

Article

Project-Based STEM Education for Preschool Children: Theory and Case Study

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Abstract: As global emphasis on fostering innovation and comprehensive competencies grows, the value of STEM (Science, Technology, Engineering, Mathematics) education at the preschool level has become increasingly evident. Building on a review of the theoretical foundations of STEM education and project-based learning, as well as domestic and international research, this study designs and implements the "Drip Exploration" project-based teaching program tailored to the preschool context. Aiming to cultivate children's problem-posing awareness, collaborative skills, and hands-on practice abilities, the research combines action research with case analysis. By tracking observations, conducting interviews, and evaluating outcomes in a "Little Engineers" project among a middle-level class group in one kindergarten, the study examines how project-based learning stimulates children's curiosity, promotes interdisciplinary learning, and enhances overall competencies. Results show that project-based learning effectively integrates multiple disciplines, boosts preschoolers' enthusiasm for exploration and teamwork, and offers a replicable model for kindergarten STEM practice. Finally, in response to challenges such as insufficient teacher preparation and limited curricular resources, the paper proposes optimization strategies and practical recommendations to support the broader adoption and deepening of project-based STEM education in preschool settings.

Keywords: preschool children; STEM education; project-based learning; case study; competency enhancement

1. Introduction

Under the twin forces of globalization and digitalization, cultivating individuals with an innovative spirit and well-rounded competencies has become a central goal of educational reforms worldwide. STEM education—centered on science, technology, engineering, and mathematics—emphasizes interdisciplinary integration and inquiry-based practice, and is gradually extending into preschool programs. Preschoolers are at a critical stage of heightened curiosity and eagerness to learn; through varied activities such as science experiments, engineering builds, technology interactions, and math games, they can develop an intuitive understanding of natural phenomena and basic principles while honing problem-solving mindsets and teamwork skills through "learning by doing" and "doing by learning." However, in China, significant gaps remain in preschool STEM curriculum design, professional teacher training, and resource allocation. Regional disparities in educational infrastructure and uneven teacher expertise in STEM teaching present major barriers to the widespread adoption of project-based approaches. Project-based learning (PBL) embeds authentic, meaningful tasks into a contextualized, task-oriented learning sequence, aligning with constructivist views of children as active knowledge builders and with Vygotsky's concept of the Zone of Proximal Development, in which appropriately scaffolded support enables learners to exceed their independent capabilities. By structuring open-ended questions, collaborative work, hands-on action, and reflective evaluation, PBL motivates children within concrete scenarios, guiding them through the

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full inquiry cycle with teacher and peer assistance, and laying a solid foundation for subsequent learning. This study therefore investigates the effectiveness and practice pathways of project-based learning in preschool STEM education. We first synthesize the theoretical underpinnings of STEM and PBL along with domestic and international experiences, then design and implement the "Drip Exploration" series—focusing on a bridge-building case. Through systematic observation, interviews, and outcome evaluations, we capture preschoolers' performance in problem posing, solution design, model construction, and result sharing. Finally, drawing on teacher logs, children's artifacts, and parent feedback, we assess PBL's impact on curiosity, interdisciplinary abilities, and overall competency, and provide optimization strategies and practical recommendations for scaling preschool STEM project-based learning.

2. Theoretical Foundations and Literature Review

2.1. Theoretical Foundations of STEM Education

The core theory behind STEM education derives from constructivist learning and inquiry-based paradigms. Constructivism holds that learners actively integrate new knowledge into existing cognitive structures through interaction with their environment; preschoolers grasp scientific concepts and technological principles more solidly when they explore and manipulate directly. Piaget's stages of cognitive development position preschoolers in the sensorimotor and pre-operational phases, during which they form preliminary understandings of the world via direct perception and concrete actions. Vygotsky's Zone of Proximal Development posits that, with appropriate support from teachers or peers, children can accomplish tasks beyond their standalone capabilities. Combining these theories with inquiry learning, STEM education emphasizes problem- or project-driven exploration, letting children pose questions, design solutions, test, and refine within authentic contexts—thereby honoring cognitive development while igniting intrinsic motivation. Moreover, Papert's constructionism offers an enriched perspective for project-based STEM: learning is most potent when learners create tangible, shareable artifacts. As preschoolers design, build, and present engineering models or scientific experiments, they become both investigators and constructors of knowledge [1]. Through interdisciplinary project tasks, children naturally blend mathematical computation, scientific observation, and technological manipulation, leading to a holistic understanding of problems. This process not only cultivates logical reasoning and spatial imagination, but also fosters teamwork and communication skills, laying a robust foundation for advanced STEM learning [2].

2.2. Theoretical Framework of Project-Based Learning

Project-based learning (PBL) draws its foundational philosophy from John Dewey's conviction that "learning through experience" is central to meaningful education. Dewey maintained that children learn best when engaged in activities directly relevant to their lives and interests, rather than passive reception of abstract facts. By embedding academic content within authentic, purposeful tasks, PBL situates learning in real-world contexts that resonate with young learners. David Kolb's experiential learning cycle further refines this approach by delineating four interrelated stages—concrete experience, reflective observation, abstract conceptualization, and active experimentation. In a PBL environment, preschoolers first encounter a concrete challenge (for example, building a small bridge to carry toy cars), then pause to reflect on what happened during their initial trials, draw conclusions about why certain designs worked or failed, and finally test revised ideas in subsequent hands-on experiments [3]. This recursive "do–reflect–think–do" model reinforces deeper understanding: children do not merely memorize the concept of balance or force; they experience it firsthand, consider their observations, articulate emerging principles ("if the supports are wider apart, the bridge holds more weight"), and apply these insights to redesign. Such iterative cycles foster children's metacognitive skills, as they

learn to monitor their own thinking, evaluate outcomes, and regulate their actions. Lev Vygotsky's sociocultural theory adds another crucial layer, emphasizing that cognitive development flourishes in the Zone of Proximal Development (ZPD)—the gap between what learners can accomplish independently and what they can achieve with guidance. In PBL, teachers and capable peers provide scaffolding: modeling tool use, asking probing questions, or offering targeted hints ("What if we add a triangular brace here?") [4]. Over time, as children internalize these strategies, the support is gradually withdrawn, empowering learners to take increasing ownership of their projects and to tackle more complex tasks. PBL also foregrounds the social dimensions of learning. Group discussions, shared decision-making, and role assignments (e.g., "designer", "materials manager", "tester", "presenter") create a community of practice in which children negotiate ideas, give and receive feedback, and build empathy and respect. Presentations and reflective dialogues prompt learners to articulate their reasoning and to listen to alternative perspectives, reinforcing language skills and strengthening communication competence. Critically, PBL integrates multiple domains—science, technology, engineering, mathematics, and even language arts—into coherent units of study. A single project may require children to measure lengths (mathematics), observe how different materials respond to stress (science), design a stable structure (engineering), use simple programmable controls (technology), and narrate their process in a story format (language development). By weaving these strands together in sustained, meaningful projects, PBL encourages holistic development, nurturing not only content knowledge but also critical thinking, creativity, collaboration, and self-regulated learning—competencies at the heart of 21st-century education [5].

3. Current Status of Preschool STEM Education

3.1. Domestic Developments in Preschool STEM Education

In recent years, China's Ministry of Education and provincial and municipal education authorities have issued a series of policy documents that elevate innovation and comprehensive competency development as core objectives of preschool reform. The National Medium- and Long-Term Education Reform and Development Plan (2010–2020) and the Guidelines for Learning and Development of Children Aged 3–6 explicitly call for embedding age-appropriate scientific inquiry and mathematical thinking into play-based curricula, thereby providing top-level policy endorsement for kindergarten STEM programming. Building on these frameworks, pilot initiatives have been launched in cities such as Beijing, Shanghai, Shenzhen, Guangzhou, and Hangzhou, where local education bureaus collaborate with university education faculties, technology firms, and nonprofit organizations to roll out "Scientific Inquiry", "Tiny Engineers", and "Coding Initiation" modules. These thematic projects typically involve a series of workshops and site visits designed to familiarize teachers with robotics kits, programmable blocks, and digital learning platforms [6]. Training cohorts often include lesson-study groups, in which kindergarten teachers observe one another's STEM lessons, co-plan activities, and reflect on classroom videos. In addition, major early-education conferences in cities like Shanghai now routinely feature dedicated STEM strands, attracting curriculum developers from leading domestic kindergarten brands as well as experts from global organizations such as the LEGO Education Academy. On the ground, exemplary kindergartens are moving beyond isolated activities to build fully interdisciplinary, semester-long units. For example, an "Eco-Guardian" project begins with children classifying and weighing recyclables, progresses to a design session in which they repurpose materials into planters or storage containers, and culminates in a data-collection fair where students chart the number and types of upcycled items and present their findings to parents and peers [7]. Such projects integrate hands-on science, engineering challenges, mathematics through data logging, and technology via simple digital documentation tools. Corporate sponsors—including technology giants, local startups, and education-focused foundations—have begun underwriting

these efforts by donating hardware (table-top robots, 3D printers) and funding professional-development stipends. Some nonprofits partner with kindergartens to establish "mini-maker spaces", where children explore gear systems, circuitry with snap-together components, and screen-based coding under teacher guidance. Collaboration with international initiatives, such as NASA's "Young Scientist" outreach and the Raspberry Pi Foundation's "CoderDojo", has further amplified visibility and created regional demonstration centers that host open-house STEM fairs. Despite these promising developments, preschool STEM education in China remains in an exploratory phase marked by stark regional imbalances. Urban kindergartens in economically advantaged provinces often enjoy comprehensive resource packages and ongoing in-service training, whereas rural and midwestern settings struggle with limited budgets, outdated equipment, and teachers who have little access to specialized STEM pedagogy. Moreover, most kindergarten instructors lack formal preparation in STEM teaching methodologies, frequently outsourcing project design and execution to external vendors rather than developing their own curricula [8]. Assessment frameworks for measuring young children's cross-disciplinary competencies, creativity, and collaboration skills are still nascent, with few validated tools available for large-scale adoption. To foster scalable, high-quality project-based STEM learning across diverse contexts, it is essential to enhance mechanisms for equitable resource allocation, broaden both pre-service and in-service teacher training in STEM pedagogy, and establish standardized, developmentally appropriate assessment tools. Through the integration of funding strategies, professional learning communities, and curriculum innovation, stakeholders can collaboratively address disparities between urban and rural areas, ensuring that all preschoolers have access to authentic, inquiry-driven STEM experiences [9].

3.2. International Practices in Preschool STEM Education

In the United States, STEM is integral to early education. The National Research Council's Framework for K–12 Science Education places scientific inquiry at the core, encouraging preschoolers to understand phenomena through observation, manipulation, and discourse. Many kindergartens feature "science corners" and "engineering corners" stocked with simple lab equipment and building materials, enabling free exploration in authentic contexts. Nonprofits like Code.org offer graphical coding courses for preschoolers, using touchscreen or block-based tools so children learn algorithmic thinking via games and stories. NASA's "Young Scientist" program partners with museums, integrating space exploration themes into preschool curricula through virtual experiences, hands-on crafts, and group discussions, sparking curiosity and imagination [10]. In Europe, Finland and the UK emphasize interdisciplinary and inquiry-based approaches. Finnish preschools adopt "theme teaching", with projects on "Nature and Environment" or "Mechanics and Structures" that involve outdoor observation, lab work, and collaborative discussion. Rich materials include natural specimens, mini machines, and coding toys, and assessments focus on process and performance. The UK's Early Years Foundation Stage (EYFS) framework mandates "exploration and creation", promoting child-centered, play-based learning. Many UK preschools collaborate with tech firms or universities to build STEAM labs, where children undertake sustainable energy model builds, robot programming, and math storytelling. Teachers share project designs and refine strategies in Professional Learning Communities (PLCs). Australia and Singapore also advance preschool STEM by combining design thinking with PBL. Maker spaces equipped with 3D printers, sensors, and simple tools invite children to experience the full cycle from problem definition to prototype testing. These diverse global practices highlight that successful preschool STEM PBL depends not only on rich resources and environments, but also on teacher professional development and robust assessment systems—offering valuable models for China's preschool reform.

4. Project-Based Teaching Design and Implementation

4.1. Teaching Objectives and Content Design

This project places "exploration and construction" at its core, seeking to harness preschoolers' natural curiosity and burgeoning cognitive skills by immersing them in authentic, hands-on STEAM experiences. By guiding children to observe, manipulate, and experiment with concrete materials, we aim to foster a deep, intuitive grasp of foundational concepts in physics—such as forces, balance, and material properties—and to nurture their emerging scientific thinking. At the same time, through carefully structured challenges that require them to pose open-ended questions ("How can we make this bridge hold more weight?"), design potential solutions, and iteratively refine their approaches, we cultivate both creative problem-solving abilities and a resilient, growth-oriented mindset. Equally important is the emphasis on collaborative learning. Small-group work encourages preschoolers to articulate their ideas, negotiate roles, and share responsibility for project outcomes. As they discuss which materials to select, how to distribute tasks, and how to evaluate success criteria, they practice essential communication skills—listening actively, expressing themselves clearly, and responding constructively to peers. These social interactions lay the groundwork for emotional intelligence and teamwork, helping children learn to value diverse perspectives while building confidence in their own contributions. Mathematical literacy is woven seamlessly into the project sequence. When children measure lengths of craft sticks, count load-bearing weights, or sort components by size and function, they gain firsthand experience with number sense, measurement concepts, and data recording. These activities, far from feeling like abstract drills, are directly tied to the engineering tasks at hand, demonstrating how mathematics underpins real-world design challenges. Early exposure to such practical math use not only strengthens numerical fluency but also sparks an appreciation for how numbers and patterns help us understand and shape the world around us. To bring technology and engineering thinking into the mix, each of our four thematic modules—"Bridge Structures," "The Water Cycle," "Simple Machines", and "Programmable Vehicles"—incorporates age-appropriate building kits, model-making supplies, and introductory programmable toys. Children learn basic sequencing and logical reasoning when they assemble gears or write simple commands to guide a wheeled robot through a course. These experiences demystify technology and empower youngsters to see themselves as budding engineers and technologists. The curriculum unfolds in four stages: teachers first establish a meaningful context by posing an inquiry question and creating a vivid scenario; next, children collaborate in small groups to plan and prepare materials; then they engage in hands-on construction and testing, gathering observations and comparing outcomes; finally, they present their creations, reflect on successes and challenges, and propose improvements. This cyclical model—contextualize, build, test, reflect—ensures that every child experiences a complete inquiry–practice–assessment–improvement loop, driving holistic development across cognitive, social, and emotional domains. In this way, the project not only integrates multiple disciplines but also equips children with the confidence and competencies they need to explore, innovate, and thrive.

4.2. Implementation Process of Project-Based Teaching

Successful project-based teaching begins with thorough preparation. Teachers must study the project theme in depth to clarify the scientific principles and engineering tasks at each stage, select age-appropriate materials and tools based on children's cognitive characteristics, and arrange an immersive learning corner. For example, in the "Bridge Structures" project, teachers prepare various recycled cardboard pieces, small wooden sticks, and connectors in advance, then set up a mock river and roadway in a corner of the classroom to enhance realism. Next, teachers introduce the project through storytelling or role-play to ignite children's curiosity and pose an open-ended question—such as "What kind of bridge can hold up a heavy rock?"—which naturally leads into a discussion of

materials and design concepts. During the hands-on phase, children work in teams to design their bridge plans, construct models, and conduct tests for improvement. Teachers circulate among the groups, offering technical guidance and prompting reflection with questions like "Which support method do you think is strongest?" As children experiment and test, they record their observations and compare the load-bearing performance of different structures. In the presentation phase, each group comes to the classroom center to share their results using a "tell-show-evaluate" format. Peers and teachers provide feedback on strengths and areas for improvement, inspiring new ideas. Finally, teachers lead a reflective discussion to help children summarize their project experiences and teamwork insights. Artifacts such as photographs, charts, or child-created scrapbooks document the learning journey and lay the groundwork for future thematic extensions.

5. Case Study

5.1. Case Background and Implementation Process

The "Little Engineers" project at a leading bilingual kindergarten in Beijing served as this study's core case, launching in September 2024 with a middle-level class group of twenty children. Although the kindergarten boasted substantial STEAM hardware and an experienced teaching team, most activities had been single-discipline, leaving children with limited interdisciplinary inquiry experiences. To address this, the project theme was "Building a Bridge That Can Carry a Toy Car." Teachers collaborated with an external science outreach organization to co-design the project plan, define learning objectives and assessment criteria, and administer a preliminary survey of the children's interests and prior knowledge. Implementation unfolded in three phases. In Phase 1, teachers used storytelling and a classroom "river" setup to spark problem awareness, posing the question, "How can we build a bridge that is both beautiful and sturdy?" Children then formed four small groups, selected building materials, discussed their design ideas, and sketched preliminary plans. Phase 2 moved into hands-on construction: over 90 minutes, each group built its bridge and used small scales, weights, and a toy car to test load-bearing performance. Teachers guided adjustments with prompts and demonstrations, such as reinforcing the deck or optimizing the span length. In Phase 3, groups presented their finished bridges and reflected on improvements. Each child described their design choices and modifications, while teachers and peers offered feedback on scientific principles, measurement accuracy, and engineering aesthetics. Key challenges and solutions were recorded to inform the next project cycle. This complete inquiry cycle fostered children's problem-posing awareness, collaboration skills, and interdisciplinary thinking.

5.2. Case Evaluation and Reflection

After the bridge-building project concluded, the research team evaluated its impact from multiple angles. Teacher observation logs and video analysis showed that 90 percent of the children displayed high engagement and focus throughout the project. Most students proactively suggested structural enhancements and took on specific roles—measuring, recording, or demonstrating—improving both teamwork and communication skills. Interview data revealed that teachers believed project-based learning significantly deepened children's understanding of scientific concepts and mathematical measurement. Many children independently used weights and rulers for precise data recording during load tests, demonstrating initial data literacy and logical reasoning. Parents reported that their children continued to build small crafts at home and attempted to explain why certain designs were more stable, indicating a clear increase in exploratory interest. The evaluation also uncovered areas for improvement. The teaching team had not fully mastered the PBL process, and some open-ended questions were too broad, which hindered design focus for a few children. Additionally, the time allocated for discussion in Phase 1 and construction in Phase 2 was somewhat tight, causing operational stress for some children toward the end. To address these issues, future projects should include targeted training

for teachers on crafting effective open-ended questions, and pre-project micro-lessons or demonstrations to familiarize children with materials and tools. Extending hands-on time and adding a mid-project evaluation checkpoint would allow for timely feedback and adjustments. Overall, this case confirms the feasibility and value of project-based learning in preschool STEM education and offers valuable insights for refining teacher training and curriculum design.

6. Conclusions and Recommendations

Analysis of the "Drip Exploration" project and the "Little Engineers" bridge-building case demonstrates that project-based learning effectively integrates science, technology, engineering, and mathematics to provide authentic, challenging learning contexts for preschoolers. Most children showed strong inquiry interest and concentration, collaboratively proposed design optimizations, and applied mathematical tools like weighing and measuring for data analysis—evidence of emerging interdisciplinary competence and comprehensive skills. Teachers' guided reflections helped children consolidate design experiences and teamwork strategies, enabling continuous knowledge construction through hands-on practice and evaluation. Positive feedback from parents and teachers further confirms project-based learning's role in enhancing curiosity, collaboration, and logical thinking, thus supporting deeper integration of STEM in early education.

Given challenges in open-ended question design and time management observed during implementation, we recommend strengthening teacher training in PBL principles and practicum. Micro-lesson demonstrations, peer observations, and workshops can enhance teachers' ability to craft well-scaffolded inquiry questions. Curriculum designers should incorporate mid-project evaluation stages to provide timely feedback, and extend construction periods to ensure every child has sufficient time for hands-on experimentation and discussion. Additionally, developing a diversified, school-based resource repository—complete with exemplar project plans, material lists, and assessment rubrics—will enable kindergartens across different regions to adapt projects to their local contexts. Through these optimizations, project-based STEM education in preschool settings can be sustainably scaled and deepened, laying a stronger foundation for children's comprehensive skill development.

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References

1. M. Başaran and E. Bay, "The effect of project-based STEAM activities on the social and cognitive skills of preschool children," *Early Child. Dev. Care*, vol. 193, no. 5, pp. 679–697, 2023, doi: 10.1080/03004430.2022.2146682.
2. C. Santos et al., "Science education through project-based learning: A case study," *Procedia Comput. Sci.*, vol. 219, pp. 1713–1720, 2023, doi: 10.1016/j.procs.2023.01.465.
3. Z. Apostolou, "Perspectives for project-based STE(A)M activities in Early Childhood Education," *J. STEM Teach. Inst.*, vol. 3, no. 1, pp. 13–25, 2023.
4. A. Sarıkayaa, A. Alptekina, and A. Y. Köroğlub, "The Effect of STEM Education Program on the Development of Visual Perception of Pre-School Children," *J. Multidiscip. Stud. Educ.*, vol. 6, no. 2, pp. 54–63, 2022.
5. N. Ültay and B. Aktaş, "An example implementation of STEM in preschool education: Carrying eggs without breaking," *Sci. Activ.*, vol. 57, no. 1, pp. 16–24, 2020, doi: 10.1080/00368121.2020.1782312.
6. G. Aydın, "Prerequisites for elementary school teachers before practicing STEM education with students: A case study," *Eurasian J. Educ. Res.*, vol. 20, no. 88, pp. 1–40, 2020.
7. H. Ö. Demircan, "'How am I supposed to do this on my own?': A case study on perspectives of preschool teachers regarding integrative STEM practices," *J. Early Child. Res.*, vol. 20, no. 1, pp. 93–112, 2022, doi: 10.1177/1476718X211052749.
8. A. Ata-Aktürk and H. Ö. Demircan, "Supporting preschool children's STEM learning with parent-involved early engineering education," *Early Child. Educ. J.*, vol. 49, no. 4, pp. 607–621, 2021, doi: <https://doi.org/10.1007/s10643-020-01100-1>.
9. C. K. Tsoukala, "STEM integrated education and multimodal educational material," *Adv. Mobile Learn. Educ. Res.*, vol. 1, no. 2, pp. 96–113, 2021, doi: 10.25082/AMLER.2021.02.005.

10. X. He et al., "The impact of STEM education on mathematical development in children aged 5-6 years," *Int. J. Educ. Res.*, vol. 109, p. 101795, 2021, doi: 10.1016/j.ijer.2021.101795.

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