NAK-KANAK: Journal of Child Research
E-ISSN: 3047-1168 P-ISSN: 3047-504X
JCR, Vol. 3 (3), August 2026 (153-164)
DOI: https://doi.org/10.21107/njcr.v3i3.294

# Application of Mathematical Concepts and Fully Autonomous Robot to Early Childhood Education

**Gregory K. Tharp**✉

[1]Independent Researcher, Watertown, United States

**ARTICLE INFO**

**Article History:**
*Received: June 22, 2026*
*Revised: August 11, 2026*
*Accepted: August 14, 2026*

**Keywords**:
*Early Childhood Education;*
*Autonomous Robots;*
*Mathematics;*
*Educational Technology;*
*Resource Efficiency.*

This is an open-access article under the CC BY-NC license.

Copyright © 2026 by Author, Published Universitas Trunodjoyo Madura

## ABSTRACT

**Background of the study:** The increasing financial pressures and resource constraints faced by early childhood education (ECE) centers have created a need to explore approaches that may improve the efficiency and sustainability of educational services. Mathematics and fully autonomous robots have potential applications in ECE, particularly in supporting decision-making, resource management, and educational processes. However, the mathematical concepts underlying these applications and the mechanisms through which autonomous robots may be integrated into ECE remain insufficiently synthesized and explained.
**Aims and scope of paper:** This paper aims to examine the potential applications of mathematical concepts and fully autonomous robots in early childhood education. It also explores trends in early childhood development (ECD) in the United States over the past 50 years through a multivariate regression perspective. The paper focuses on how mathematical approaches and autonomous robotic technologies may contribute to the efficiency and delivery of ECE services.
**Methods:** The study employed a brief narrative literature review to synthesize existing research on mathematics, autonomous robotics, and their applications in early childhood education. In addition, multivariate regression analysis was used to examine selected ECD trends in the United States over a 50-year period. Relevant literature and historical data were reviewed and analyzed to identify patterns, applications, and potential relationships relevant to ECE efficiency.
**Results:** The review indicates that mathematical approaches can support several aspects of ECE, including quantitative decision-making, resource allocation, planning, and analysis of educational trends. Fully autonomous robots also show potential for supporting selected educational and operational functions in ECE settings. The regression analysis provides evidence of measurable trends in U.S. ECD over the examined period, although the findings should be interpreted in relation to the available historical data and the limitations of regression-based analysis. Overall, the findings suggest that mathematics and autonomous robotics may offer complementary tools for addressing resource and efficiency challenges in ECE..
**Contribution:** This paper contributes an interdisciplinary perspective linking mathematics, autonomous robotics, and early childhood education. By synthesizing mathematical applications, robotic mechanisms, and long-term ECD trends, the paper provides an accessible conceptual foundation for policymakers, ECE administrators, teachers, and researchers interested in technology-supported approaches to improving the efficiency and sustainability of early childhood education services.

✉ **Corresponding Author**
Address : Westport, United States
Email : gregtharp08@gmail.com

## INTRODUCTION

Tolerance is a fundamental value in character education and plays an essential role in fostering peaceful, inclusive, and respectful social relationships within diverse societies. UNESCO defines tolerance as respect, acceptance, and appreciation of the diversity of cultures, forms of expression, and ways of being human. This definition emphasizes that tolerance extends beyond merely accepting differences; it also involves recognizing every individual's right to maintain their identity, beliefs, and perspectives without discrimination. From this perspective, tolerance constitutes an important foundation for the development of democratic, harmonious, and inclusive societies (UNESCO, 1995).

Early childhood education centers are increasingly expected to provide high-quality services while operating under financial, staffing, and resource constraints. Concerns about artificial intelligence and broader economic pressures have increased the importance of considering how technological and mathematical tools can be applied responsibly within educational settings. Recent public concern about artificial intelligence and post-pandemic inflation provide part of the broader context in which organizations are examining how to operate efficiently with limited resources (Pew Research Center, 2025; Jorda & Nechio, 2023).

Mathematics provides a toolkit for understanding, modeling, and optimizing educational operations. Within early childhood education, mathematical approaches can be applied to data analysis, resource allocation, developmental measurement, prediction, evaluation, and operational planning. Regression analysis, for example, can be used to examine relationships among socioeconomic, family, educational, and developmental variables. Longitudinal early childhood datasets provide opportunities to examine developmental trajectories and the relationships between early experiences and later outcomes.

The development of autonomous robotic systems introduces another potential technological dimension. A fully autonomous early childhood education robot could theoretically combine physical robotics, computer vision, machine learning, artificial intelligence, data processing, and automated decision support. Such a system could potentially perform routine operational activities while leaving pedagogical, ethical, and high-risk decisions under human supervision. However, the use of autonomous systems around young children raises significant questions concerning safety, privacy, accountability, data security, and the appropriate boundaries between automation and human responsibility.

The relationship between mathematics, statistical analysis, data management, cryptology, and autonomous robotics therefore warrants examination as an integrated technological and analytical framework. The issue is not simply whether a robot can perform a task, but whether the underlying data, mathematical models, information systems, and physical mechanisms can operate reliably and safely in an early childhood environment.

This paper has two principal aims. First, it examines how mathematical and statistical concepts can be applied to early childhood education, particularly through regression analysis and publicly available longitudinal datasets. Second, it explores the conceptual design of a fully autonomous robot that could potentially support routine activities within early childhood education centers.

A secondary objective is to examine trends in early childhood development research in the United States over approximately five decades through the development of multivariate and longitudinal regression methods. The paper does not claim that autonomous robots are currently ready to replace human personnel in early childhood education. Rather, it presents mathematical, statistical, data-management, and robotic concepts that may inform future research and feasibility studies.

## METHOD

*Research Design*

This study uses a cross-sectional observational approach to existing literature. Cross-sectional approaches can provide relatively inexpensive preliminary evidence and can be useful for

establishing a basis for subsequent research planning (Wong & Cheng, 2020). The review was designed to provide a broad overview rather than a systematic estimation of a single intervention effect.

A selective sampling approach was used to identify resources concerning mathematics, early childhood education, regression analysis, longitudinal datasets, data management, cryptology, and autonomous robotic systems. The level of precision required for the review was relatively low because the principal objective was conceptual exploration rather than formal effect-size estimation.

The review also considered the balance between breadth and information overload. Although studies with large samples can improve statistical power and some aspects of replicability, a broad conceptual review can become difficult to interpret when excessive numbers of sources are included. Consequently, the review focused on selected datasets, studies, repositories, and methodological developments that illustrate major developments in the field.

*Type of Literature Review*

Several forms of literature review were considered, including narrative reviews, systematic reviews, integrative reviews, systematic reviews with meta-analysis, semi-systematic reviews, and review papers (Snyder, 2019). A narrative review was selected because the purpose was to provide a readable and practical synthesis across several disciplines rather than to estimate a single pooled effect.

The topic also crosses education, economics, statistics, information science, robotics, artificial intelligence, and data security. A formal systematic review would require a more narrowly defined research question and a more standardized evidence-selection procedure. The present review instead seeks to connect concepts that are ordinarily discussed in separate disciplinary literatures.

The novelty of autonomous robotics in early childhood education also limits the availability of mature protocols concerning privacy, data security, liability, and operational responsibility. Existing discussions of autonomous robotic systems in other sectors illustrate that responsibility for harm remains an important issue when decision-making is delegated to autonomous technologies (Jamjoom et al., 2022; Rhim et al., 2021).

*Literature Search Procedure*

The literature search included educational, psychological, medical, economic, and interdisciplinary databases. The principal databases considered were ERIC, PsycINFO, PubMed/MEDLINE, EconLit, and Web of Science/Scopus.

Dataset-specific search terms were used. For the Early Childhood Longitudinal Study, search terms included “ECLS-K,” “ECLS-B,” “ECLS-K:2011,” “NCES,” and “ECLS-K:2024.” For the Chicago Longitudinal Study, the terms included “Chicago Longitudinal Study,” “Child-Parent Center,” and “CPC.” For the NICHD Study of Early Child Care and Youth Development, search terms included “SECCYD,” “NICHD Study of Early Child Care,” and “NICHD ECCRN.” For the Carolina Abecedarian Project, terms included “Abecedarian Project,” “Carolina Abecedarian,” and “Abecedarian Approach.” For the Perry Preschool Project, the terms included “Perry Preschool Project,” “HighScope Perry,” and “HighScope.”

The databases were selected because they represent different dimensions of early childhood research. ERIC provides access to educational research and policy literature, PsycINFO provides psychological and behavioral research, EconLit provides economic research, PubMed/MEDLINE provides health-related literature, and Web of Science/Scopus provides interdisciplinary coverage.

In addition to conventional academic databases, institutional repositories were searched. The NCES DataLab and ECLS resources were used to identify technical documentation and user materials, while ICPSR was considered for archived datasets and related publications. The Frank Porter Graham Child Development Institute was considered for Abecedarian materials, and HighScope research archives were considered for long-term Perry Preschool follow-up materials.

*Data Collection*

Data were collected through documentary observation and repeated non-participant viewing of *Na Willa*. The researchers watched the film repeatedly to develop a comprehensive understanding of its narrative structure, characters, social interactions, and potentially relevant representations of tolerance.

During the observation process, dialogues, scenes, character behaviors, interpersonal interactions, and conflict-resolution events considered relevant to the research focus were documented through transcripts and analytical notes. Each relevant segment was recorded together with its contextual information, including the characters involved, the nature of the interaction, and the circumstances in which the behavior occurred. Repeated viewing was conducted to verify the completeness and contextual accuracy of the recorded data and to ensure that relevant representations were not overlooked.

*Inclusion, Exclusion, and Data Extraction*

The review focused on studies and resources that could inform one or more of the following areas:

1. early childhood development;
2. longitudinal early childhood datasets;
3. regression and econometric analysis;
4. randomized or quasi-experimental early childhood interventions;
5. data management and information systems;
6. cryptology and data security;
7. autonomous robotic systems; and
8. mathematical or computational approaches relevant to educational operations.

A master data-extraction framework was used to identify methodological characteristics and dataset-specific issues. The extraction process considered study design, population, intervention or exposure, outcome variables, statistical methods, longitudinal structure, data restrictions, and implications for interpretation.

*Dataset-Specific Extraction Checklist*

For the Early Childhood Longitudinal Study (ECLS), the review considered cohort specification, sampling weights, probability weights, primary sampling units, clustering, and differences among ECLS-B, ECLS-K, ECLS-K:2011, and ECLS-K:2024.

For the Chicago Longitudinal Study (CLS), attention was given to the formation of comparison groups and distinctions between preschool Child-Parent Center interventions, school-age interventions, and extended intervention periods.

For the NICHD Study of Early Child Care and Youth Development (SECCYD), the extraction process distinguished among the quantity, quality, and type of childcare. It also considered whether analyses controlled for differences among the study's data-collection sites.

For the Carolina Abecedarian Project, the review considered whether studies combined datasets, whether the analysis concerned the infant-to-five intervention or the later school-age intervention, and how treatment phases were distinguished.

For the Perry Preschool Project, attention was given to randomization procedures, post-randomization changes, small sample size, and statistical corrections associated with the original study design.

*Literature Review Quality Appraisal*

The literature review considered methodological quality through five broad domains:

1. Experimental control and internal validity, referring to the ability of a study to isolate causal effects from selection bias.
2. Sample power and generalizability, referring to sample size, diversity, and representativeness.

3. Long-term retention and attrition control, referring to the ability to maintain participants across longitudinal follow-ups.
4. Measurement rigor and data depth, referring to the breadth and quality of cognitive, behavioral, health, and observational measures.
5. Ecological and policy replicability, referring to the extent to which an intervention reflects real-world implementation conditions.

The scoring framework used three levels: 3 for high rigor or low risk of bias, 2 for moderate rigor or partial limitations, and 1 for significant methodological limitations.

## RESULTS

*Publicly Available Early Childhood Education Datasets*

The review identified several publicly available or institutionally accessible longitudinal datasets that provide substantial opportunities for mathematical and statistical analysis of early childhood development.

The Early Childhood Longitudinal Study (ECLS), administered by the National Center for Education Statistics, includes several cohorts. ECLS-B follows children born in 2001 from birth through kindergarten, while ECLS-K follows children beginning in kindergarten and includes longitudinal information extending into later schooling. These datasets include information concerning socioeconomic status, maternal employment, home literacy environments, childcare exposure, school resources, reading and mathematics outcomes, executive function, approaches to learning, and socio-emotional development (NCES, 2026).

The NICHD Study of Early Child Care and Youth Development (SECCYD) was established in 1991 and followed more than 1,300 children from birth through adolescence. The study includes information on childcare settings, hours of non-parental care, home and childcare quality, maternal characteristics, attachment, language development, and behavioral outcomes (NICHD, 2026).

The Chicago Longitudinal Study (CLS) examined participation in Child-Parent Centers, parental involvement, and neighborhood-level socioeconomic conditions. Outcomes included grade retention, special education participation, high school completion, employment, and contact with the criminal justice system.

The Future of Families and Child Wellbeing Study (FFCWS) followed a large cohort of children born between 1998 and 2000 in large U.S. cities. The study provides information concerning family structure, parental incarceration, economic hardship, paternal support, child behavior, cognitive development, and health outcomes (Princeton University, 2026).

Together, these datasets provide a foundation for multivariate analysis because they contain multiple predictors, outcomes, control variables, and repeated observations.

*Foundational Econometric Studies and Randomized Controlled Trials*

Observational datasets are useful but can be affected by selection bias and unobserved confounding. Randomized controlled trials provide an important complementary source of evidence because random assignment can improve causal identification.

The Perry Preschool Project is one of the major longitudinal early childhood intervention studies. The project followed disadvantaged children who participated in a high-quality preschool program and subsequently examined outcomes over several decades. Long-term analyses have examined cognitive, economic, social, and intergenerational outcomes (Garcia, 2023; Baulos et al., 2024).

The Carolina Abecedarian Project provides another important example of intensive early childhood intervention research. Beginning during infancy, the project examined the long-term consequences of intensive early education and care. Economic analyses have considered returns associated with health, employment, and other adult outcomes (Garcia, 2020).

These studies provide a methodological counterpoint to observational longitudinal datasets because their research designs allow different approaches to causal inference.

*Selected Literature and Institutional Repositories*

The reviewed literature demonstrates the importance of distinguishing correlation from causation. Crosby et al. (2010), for example, compared regression and instrumental-variable estimates in examining the effects of preschool childcare type. Such comparisons illustrate how estimates can change when researchers address potential unobserved selection characteristics.

Nelson et al. (2016) used multivariate logistic regression to examine cumulative socio-environmental risks associated with school readiness. Such work demonstrates how regression analysis can be used to identify combinations of risk factors rather than focusing on isolated predictors.

Institutional repositories are also important because a substantial portion of longitudinal research is supported by technical reports, codebooks, restricted-use files, and archived data rather than conventional journal publications. ICPSR, NCES DataLab, HighScope archives, and other institutional repositories therefore provide important resources for researchers seeking to reproduce or extend previous analyses.

*Quality Appraisal of Longitudinal Studies*

The reviewed intervention studies illustrate different relationships between internal validity, sample size, and ecological validity.

The Perry Preschool Project received strong consideration for internal validity because of its randomized design and long-term follow-up. However, its relatively small and specific original sample limits direct generalization to all early childhood populations.

The Abecedarian Project also demonstrates strong experimental control and extensive measurement. At the same time, the intensity and cost of the intervention make direct replication within ordinary public systems more difficult.

The Chicago Longitudinal Study represents a different methodological model. Its quasi-experimental design and large sample provide stronger ecological relevance, although the absence of formal randomization means that statistical adjustment remains important for addressing selection bias.

These differences demonstrate that no single study design provides all forms of evidence required for early childhood policy and practice. Experimental studies provide strong evidence concerning causal effects under particular conditions, whereas longitudinal observational studies can provide broader information concerning population variation and real-world conditions.

*Statistical Framework and Developmental Outcomes*

Regression analysis provides a mathematical framework for examining the relationship between early childhood predictors and developmental outcomes. Weighted ordinary least squares can be used when survey designs require probability weighting. Multilevel and hierarchical models can account for nested structures such as children within classrooms, schools, or communities.

Structural equation modeling can be used when researchers are interested in latent developmental constructs and relationships among multiple pathways. Instrumental-variable approaches can be used when endogeneity and unobserved selection are major concerns. Regression-discontinuity designs provide another quasi-experimental approach when treatment assignment is determined by a measurable threshold (Hahn et al., 2008; Ludwig & Miller, 2007).

The development of these methods reflects a broader shift from simple associations toward increasingly sophisticated approaches to longitudinal, hierarchical, nonlinear, and causal analysis.

*Landmark Datasets and Long-Term Methodological Trends*

Across approximately five decades, early childhood research has progressively increased the complexity of its statistical models. Earlier research relied more heavily on basic comparisons and ordinary regression models. Later research incorporated hierarchical structures, longitudinal trajectories, structural equation models, quasi-experimental designs, and heterogeneous treatment effects.

The availability of large longitudinal datasets has been a major factor in this methodological development. As datasets have become larger and more complex, researchers have required methods capable of handling repeated observations, nested environments, missing data, treatment selection, and heterogeneous effects.

*Methodological Progress and Challenges*

The methodological progression also introduces new challenges. Complex models require appropriate assumptions, adequate statistical power, high-quality measurements, and transparent reporting. Increasing model complexity does not automatically guarantee better evidence.

Researchers must also distinguish between statistical prediction and causal explanation. A model that predicts an outcome accurately may not identify the mechanism responsible for that outcome. Consequently, early childhood research requires attention not only to mathematical sophistication but also to research design and substantive interpretation.

*Evolution of Regression Modeling in Early Childhood Education*

*1970s–1980s: Classical OLS and ANCOVA*

During the 1970s and 1980s, classical ordinary least squares and analysis of covariance represented important approaches to examining educational and developmental outcomes. These methods were useful for estimating average associations and treatment differences.

*1990s: Multilevel and Hierarchical Models*

During the 1990s, greater attention was given to nested educational environments. Multilevel and hierarchical models allowed researchers to distinguish individual-level variation from variation associated with classrooms, schools, and other contextual units (Goldstein, 1986).

*2000s: Latent Growth Curve and Structural Equation Models*

During the 2000s, longitudinal datasets increasingly supported latent growth curve models and structural equation modeling. These approaches allowed researchers to examine developmental trajectories and relationships among latent constructs.

*2010s: Causal and Quasi-Experimental Regression*

During the 2010s, causal inference became increasingly important. Regression-discontinuity, instrumental-variable, fixed-effects, and two-stage least-squares approaches were used to address selection bias and unobserved confounding.

*2020s: Cross-Classification, Nonlinear Models, and Causal Machine Learning*

More recent approaches include cross-classified models, generalized additive models, causal forests, and heterogeneous treatment-effect models. These approaches can address increasingly complex educational structures and nonlinear relationships, although their interpretation and implementation require substantial statistical expertise.

## DISCUSSION

*Mathematics, Data Management, and Cryptology*

The application of mathematics to early childhood education extends beyond regression analysis. Mathematical concepts are also embedded in information organization, database design, optimization, encryption, error detection, and computational decision-making.

A technologically advanced early childhood education center would potentially depend on interconnected databases containing information about children, staff, parents, learning materials, schedules, facilities, and services. Such systems require reliable data structures and mechanisms for protecting sensitive information.

Cryptographic technologies may therefore become an important component of future digital early childhood systems. Encryption, hashing, authentication, and digital signatures can

provide mechanisms for protecting information and verifying data integrity. The use of such technologies must be considered carefully because early childhood data can contain highly sensitive personally identifiable information.

*Mathematical Analogies for Early Childhood Education Data Operations*

The original paper uses several mathematical concepts as analogies for data-management operations. These include concepts associated with the Riemann Hypothesis, random matrix theory, the Yang–Mills mass-gap problem, computational complexity, the Hodge conjecture, Navier–Stokes equations, and the Birch and Swinnerton-Dyer conjecture.

These analogies should be understood as conceptual illustrations rather than claims that unresolved mathematical problems have been directly solved or empirically demonstrated in early childhood education.

For example, the discussion of the Riemann Hypothesis is used to illustrate the idea of error bounds and fluctuations around expected patterns. In an operational setting, an analogous concept could be used to think about deviations in workload, data-entry demand, or resource allocation.

Random matrix theory is used as an analogy for identifying patterns in complex systems. In an early childhood information environment, similar conceptual thinking could be applied to large collections of interconnected observations.

*Data Integrity, Yang–Mills Analogy, and Operational Thresholds*

The paper also uses the Yang–Mills mass-gap problem as an analogy for distinguishing observable operational behavior from underlying system structure. The analogy emphasizes that complex systems may exhibit measurable outcomes that emerge from deeper underlying mechanisms.

In practical early childhood education data systems, the relevant principle is that operational indicators should not be interpreted independently of the underlying data-generation process. A change in the number of recorded activities, for example, may reflect an actual change in service provision, a change in recording procedures, or an error in the underlying information system. Therefore, mathematical modeling should be accompanied by data-quality monitoring and validation procedures.

*Computational Complexity and Optimization*

Computational complexity is another relevant consideration when mathematical systems are implemented technologically. A theoretically useful model may become impractical if it requires excessive computational resources.

Optimization in early childhood education can therefore involve balancing accuracy, speed, cost, and interpretability. Automated systems should not simply maximize computational efficiency. They must also maintain appropriate safety standards and preserve human oversight.

This consideration becomes particularly important when autonomous robotic systems operate in physical environments containing young children. The cost of an incorrect decision can be substantially higher than the cost of a computational error in a conventional administrative system.

*Hodge, Navier–Stokes, and BSD Conjecture Analogies*

The Hodge conjecture, Navier–Stokes equations, and Birch and Swinnerton-Dyer conjecture are used in the original paper to develop further analogies concerning information structure, system dynamics, and discovery.

The BSD analogy, for example, conceptualizes the relationship between an internal information structure and the external discovery layer of a system. In an early childhood information environment, this can be interpreted as the relationship between interconnected records and the interfaces through which authorized users locate information.

The Navier–Stokes analogy is used to conceptualize flows and operational dynamics. In practical terms, early childhood centers experience flows of children, information, materials, staff

activities, and administrative requests. Modeling these flows may help researchers understand bottlenecks and resource demands. Again, these are conceptual analogies rather than direct mathematical applications of the corresponding unresolved problems to early childhood education.

*Fully Autonomous Early Childhood Education Robot*

A fully autonomous early childhood education robot would represent a significant technological progression beyond simple automation. The proposed system would integrate physical robotics, computer vision, machine learning, generative artificial intelligence, data processing, and automated decision support. The system can be conceptualized through several layers.

*Physical Material Intake and Processing*

The physical layer would involve robotic manipulation of educational materials and other objects. Toys and educational materials vary in weight, shape, texture, size, and structural integrity. A robotic system would therefore require dexterous manipulation technologies, potentially including soft robotic grippers and three-dimensional sensing.

Computer vision could be used to identify objects and separate individual items. Optical Character Recognition could be used to read labels, packing slips, or inventory information. The system could compare physically received items with an electronic inventory and identify discrepancies, damaged materials, or missing items.

*Material Organization and Retrieval*

After identification, materials could be classified and assigned to appropriate storage locations. The robot could potentially retrieve materials according to teacher instructions or predefined classroom schedules.

A similar mechanism could be used for post-activity organization. After children complete play activities, the system could identify materials and return them to appropriate locations.

*Data and Information Layer*

The robot would also require a data-management system connecting physical objects with digital records. This could include information concerning inventory, maintenance, licensing, schedules, and authorized users.

Because early childhood environments contain sensitive information, the information layer would require strong authentication, authorization, encryption, data-integrity mechanisms, and appropriate privacy protections.

*Human Oversight*

Despite the use of autonomous technologies, human oversight remains essential. A robot operating in an early childhood environment should not be assumed to possess the ethical, developmental, relational, or contextual understanding of teachers and other professionals.

Consequently, autonomy should be considered task-specific rather than equivalent to independent professional judgment. Routine logistical tasks may potentially be automated, while decisions involving children's safety, developmental needs, discipline, health, or emotional well-being require appropriate human responsibility.

*Implications*

However, implementation should not proceed solely on the basis of theoretical efficiency. Empirical feasibility studies, lifecycle analyses, usability studies, safety assessments, focus groups, cost analyses, and implementation research are needed before autonomous robotic systems can be considered appropriate for widespread deployment.

*Research Contributions*
The contribution of the paper lies in connecting several areas that are often treated separately: multivariate mathematics, regression analysis, longitudinal early childhood research, data management, cryptology, and autonomous robotics.

*Limitations*
the study uses a brief narrative review rather than a systematic review or meta-analysis. The selection of literature was therefore intended to provide a broad conceptual overview rather than a comprehensive synthesis of all available evidence. Consequently, the findings should not be interpreted as representing the complete body of research on mathematics, robotics, or early childhood education.

*Suggestions*
The combination suggests a possible future research agenda in which early childhood centers use mathematical models to understand resource requirements while technological systems automate selected routine activities.

## CONCLUSION

The application of mathematics and autonomous robotics to early childhood education represents a potential area for interdisciplinary research. Existing longitudinal datasets demonstrate the value of mathematical and statistical approaches for examining developmental outcomes, while the historical development of regression modeling illustrates the increasing sophistication of early childhood research. The review also indicates that mathematical applications extend beyond statistical analysis to information management, optimization, computational processes, data integrity, and cryptographic protection. These components could provide part of the technological infrastructure required for future autonomous systems. A fully autonomous early childhood education robot could potentially support routine operational activities such as material intake, identification, inventory management, retrieval, and organization. Nevertheless, such systems would require reliable physical sensing, computational infrastructure, secure information systems, and clear mechanisms for human oversight.

The principal limitation of the present review is that the proposed robotic applications remain largely conceptual and are not supported by direct empirical trials in ordinary early childhood education settings. Additional feasibility, safety, lifecycle, economic, ethical, and implementation studies are therefore necessary. Future research should examine not only whether autonomous technologies can perform particular tasks, but also whether their use improves educational operations without compromising children's safety, privacy, developmental needs, or the professional responsibilities of educators.

## AUTHOR CONTRIBUTION STATEMENT

**Gregory K. Tharp:** Conceptualization, Investigation, Data Curation, Visualization, Project Administration, Writing – Original Draft, Writing – Review & Editing.

## REFERENCES

American Economic Association. (2026). *EconLit*. https://www.aeaweb.org/econlit/

American Psychological Association. (2026). *APA PsycNet*. https://www.apa.org/pubs/databases/psycnet

Ardoin, N. M., & Bowers, A. W. (2020). Early childhood environmental education: A systematic review of the research literature. *Educational Research Review, 31*, 100353. https://doi.org/10.1016/j.edurev.2020.100353

Baulos, A. W., Garcia, J. L., & Heckman, J. J. (2024). *Perry Preschool at 50: What lessons should be drawn and which criticisms ignored?* (NBER Working Paper No. 32972). National Bureau of Economic Research. https://doi.org/10.3386/w32972

Crosby, D. A., Dowsett, C. J., Gennetian, L. A., & Huston, A. C. (2010). A tale of two methods: Comparing regression and instrumental variables estimates of the effects of preschool child care type on the subsequent externalizing behavior of children in low-income families. *Developmental Psychology, 46*(5), 1030–1048. https://doi.org/10.1037/a0020384

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani, L. S., Feinstein, L., Engel, M., Brooks-Gunn, J., Sexton, H., Duckworth, K., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology, 43*(6), 1428–1446. https://doi.org/10.1037/0012-1649.43.6.1428

García, J. L., Heckman, J. J., Leaf, D. E., & Prados, M. J. (2020). Quantifying the life-cycle benefits of an influential early-childhood program. *Journal of Political Economy, 128*(7), 2502–2541. https://doi.org/10.1086/705718

García, J. L., Heckman, J. J., & Ronda, V. (2023). The lasting effects of early-childhood education on promoting the skills and social mobility of disadvantaged African Americans and their children. *Journal of Political Economy, 131*(6), 1477–1506. https://doi.org/10.1086/722936

Goldstein, H. (1986). Efficient statistical modelling of longitudinal data. *Annals of Human Biology, 13*(2), 129–141. https://doi.org/10.1080/03014468600008271

Gormley, W. T., Jr., Gayer, T., Phillips, D., & Dawson, B. (2005). The effects of universal pre-K on cognitive development. *Developmental Psychology, 41*(6), 872–884. https://doi.org/10.1037/0012-1649.41.6.872

Hahn, J., Todd, P., & Van der Klaauw, W. (2001). Identification and estimation of treatment effects with a regression-discontinuity design. *Econometrica, 69*(1), 201–209. https://doi.org/10.1111/1468-0262.00183

Inter-university Consortium for Political and Social Research. (2026). *Data excellence. Research impact*. University of Michigan. https://www.icpsr.umich.edu/

Jamjoom, A. A. B., Jamjoom, A. M. A., Thomas, J. P., Palmisciano, P., Kerr, K., Collins, J. W., Vayena, E., Stoyanov, D., & Marcus, H. J. (2022). Autonomous surgical robotic systems and the liability dilemma. *Frontiers in Surgery, 9*, 1015367. https://doi.org/10.3389/fsurg.2022.1015367

Jorda, Ò., & Nechio, F. (2023). Inflation and wage growth since the pandemic. *European Economic Review, 156*, 104474. https://doi.org/10.1016/j.euroecorev.2023.104474

Ludwig, J., & Miller, D. L. (2007). Does Head Start improve children's life chances? Evidence from a regression discontinuity design. *The Quarterly Journal of Economics, 122*(1), 159–208. https://doi.org/10.1162/qjec.122.1.159

National Center for Education Statistics. (2026a). *DataLab*. U.S. Department of Education. https://nces.ed.gov/datalab/

National Center for Education Statistics. (2026b). *Early Childhood Longitudinal Studies Program*. U.S. Department of Education. https://nces.ed.gov/ecls/

National Institute of Child Health and Human Development. (2026). *The NICHD Study of Early Child Care and Youth Development*. National Institutes of Health.

Nelson, B. B., Dudovitz, R. N., Coker, T. R., Barnert, E. S., Biely, C., Li, N., Szilagyi, P. G., Larson, K., Halfon, N., Zimmerman, F. J., & Chung, P. J. (2016). Predictors of poor school

readiness in children without developmental delay at age 2. *Pediatrics, 138*(2), e20154477. https://doi.org/10.1542/peds.2015-4477

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*, n71. https://doi.org/10.1136/bmj.n71

Pew Research Center. (2025). *How the U.S. public and AI experts view artificial intelligence*. https://www.pewresearch.org/

Pillinger, C., & Vardy, E. J. (2022). The story so far: A systematic review of the dialogic reading literature. *Journal of Research in Reading, 45*(4), 533–548. https://doi.org/10.1111/1467-9817.12407

Princeton University. (2026). *Future of Families and Child Wellbeing Study*. https://ffcws.princeton.edu/

Rhim, J., Lee, J.-H., Chen, M., & Lim, A. (2021). A deeper look at autonomous vehicle ethics: An integrative ethical decision-making framework to explain moral pluralism. *Frontiers in Robotics and AI, 8*, 632394. https://doi.org/10.3389/frobt.2021.632394

Sataloff, R. T., Bush, M. L., Chandra, R., Chepeha, D., Rotenberg, B., Fisher, E. W., Goldenberg, D., Hanna, E. Y., Kerschner, J. E., Kraus, D. H., Krouse, J. H., Li, D., Link, M., Lustig, L. R., Selesnick, S. H., Sindwani, R., Smith, R. J., Tysome, J., Weber, P. C., & Welling, D. B. (2021). Systematic and other reviews: Criteria and complexities. *Journal of Otolaryngology—Head & Neck Surgery, 50*, 41. https://doi.org/10.1186/s40463-021-00527-9

Sterne, J. A. C., Savović, J., Page, M. J., Elbers, R. G., Blencowe, N. S., Boutron, I., Cates, C. J., Cheng, H.-Y., Corbett, M. S., Eldridge, S. M., Emberson, J. R., Hernán, M. A., Hopewell, S., Hróbjartsson, A., Junqueira, D. R., Jüni, P., Kirkham, J. J., Lasserson, T., Li, T., McAleenan, A., Reeves, B. C., Shepperd, S., Shrier, I., Stewart, L. A., Tilling, K., White, I. R., Whiting, P. F., & Higgins, J. P. T. (2019). RoB 2: A revised tool for assessing risk of bias in randomised trials. *BMJ, 366*, l4898. https://doi.org/10.1136/bmj.l4898

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research, 104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Sukhera, J. (2022). Narrative reviews: Flexible, rigorous, and practical. *Journal of Graduate Medical Education, 14*(4), 414–417. https://doi.org/10.4300/JGME-D-22-00480.1

University of Minnesota Twin Cities. (2026). *Chicago Longitudinal Study*. Institute of Child Development.

Wang, X., & Cheng, Z. (2020). Cross-sectional studies: Strengths, weaknesses, and recommendations. *Chest, 158*(1S), S65–S71. https://doi.org/10.1016/j.chest.2020.03.012

Wong, G., Greenhalgh, T., Westhorp, G., Buckingham, J., & Pawson, R. (2013). RAMESES publication standards: Meta-narrative reviews. *Journal of Advanced Nursing, 69*(5), 987–1004. https://doi.org/10.1111/jan.12092