00400-3

Deepa, V., Sujatha, R., & Mohan, J. (2022). Unsung voices of technology in school education-findings using the constructivist grounded theory approach. *Smart Learning Environments*, *9*, Article 1. https://doi.org/10.1186/s40561-021-00182-7

Diago, P. D., Gonzalez-Calero, J. A., & Yanez, D. F. (2022). Exploring the development of mental rotation and computational skills in elementary students through educational robotics. *International Journal of Child-Computer Interaction*, *32*, Article 100388. https://doi.org/10.1016/j.ijcci.2021.100388

Fortunati, L., Manganelli, A. M., & Ferrin, G. (2022). Arts and crafts robots or LEGO® MINDSTORMS robots? A comparative study in educational robotics. *International Journal of Technology and Design Education*, *32*, 287–310. https://doi.org/10.1007/s10798-020-09609-7

Hanus, M. D., & Fox, J. (2015). Assessing the effects of gamification in the classroom: A longitudinal study on intrinsic motivation, social comparison, satisfaction, effort, and academic performance. *Computers & Education*, *80*, 152–161. https://doi.org/10.1016/j.compedu.2014.08.019

Heyward, J., Mansour, O., Olson, L., Singh, S., & Alexander, G. C. (2020). Association between sodium-glucose cotransporter 2 (SGLT2) inhibitors and lower extremity amputation: A systematic review and meta-analysis. *PLOS ONE*, *15*(6), Article e0234065. https://doi.org/10.1371/journal.pone.0234065

Higgins, J. P. T., & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine*, *21*(11), 1539–1558. https://doi.org/10.1002/sim.1186

Hsiao, H. -S., Lin, Y. -W., Lin, K. -Y., Lin, C. -Y., Chen, J. -H., & Chen, J. -C. (2022). Using robot-based practices to develop an activity that incorporated the 6E model to improve elementary school students' learning performances. *Interactive Learning Environments*, *30*(1), 85–99. https://doi.org/10.1080/10494820.2019.1636090

Jdeed, M., Schranz, M., & Elmenreich, W. (2020). A study using the low-cost swarm robotics platform Spiderino in education. *Computers and Education Open*, *1*, Article 100017. https://doi.org/10.1016/j.caeo.2020.100017

Jung, S. E., & Won, E. -S. (2018). Systematic review of research trends in robotics education for young children. *Sustainability*, *10*(4), Article 905. https://doi.org/10.3390/su10040905

Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal*, *41*, 245–255. https://doi.org/10.1007/s10643-012-0554-5

Kert, S. B., Erkoc, M. F., & Yeni, S. (2020). The effect of robotics on six graders' academic achievement, computational thinking skills and conceptual knowledge levels. *Thinking Skills and Creativity*, *38*, Article 100714. https://doi.org/10.1016/j.tsc.2020.100714

Kim, S., & Lee, C. (2016). Effects of robot for teaching geometry to fourth graders. International *Journal of Innovation in Science and Mathematics Education*, *24*(2), 52-70. https://bit.ly/3p6L8VH

Kubilinskiene, S., Zilinskiene, I., Dagiene, V., & Sinkevicius, V. (2017). Applying robotics in school education: A systematic review. *Baltic Journal of Modern Computing*, *5*(1), 50–69. https://doi.org/10.22364/bjmc.2017.5.1.04

La Paglia, F., Francomano, M. M., Giuseppe, R., & La Barbera, D. (2018). Educational robotics to develop executive functions, visual spatial abilities, planning, and problem solving. *Annual Review of CyberTherapy and Telemedicine*, *16*, 80-86. http://hdl.handle.net/10807/148018

Li, L. (2022). Reskilling and upskilling the future-ready workforce for Industry 4.0 and beyond. *Information Systems Frontiers*. Advance online publication. https://doi.org/10.1007/s10796-022-10308-y

Li, Y., Huang, Z., Jiang, M., & Chang, T.-W. (2016). The effect on pupils' science performance and problem-solving ability through LEGO: An engineering design-based modeling approach. *Educational Technology & Society*, *19*(3), 143–156. https://www.jstor.org/stable/jeductechsoci.19.3.143

Lindsay, S., Hounsell, K. G., & Cassiani, C. (2017). A scoping review of the role of LEGO® therapy for improving inclusion and social skills among children and youth with autism. *Disability and Health Journal*, *10*(2), 173–182. https://doi.org/10.1016/j.dhjo.2016.10.010

Lopez-Belmonte, J., Segura-Robles, A., Moreno-Guerrero, A. -J., & Parra-Gonzalez, M. -E. (2021). Robotics in education: A scientific mapping of the literature in Web of Science. *Electronics*, *10*(3), Article 291. https://doi.org/10.3390/electronics10030291

Lupion-Cobos, T., Giron-Gambero, J., & Garcia-Ruiz, C. (2022). Building STEM inquiry-based teaching proposal through collaborations between schools and research centres: Students' and teachers' perceptions. *European Journal of Educational Research*, *11*(2), 899-915. https://doi.org/10.12973/eu-jer.11.2.899

Madariaga, L., Allendes, C., Nussbaum, M., Barrios, G., & Acevedo, N. (2023). Offline and online user experience of gamified robotics for introducing computational thinking: Comparing engagement, game mechanics and coding motivation. *Computers & Education*, *193*, Article 104664. https://doi.org/10.1016/j.compedu.2022.104664

Malinverni, L., Valero, C., Schaper, M. M., & De La Cruz, I. G. (2021). Educational robotics as a boundary object: Towards a research agenda. *International Journal of Child-Computer Interaction*, *29*, Article 100305. https://doi.org/10.1016/j.ijcci.2021.100305

Marks-Anglin, A., & Chen, Y. (2020). A historical review of publication bias. *Research Synthesis Methods*, *11*(6), 725–742. https://doi.org/10.1002/jrsm.1452

Marouani, H. (2022). Exploration of applying Lego NXT and Arduino in situated engineering teaching: A case study of a robotics contest at King Saud University. *International Journal of Robotics and Control Systems*, *2*(1), 67–78. https://doi.org/10.31763/ijrcs.v2i1.508

Narzisi, A., Sesso, G., Berloffa, S., Fantozzi, P., Muccio, R., Valente, E., Viglione, V., Villafranca, A., Milone, A., & Masi, G. (2021). Could you give me the blue brick? LEGO®-based therapy as a social development program for children with autism spectrum disorder: A systematic review. *Brain Sciences*, *11*(6), Article 702. https://doi.org/10.3390/brainsci11060702

Peterson, S. J., & Foley, S. (2021). Clinician's guide to understanding effect size, alpha level, power, and sample size. *Nutrition in Clinical Practice*, *36*(3), 598–605. https://doi.org/10.1002/ncp.10674

Rasmitadila, R., Aliyyah, R. R., Rachmadtullah, R., Samsudin, A., Syaodih, E., Nurtanto, M., & Tambunan, A. R. S. (2020). The perceptions of primary school teachers of online learning during the COVID-19 pandemic period: A case study in Indonesia. *Journal of Ethnic and Cultural Studies*, *7*(2), 90–109. https://doi.org/10.29333/ejecs/388

Saez Lopez, J. M., Buceta Otero, R., & De Lara Garcia-Cervigon, S. (2021). La aplicación de la robotica y programacion por bloques en la ensenanza elemental [Introducing robotics and block programming in elementary education]. *RIED. Revista Iberoamericana De Educacion a Distancia*, *24*(1), 95-113. https://doi.org/10.5944/ried.24.1.27649

Saez-Lopez, J. -M., Sevillano-Garcia, M. -L., & Vazquez-Cano, E. (2019). The effect of programming on primary school students' mathematical and scientific understanding: Educational use of mBot. *Educational Technology Research and Development*, *67*, 1405–1425. https://doi.org/10.1007/s11423-019-09648-5

Sapounidis, T., Tselegkaridis, S., & Stamovlasis, D. (2023). Educational robotics and STEM in primary education: A review and a meta-analysis. *Journal of Research on Technology in Education*. Advance online publication. https://doi.org/10.1080/15391523.2022.2160394

Singh, D. K., Kumar, M., Fosch-Villaronga, E., Singh, D., & Shukla, J. (2022). Ethical considerations from child-robot interactions in under-resourced communities. *International Journal of Social Robotics.* Advance online publication. https://doi.org/10.1007/s12369-022-00882-1

Sothivannan, A., Eshtiaghi, A., Dhoot, A. S., Popovic, M. M., Garg, S. J., Kertes, P. J., & Muni, R. H. (2022). Impact of the time to surgery on visual outcomes for rhegmatogenous retinal detachment repair: A meta-analysis. *American Journal of Ophthalmology*, *244*, 19–29. https://doi.org/10.1016/j.ajo.2022.07.022

Souza, I. M. L., Andrade, W. L., & Sampaio, L. M. R. (2022). Educational robotics applications for the development of computational thinking in a Brazilian technical and vocational high school. *Informatics in Education*, *21*(1), 147–177. https://doi.org/10.15388/infedu.2022.06

Stein, G., Jean, D., Brady, C., & Ledeczi, A~~K~~. (2023). Browser-based simulation for novice-friendly classroom robotics. *Frontiers in Computer Science, 4*. Advance online publication. https://doi.org/10.3389/fcomp.2022.1031572

Suurmond, R., van Rhee, H., & Hak, T. (2017). Introduction, comparison, and validation of Meta-Essentials: A free and simple tool for meta-analysis. *Research Synthesis Methods*, *8*(4), 537-553. https://doi.org/10.1002/jrsm.1260

Toh, L. P. E., Causo, A., Tzuo, P. -W., Chen, I.-M., & Yeo, S. H. (2016). A review on the use of robots in education and young children. *Educational Technology & Society*, *19*(2), 148–163. https://bit.ly/3JKCPGK

Tselegkaridis, S., & Sapounidis, T. (2022). Exploring the features of educational robotics and STEM research in primary education: A systematic literature review. *Education Sciences*, *12*(5), Article 305. https://doi.org/10.3390/educsci12050305

Viechtbauer, W. (2010). Conducting meta-analyses in R with the metafor package. *Journal of Statistical Software*, *36*(3), 1–48. https://doi.org/10.18637/jss.v036.i03

Wallace, B. C., Dahabreh, I. J., Trikalinos, T. A., Lau, J., Trow, P., & Schmid, C. H. (2012). Closing the gap between methodologists and end-users: R as a computational back-end. *Journal of Statistical Software*, *49*(5), 1–15. https://doi.org/10.18637/jss.v049.i05

Wang, L. -H., Chen, B., Hwang, G. -J., Guan, J. -Q., & Wang, Y. -Q. (2022). Effects of digital game-based STEM education on students' learning achievement: A meta-analysis. *International Journal of STEM Education*, *9*, Article 26. https://doi.org/10.1186/s40594-022-00344-0

Yu, J., & Roque, R. (2019). A review of computational toys and kits for young children. *International Journal of Child-Computer Interaction*, *21*, 17–36. https://doi.org/10.1016/j.ijcci.2019.04.001

Yu, X., Gutierrez-Garcia, M. A., & Soto-Varela, R. (2023). Are educational robots any good for communicative English learning for primary school students? *Texto Livre*, *16*, Article e41469. https://doi.org/10.1590/1983-3652.2023.41469

Zhang, Y., Luo, R., Zhu, Y., & Yin, Y. (2021). Educational robots improve K-12 students' computational thinking and STEM attitudes: Systematic review. *Journal of Educational Computing Research*, *59*(7), 1450–1481. https://doi.org/10.1177/0735633121994070

Zhang, Y., & Zhu, Y. (2022). Effects of educational robotics on the creativity and problem-solving skills of K-12 students: A meta-analysis. *Educational Studies*. Advance online publication. https://doi.org/10.1080/03055698.2022.2107873