Developmental trajectories of children's social–emotional competence in kindergarten STEM activities

Trayectorias de desarrollo de la competencia socioemocional de los niños en las actividades STEM de la educación infantil

Authors

Jingfang Zhang [1]
Kamariah Abu Bakar [2]
Nurazidawati Mohamad Arsad [3]

[1,2,3] Universiti Kebangsaan Malaysia/ The National University of Malaysia (Malaysia)

Corresponding author:
Kamariah Abu Bakar
kamariah_abubakar@ukm.edu.my

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Abstract

Introduction: Growing interest in interdisciplinary learning has highlighted the potential of kindergarten Science, Technology, Engineering, and Mathematics (STEM) activities to support children's social–emotional competence.
Objective: This study examined whether kindergarten STEM activities promoted children's longitudinal development of social-emotional competence and explored whether developmental trajectories differed according to children's baseline SEC and gender.
Methodology: A quasi-experimental longitudinal design was employed with 224 preschool children from 12 kindergarten classrooms. The experimental group participated in an 8-week structured STEM program, whereas the control group received regular classroom instruction. Teachers assessed children's SEC at four time points (pre-test, mid-test, post-test, and a follow-up 4 weeks later). Data were analyzed using linear mixed-effects models.
Results: Children in the STEM group demonstrated significantly greater longitudinal growth in SEC than those in the control group. Group differences emerged at the mid-test and continued to increase through the post-test and follow-up assessments. Baseline SEC significantly predicted children's overall SEC levels but did not significantly moderate the intervention effect. Likewise, no significant gender differences were found in developmental trajectories.
Discussion: The findings suggest that participation in structured STEM activities was associated with greater improvements in children's overall SEC than regular classroom instruction, and these differences were maintained during the follow-up period.
Conclusions: This study provides longitudinal evidence supporting the developmental value of kindergarten STEM activities for children's overall SEC and contributes new evidence from Chinese kindergarten classrooms using a four-wave quasi-experimental design.

Keywords

Early childhood education; kindergarten STEM education; longitudinal development; quasi-experimental study; social-emotional competence.

Resumen

Introducción: El creciente interés por el aprendizaje interdisciplinar ha destacado el potencial de las actividades de Ciencia, Tecnología, Ingeniería y Matemáticas (STEM) en educación infantil para promover la competencia socioemocional (SEC) de los niños.
Objetivo: Analizar si las actividades STEM favorecen el desarrollo longitudinal de la SEC y explorar si las trayectorias de desarrollo difieren según el nivel inicial de SEC y el género.
Metodología: Se utilizó un diseño longitudinal cuasi-experimental con 224 niños de 12 aulas de educación infantil. El grupo experimental participó en un programa STEM estructurado de 8 semanas y el grupo de control continuó con la enseñanza habitual. La SEC fue evaluada por los docentes en cuatro momentos (preprueba, prueba intermedia, postprueba y seguimiento a las 4 semanas). Los datos se analizaron mediante modelos lineales de efectos mixtos.
Resultados: Los niños del grupo STEM mostraron un crecimiento significativamente mayor de la SEC que los del grupo de control. Las diferencias aparecieron en la evaluación intermedia y se mantuvieron hasta la postprueba y el seguimiento. El nivel inicial de SEC predijo los niveles generales posteriores, pero no moderó el efecto de la intervención. Tampoco se observaron diferencias significativas según el género.
Discusión: La participación en actividades STEM estructuradas se asoció con mayores mejoras en la SEC que la enseñanza habitual, y estos beneficios persistieron durante el seguimiento.
Conclusiones: El estudio aporta evidencia longitudinal de que las actividades STEM en educación infantil favorecen el desarrollo de la SEC y ofrece nuevas evidencias procedentes de aulas de educación infantil en China mediante un diseño cuasi-experimental con cuatro mediciones.

Palabras clave

Educación infantil; educación STEM en el jardín de infancia; desarrollo longitudinal; estudio cuasi-experimental; competencia socioemocional.

Introduction

Social–emotional competence (SEC) is one of the main developmental goals of early childhood education because it enables children to engage in learning, relationships, and everyday social life. According to the Collaborative for Academic, Social and Emotional Learning, SEC describes a set of interrelated competencies which enable individuals to understand emotions, establish positive relationships, demonstrate empathy, make responsible decisions, and navigate social situations(CASEL, 2020; Kang et al., 2025). SEC is not just behavioral skills, but emotional, cognitive, and interpersonal processes developed by children's constant interaction with social and educational environments (Denham et al., 2012; S. M. Jones et al., 2019).

The pre-school years are very sensitive to SEC because of the children's emotional understanding, behavior regulation, and peer relationships changing rapidly (Denham, 2023). More complex interactions with teachers and peers provide children with repeated opportunities to practice emotional regulation, cooperation, perspective taking, and conflict resolution. Contemporary developmental research defines SEC not as a static personal characteristic but rather as a dynamic process evolving through participation in everyday experiences (Mahoney et al., 2021). Developmental paths can differ greatly between children depending on both individual characteristics and educational experiences, hence the importance of studying SEC longitudinally rather than relying on cross-sectional assessment (Bornstein et al., 2010).

The importance of the SEC extends far beyond children's immediate classroom adjustment. A large body of longitudinal evidence shows early SEC predicts later academic achievement, school engagement, mental health, employment, and life satisfaction (Denham et al., 2012; D. E. Jones et al., 2015). In a meta-analysis by Cipriano et al. (2023), early SEL interventions significantly improve social–emotional competence, behavioral adjustment, and academic performance of children in different settings. In a systematic review by Albritton et al. (2024), we found preschool SEL interventions consistently lead to positive developmental results, though intervention quality and adaptation strategies still play an important role.

These results have changed attention from whether children should promote SEC to how everyday environments can best support social-emotional development. Rather than view SEC as something that can be taught only by individual SEL curricula, today we see more that children develop social–emotional skills through engaging in real classrooms and social interactions (CASEL, 2020). Thus, naturally occurring learning environments that promote cognitive learning and social–emotional development is increasingly a priority in early childhood education.

Integrating Science, Technology, Engineering, and Mathematics (STEM) education has emerged as one such promising educational setting. Unlike traditional teacher-directed instruction, preschool STEM activities typically organize learning around collaborative inquiry, real problem solving, engineering design, and iterative experimentation (Brenneman et al., 2019). These pedagogical characteristics require children to communicate, negotiate, cooperate, persist through problems, and jointly build solutions while sharing scientific reasoning. Thus, researchers have increasingly suggested that the development value of STEM education may extend beyond cognitive learning to social–emotional development (M. U. Bers, 2022; Bustamante-Mora et al., 2025; Wan et al., 2021). However, the developmental mechanisms of social-emotional development are still poorly understood.

To understand why STEM education may aid children's social–emotional competence, we need a theoretical view to explain how everyday classroom experiences contribute to developmental change. We combine two theoretical perspectives (the CASEL framework and social constructivism theory) to explain how participation in kindergarten STEM activities contributes to children's social-emotional development.

CASEL defines SEC as a set of five areas: self-awareness, self-management, social awareness, relationship skills, and responsible decision making (CASEL, 2020). Importantly, CASEL does not view these skills as skills acquired by explicit instruction alone but suggests that social-emotional development occurs through repeated participation in real social situations where children regulate emotions, communicate with others, negotiate interpersonal relationships, and make cooperative decisions. Classroom environments that are enriched with meaningful interaction, emotional support, and collaborative learning provide continuous opportunities for social-emotional development.

This approach is closely related to social constructivism (Vygotsky & Cole, 1978) that children develop higher-order cognitive and social skills through social activities. Learning occurs through dialogue, problem-solving, and cooperation with teachers and peers in children's areas close to development. Social interaction is not just learning that happens, but the fundamental process through which development is built. Children participate in cooperative activities and learn increasingly sophisticated ways of thinking, controlling behavior, and interacting with others.

Integrated STEM education seems to include many of these characteristics. Rather than focusing on passive knowledge acquisition, preschool STEM activities involve kids investigating real problems, creating multiple solutions, building prototypes and testing prototypes, evaluating evidence, and refining designs through iterative cycles of inquiry (M. Bers et al., 2013; Brenneman et al., 2019). Children must explain ideas, negotiate different perspectives, coordinate actions, tolerate failure, and decide how to improve designs. These experiences require children to practice several aspects of SEC, such as emotional regulation, relationship skills, social awareness, and responsible decision-making(Su & Guo, 2023).

Integrating CASEL with social constructivism explains why STEM activities may encourage children to develop social–emotional competence. Social constructivism shows how collaborative STEM learning can produce rich interpersonal interactions through shared inquiry and problem solving, while CASEL shows why repeated participation in the same interactions may lead to social–emotional development. Collaborative interaction acts as the link between participation in STEM and SEC growth. Repeated conversations, controlling emotions to challenge, coordinating with peers, and solving real problems may lead to social–emotional competence for children.

Based on this perspective, we view kindergarten STEM classrooms not only as scientific learning environments but also as socially interactive learning environments, where cognitive and social–emotional learning play together. We also believe that any influence of STEM on SEC should be understood as a developmental process unfolding over time and not because of instructional exposure. Thus, longitudinal designs with children's developmental trajectory at multiple measurement time periods are useful for studying whether STEM experiences can affect young children's social–emotional development.

Evidence from increasing studies suggests kindergarten STEM education may contribute to children's cognitive development and social–emotional competence(Alexandre et al., 2022; Prasad‘Pandey, 2025). Social–emotional outcomes were not the primary goal of early childhood STEM education, but scientists are increasingly recognizing that collaborative and inquiry-oriented STEM learning provides children the opportunity to develop interpersonal and self-regulatory skills along with knowledge about discipline (M. U. Bers, 2022; Ramanathan et al., 2022).

Most of the evidence comes from intervention studies conducted in real preschool classrooms. In these studies, STEM activities are usually based on project-based learning, engineering design, or integrated STEAM courses that require children to work together to solve a problem(M. U. Bers, 2022; National Academies of Sciences, 2021). Instead of learning science concepts from teachers, children are encouraged to develop ideas, negotiate solutions, build prototypes, evaluate evidence, and revise work through repeated cycles of inquiry(Lange et al., 2019; Lippard et al., 2017).

In a number of intervention studies, we have reported encouraging results. Başaran and Bay (2023) implemented a six-week STEAM program with 57 preschool children and observed improvements in engineering skills, teamwork, communication, and collaborative problem solving. Sung et al. (2023) implemented a national five-week STEAM curriculum with more than 450 Korean preschool children and observed significant improvements in self-regulation, prosocial behavior, and social competence compared with regular children. Abanoz and Yabaş(2023) found that an 8-week engineering-based STEM program encouraged preschool children to engage more actively in collaborative discussions and joint problem-solving, and teachers reported noticeable improvements in children's participation and social interaction throughout the intervention.

Engineering design appears to be particularly relevant for children's social–emotional development because it repeatedly exposes children to situations where they must negotiate, persist, and share decision-making. Quantitative and qualitative approaches were used by Yalçn and Erden (2023; 2021) to show that design-based STEM activities improve preschool children's problem-solving skills while also increasing communication, responsibility, resilience, and cooperation. Ozkan and Kettler (2022) also showed that engineering challenges naturally create situations where children have to regulate frustration, negotiate competing ideas, and coordinate collectively after unsuccessful design attempts. These results are consistent with the notion that iterative engineering design allows children to practice important social–emotional skills repeatedly during authentic collaborative activities.

Additionally, it appears that explicit social–emotional learning can further enhance learning outcomes. Rather than treating STEM and SEL as separate learning programs, some scholars argue that both programs are complementary because both focus on collaboration, problem solving, communication, and reflective thinking (Ingram et al., 2021; Lee, 2022). Su and Guo (2023) designed an inter-disciplinary STEM curriculum entitled Beautiful Scenery Along the Yellow River: Bridges and Lanzhou and proposed instructional principles illustrating how STEM activities can intentionally develop social–emotional competence by real engineering problems and collaborative inquiry. Taylor and Glavey (2024) reported that technology-rich STEM activities created meaningful opportunities for autistic children to develop communication, collaboration, and independent participation.

Evidence summarized in recent review studies generally supports these results but also highlights some limitations. Bustamante-Mora et al. (2025)concluded that STEM interventions often have positive effects on children's collaboration, communication, self-regulation and prosocial behavior, Denham and Ferrier (2024) emphasized that learning environments with active participation and meaningful social interaction promoted children's social–emotional development, and Cipriano et al. (2023) also proved in meta-analysis that educational interventions with social–emotional learning improved children's social and behavior in different settings.

Despite increasing interest in early childhood STEM education and social-emotional learning, there are still several gaps in the literature. First, although many studies report improvements in children's cooperation, communication, participation in classes, or self-regulation(M. U. Bers, 2022; Sullivan & Bers, 2016), very few studies directly assess social–emotional competence using validated developmental measures. Rather, SEC is often inferred indirectly from observed classroom behavior or teacher perception of collaborative performance. Since these behaviors represent only a small part of children's functioning, it remains unclear whether participation in STEM contributes to larger changes in overall SEC(Wan et al., 2021).

Second, longitudinal evidence is very limited. Most preschool STEM interventions use a simple pretest–posttest design following relatively short interventions lasting between 4 and 8 weeks (Başaran & Bay, 2023; Sung et al., 2023; Yalçın & Erden, 2021), whereas studies that include delayed follow-up assessments (Yalçın & Erden, 2021) and studies that include multiple longitudinal measurement occasions are very rare. Moreover, the SEC develops slowly after cumulative social experiences rather than immediately after instruction (Denham, 2023). Thus, there is little information about when intervention effects arise (whether they accumulate over time or persist after structured STEM activities have finished).

Third, very little attention has been given to developmental heterogeneity. Contemporary developmental theory recognizes that children respond differently to educational experiences. Baseline developmental competence is one source of individual variation because children entering learning environments with different levels of SEC may benefit differently from the same educational experiences (Bornstein et al., 2010). Recent longitudinal studies suggest that children with lower initial SEC may have greater developmental gains under supportive environments (Durlak et al., 2011; OECD, 2021). However, whether this is the case in kindergarten STEM learning remains unclear.

Fourth, gender differences remain unknown. Girls often have slightly higher average SEC early in life, but recent longitudinal studies show developmental patterns are much more complex than simple mean differences suggest (Denham, 2023; Liu et al., 2024). Existing studies have never explored whether boys respond differently to STEM experiences, and results differ between different schools. As such, gender-mediated effects of STEM education are not well known.

Finally, the present evidence is concentrated in Western countries and some Asian countries, with only limited evidence from mainland China. This is important because Chinese kindergartens are under a major reform of curriculum focusing on inquiry-based learning, integration, and child-centered learning (Ministry of Education of the People's Republic of China, 2022), while many classrooms still follow teacher-directed instruction and participation collectively (Hu et al., 2016). In China, STEM implementation of Chinese kindergarten classrooms provides an opportunity to test whether the theory linking collaborative STEM experiences and children's social–emotional development can be generalized across educational and cultural contexts.

To address these limitations, we used a quasi-experimental longitudinal design to assess social–emotional competence of children in an eight-week kindergarten STEM program. 4 waves of assessment, including delay follow-up, were used to account for changes in development over time, and compare children's development under STEM to regular classroom instruction.

This paper makes three contributions to the existing literature: First, by a four-wave longitudinal design, we extend previous work based mostly on cross-sectional or simple pretest–posttest comparisons and provide a more dynamic understanding of children's developmental trajectories and the persistence of STEM-related developmental change. Second, by not estimating average effects of interventions, we explicitly investigate developmental heterogeneity: how do children's developmental trajectories differ according to baseline SEC and gender? This is a response to recent calls for developmental science to move beyond average treatment effects and understand which children benefit most from educational interventions. Third, by studying kindergarten STEM implementation in the context of current Chinese curriculum reform, we provide cross-cultural evidence of generalizations of theories linking collaborative STEM learning and children's social–emotional development.

Guided by the integrated framework of CASEL and social constructivist theory, the study addresses the following research questions:

RQ1. Do kindergarten STEM activities promote greater longitudinal growth in children's social–emotional competence than regular classroom instruction?

RQ2. Do children with different baseline levels of social–emotional competence demonstrate different developmental trajectories following participation in kindergarten STEM activities?

RQ3. Do boys and girls differ in their developmental responses to kindergarten STEM activities?

Method

Research Design

This study used a quasi-experimental longitudinal design to study the effects of preschool STEM activities on children's SEC. Since children were randomly assigned to existing preschool classes, participants could not be randomly assigned individually, so classes were assigned to either experimental or control groups. Experimental groups had structured activities, and control groups continued to follow the regular preschool curriculum with no structured activities.

The STEM intervention lasted eight weeks in succession, with sessions held twice a week (about 30–45 min) each session, for 16 sessions. The curriculum focused on integrated STEM learning experiences, including inquiry, problem-solving, and engineering design. The children worked in small groups, following a cycle of problems, ideas, prototypes, tests, solutions, and design optimization. The control group continued non-STEM activities as part of regular kindergarten activities. To avoid possible confounding factors, all other daily kindergarten activities (free play, language, outdoor activities, mealtimes, and rest) were kept identical between experimental and control groups.

Children's social-emotional competencies were assessed simultaneously and continuously after the intervention. Baseline data (T1) were collected one week before the intervention started, and mid-intervention data (T2) were collected during the fourth week of the intervention. Post-intervention (T3) was done immediately after the eight-week intervention, and follow-up (T4) was done four weeks after the intervention ended to see whether the intervention effects were maintained. Homeroom teachers assessed social-emotional competencies of each child individually using four versions of the social-emotional competency measure scale.

The repeated-measures longitudinal study design allowed for both examining the developmental trajectories of children's social-emotional competencies over time and comparing changes between the experimental and control groups. Compared to traditional pretest–posttest designs, the inclusion of a mid-intervention assessment and a delayed follow-up assessment provided a more comprehensive understanding of the timing, progression, and sustainability of the STEM intervention's effects.

This work is based on repeated observations to ensure that each class delivered the STEM curriculum in the same manner as the experiment design. Before the intervention started, all participating teachers in the experimental group received standard professional development training on the STEM curriculum covering learning objectives, instructional procedures, engineering design, classroom organization, and expected teaching practices. Teachers also received lesson plans, instructional materials, and activity guides to support consistent implementation of the curriculum.

During the intervention, research team members regularly observed classroom implementation using a structured observation checklist aligned with the planned instructional sequence. The checklist focused on key components of the intervention, including adherence to curriculum objectives, implementation of engineering design activities, opportunities for collaborative learning, teacher guidance strategies, and completion of core learning tasks. Following each observation, researchers provided brief feedback to teachers, clarifying instructional procedures when necessary while avoiding substantive modifications to the curriculum.

Participants

The children from public kindergartens in Hanzhong City, Shaanxi Province, China, were K3 children (5–6) not receive STEM education; children in this age group are cognitively and socially ready to participate in structured STEM activities and collaborative learning. Random sampling and paired groups were used to improve representativeness and comparability of the sample. One kindergarten was selected from each of three groups (high, medium, and low). Four classes were randomly selected from each kindergarten, which resulted in 12 classes (6 experimental classes, 6 control classes) of children and teachers who participated in experimental activities. Parents of all children gave informed consent. None of the teachers had previous experience teaching STEM, and all agreed to participate in training and data collection. Finally, 251 children were selected for the study, including 126 experimental and 125 control groups; 12 classroom teachers participated in the study, with one teacher for each class.

The experimental and control groups were balanced in terms of the number of classes, number of teachers, and number of children. Some children could not continue to participate in the curriculum due to common childhood illnesses such as colds and fevers in the fall and winter, or long absences (2 or more weeks) for personal reasons. These were considered sample attrition and excluded from the final data. In fact, 15 children were excluded from the experiment due to long absences, and 12 children from the control group. In conclusion, valid data were obtained from 111 children in the experimental group and 113 children in the control group for a total of 224 children included in the final analysis (Table 1&Table 2).

Table 1. Data recovery and missing values

Group	Initial sample	Number of dropouts	Final sample	Attrition rate
EG	126	15	111	11.90%
CG	125	12	113	9.60%
Total	251	27	224	10.76%

Table 2. Sociodemographic characteristics of the sample (N = 224)

variable	Experimental Group	Control Group
boy	53（47.7%）	56（49.6%）
girl	58（52.3%）	57（50.4%）

Intervention

This STEM intervention aims to integrate subject-area learning with social-emotional development by combining the “National Preschool Curriculum Standards” with the SEL framework. It integrates science, technology, engineering, and mathematics through problem-based, design-oriented activities and explicit SEC objectives. A total of 16 lessons were conducted over 8 weeks, centered around a real-world design challenge (e.g., creating a functional umbrella). The activities followed the engineering design cycle, including problem identification, idea generation, prototyping, testing, and redesign. To support social-emotional development, all activities included structured opportunities for collaborative problem-solving (peer interaction and negotiation), emotional expression and regulation (guided reflection and feedback), conflict resolution, and perspective-taking (group decision-making tasks). The curriculum was based on the "Umbrella Design Project", which involves designing a sturdy, durable, and weatherproof handheld shelter for a fictional animal character in distress. The project is carried out in subtasks, increasing in complexity. For example, we studied breathability, flexibility, and tensile strength of different materials in early solution generation, whereas in later prototyping and testing tasks, we built canopy frames and spray bottles for "rain tests" to measure and test the waterproofing of structures.

SEL content was not taught alone but was integrated into ongoing engineering tasks as real-time emotional support. Each activity was designed to stimulate and guide CASEL competencies. For example, collaborative problem-solving scenarios were designed to cultivate interpersonal skills: teams of four children were given limited shared resources (e.g., scissors and tape), and naturally asked to negotiate, split tasks, and work toward a common goal. To promote emotional regulation, we used structured designed failures (e.g., deliberately caused prototype structures to collapse during rain tests) as real-world triggers for students to practice managing their emotions. Finally, each class ended with a fixed 10-minute discussion session using visual emotion charts and peer feedback prompts to improve children's self-awareness about design choices and responsibility. The control group continued with regular classroom instruction that did not incorporate STEM content or include explicit SEL components.

Measures

Social–Emotional Competence

Children's SEC was assessed using the DESSA-mini (Devereux Student Strengths Assessment—Mini), a widely recognized teacher-report scale designed to measure children's social-emotional strengths. The scale aligns with the core competencies framework developed by CASEL and covers self-awareness, self-management, social cognition, relationships, and responsible decision-making. The DESSA-mini consists of 8 items rated on a 5-point Likert scale (0 = Never to 4 = Very Often), based on the frequency of positive social-emotional behaviors observed over the past four weeks. Scores from multiple measurements are aggregated into a total score. Participant bias was eliminated by administering several equivalent forms (A–D) at four time points (T1–T4). Previous studies have shown that the DESSA-mini possesses good psychometric properties, such as high internal consistency (0.92), high test-retest reliability, and high convergent validity with the full DESSA scale (Naglieri et al., 2011). We used the Chinese version. In a two-week pilot study, a kindergarten K3 class(32 preschoolers) participated in two weeks of STEM activities, and pre- and posttests of the children's social-emotional competencies were performed. The internal consistency coefficients of the scale were 0.787 and 0.799, respectively. In the following formal study, Cronbach alpha coefficients for the sample were 0.761,0.773,0.812, and 0.807, respectively. Furthermore, the alpha coefficients of both experimental groups and control groups were over 0.750, which suggests that the scale is effective in measuring these competencies under different experimental conditions.

Procedure

Data were collected at four time points: pre-test (T1), mid-intervention (T2), post-test (T3), and delay follow-up (T4). At each time point, teachers completed DESSA-mini based on children's behavior over the preceding four weeks. In order to ensure data quality, teachers received instruction and training on scale completion before data collection. The same administration procedures were followed in all classrooms. The delay follow-up (T4) was included to assess whether intervention effects are persistent, consistent with recommendations for measuring persistence over time.

Data analysis

Since repeated-measures data are repeated-measures data, we first considered a 3-level unconditional model with repeated measurements (Level 1) nested in children (Level 2) and children nested in classrooms (Level 3) to estimate the number of children's SEC variances and intraclass correlation coefficients (ICCs) and to consider whether classroom-level random effects should be included. The unconditional model showed that classroom-level variance is small (ICC = 0.005) and non-significant ($p = 0.671$), but large variance exists at the child level (ICC = 0.293, $p < 0.001$). We subsequently used a two-level linear mixed effects model with repeated measurements of nestling children with repeated observations nested in children. This model specification takes into account longitudinal dependence and avoids the complexity of a classroom-level random effect.

Fixed effects included group (STEM vs. control), time, and the Group × Time interaction to examine intervention effects over time. To investigate developmental heterogeneity, children's gender and mean-centered baseline SEC scores were entered as child-level predictors together with their interaction terms with time and intervention group (Time × Individual Characteristics and Group × Time × Individual Characteristics). Random intercepts were specified at the child level to account for stable individual differences in SEC.

Repeated measurements were modeled using a first-order autoregressive [AR(1)] covariance structure to account for temporal dependence between adjacent observations. Model parameters were estimated using restricted maximum likelihood (REML). Statistical significance was evaluated at $\alpha = 0.05$.

Results

Do kindergarten STEM activities promote greater longitudinal growth in children's social–emotional competence than regular classroom instruction?

Fixed effects analysis (Table 3) revealed a significant "Group × Time" interaction ($F = 11.845$, $p<0.001$), suggesting significant differences in social-emotional development of children in the experimental group and control group. Based on marginal estimates (

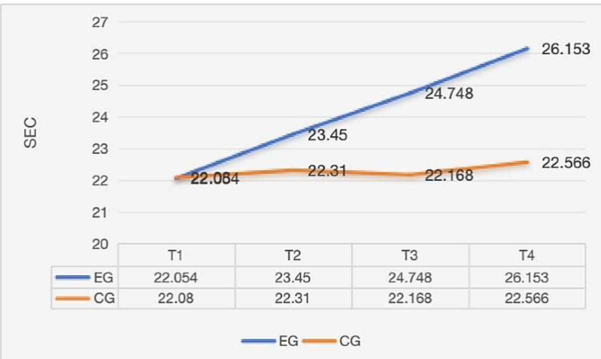
Figure 1), children in the experimental group showed a sustained increase in social-emotional competence from T1 ($M = 22.054$) to T4 ($M = 26.153$). The control group remained relatively stable with scores changing only slightly from 22.080 (T1) to 22.566 (T4). These results suggest that children in preschool STEM activities showed sustained growth in social-emotional competence while children in regular classes showed little change.

Table 3. Fixed-effects test statistic for the model

	Molecular degrees of freedom	Degrees of freedom in the denominator	F	Sig.
intercept	1	221.924	14324.454	<0.001
Time	3	487.21	17.464	<0.001
Group	1	221.924	22.065	<0.001
Time*Group	3	487.21	11.845	<0.001

*Significant differences, p< .05.

Figure 1. Trends in the social-emotional competences of children in experimental and control groups at four time points



According to Table 4, the difference in mean scores between the two groups at T1 was only -0.026, with no statistically significant difference ($p = 0.964$, Cohen's $d = -0.006$). This indicates that experimental groups and control groups were on equal footing before the program. At time point T2, the experimental group had already significantly outperformed the control group scores ($MD = 1.141$, $p = 0.042$). Although the effect size at this point was small to moderate (Cohen's $d = 0.272$), the 4-week STEM program had begun to have significant social-emotional benefits for young children. At time point T3, the gap between experimental and control groups was widened further ($MD = 2.580$, $p < 0.01$), and the effect size reached upper-medium (Cohen's $d = 0.616$). Four weeks after the program was completed, the gap between experimental and control groups did not narrow but reached its highest level for the whole study period ($MD = 3.587$, $p < 0.01$), and the effect size reached very large(Cohen's $d = 0.856$).

Table 4. Pairwise comparisons between the experimental and control groups at different time points

Time	EG	CG	Mean Difference	SE	df	Sig.	95% confidence interval	Cohen's d
T1	22.054(0.398)	22.080(0.394)	-0.026	0.56	694.3	0.964	[-1.126,1.074]	-0.006
T2	23.450(0.398)	22.310(0.394)	1.141	0.56	694.3	0.042	[0.041,2.241]	0.272
T3	24.748(0.398)	22.168(0.394)	2.580	0.56	694.3	<0.01	[1.48,3.68]	0.616
T4	26.153(0.398)	22.566(0.394)	3.587	0.56	694.3	<0.01	[2.487,4.687]	0.856

*Significant differences, p< .05.

Referring to Table 5, from T1 to T2, the children's social-emotional competence experienced a first wave of significant growth (MD = -1.396, p = 0.019, Cohen's d=0.283) in the experimental group, which indicates that providing preschoolers with structured STEM activities can develop social-emotional competence as early as 4 weeks. Subsequently, during the latter half of the progressively advancing program, social-emotional competence maintained the same significant growth momentum (MD = -1.297, p = 0.037, Cohen's d = 0.247), suggesting that STEM continued to empower children with difficulty and depth of cooperation. Four weeks after the program was finished, children in the experimental group did not experience a burnout period, but retained a significant increase in internalization (MD = -1.405, p = 0.018, Cohen's d = 0.296).

Table 5. Pairwise comparisons of young children's social-emotional competences at different time points within the experimental group

(I) Time	(J) Time	Mean Difference	SE	df	p	95% confidence interval	Cohen's d
T1	T2	-1.396	0.472	524.482	0.019	[-2.646,-0.146]	0.283
T2	T3	-1.297	0.472	524.482	0.037	[-2.547,-0.047]	0.247
T3	T4	-1.405	0.472	524.482	0.018	[-2.655,-0.155]	0.296

*Significant differences, p< .05.

Do children with different baseline levels of social–emotional competence demonstrate different developmental trajectories following participation in kindergarten STEM activities?

To investigate the heterogeneity in the developmental trajectories of children's social-emotional competencies across different baseline levels, this study treated baseline social-emotional competencies as a predictor variable and examined their interaction with time and group.

In the Type III test for fixed effects (Table 6), the main effect of baseline scores (F = 39.106, p < 0.001) was highly significant, indicating that children with higher baseline social-emotional competence consistently outperformed those with lower baseline competence at all measurement time points. However, the multiple interaction terms did not reach statistical significance. Time × SEC_T1 interaction was not significant (F = 0.141, p = 0.868), indicating that children with higher and lower baseline social-emotional competence did not change significantly over time when data from all groups were combined. The Group × SEC_T1 interaction was also not significant (F = 0.213, p = 0.645), which means that the overall group-level advantage was not significantly moderated by baseline SEL levels. Most importantly, the three-factor interaction (Group × Time × SEC_T1) was not significant (F = 0.664, p = 0.515). This means baseline social-emotional competence did not statistically moderate the differential effects of the intervention over the four time points. That means the advantage of the STEM intervention over conventional instruction and the pattern of longitudinal trajectories were relatively stable across children with different initial social-emotional competence levels.

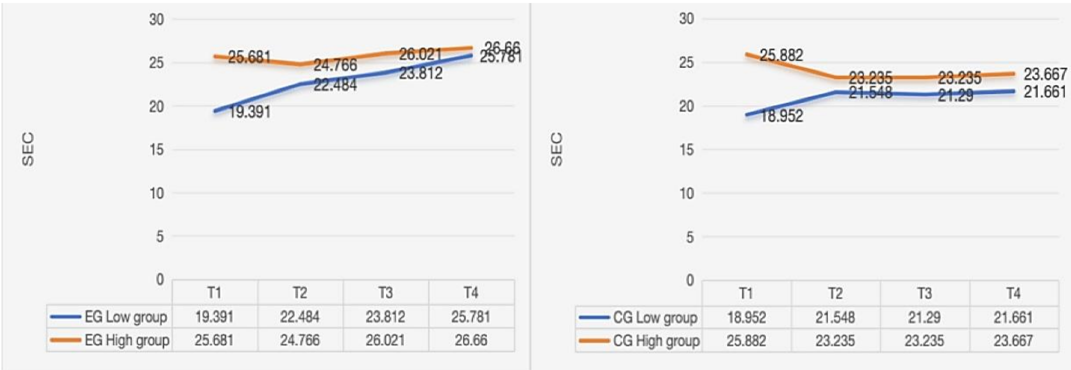
Table 6. Fixed-effects test statistic for the model

	Molecular degrees of freedom	Degrees of freedom in the denominator	F	Sig.
intercept	1	219.715	14363.1	<0.001
SEC_T1	1	219.715	39.106	<0.001
Time * SEC_T1	2	381.175	0.141	0.868
Group * SEC_T1	1	219.715	0.213	0.645
Group * Time * SEC_T1	2	381.175	0.664	0.515

*Significant differences, p< .05.

To understand the differences between children with different baseline levels in experimental and control groups, we split the social-emotional competence scores into low and high groups based on the median. Developmental paths for children with different baseline levels were plotted using marginal estimates (Note: The high-score and low-score groups were divided based on the median initial scores of the experimental and control groups.). In the experimental group, the low-baseline group was linearly increasing from 19.391 at T1 to 25.781 at T4 (+6.39). while the high-baseline group was very moderately increasing at T2 (25.681 → 24.766), rebounding and stabilizing at 26.66 by T4 (minus +0.979 from T1 to T4).

Figure 2. Developmental trajectories of kindergarten children's social emotional competences with different initial SEC in the experimental and control groups



Note: The high-score and low-score groups were divided based on the median initial scores of the experimental and control groups.

Consequently, the substantial gap between low-baseline and high-baseline groups at T1 (MD = –6.29, p < 0.001) narrowed dramatically over time. Paired comparisons (Table 7) show that this gap narrowed to –2.282 at T2 (p = 0.002, Cohen's d=0.60), to –2.209 at T3 (p = 0.002, Cohen's d=0.58), and was no longer statistically significant at T4 (MD = –0.878, p = .228, Cohen's d=0.23). This suggests that children in the STEM group who initially performed poorly experienced a "catch-up" effect, ultimately reaching the same level as their peers with higher baseline scores by the end of the intervention. In the control group, the lower baseline groups showed only moderate growth from 18.952 at T1 to 21.661 at T4 (+2.71). In contrast, the high baseline group showed a decline from T1 to T2 (25.882 → 23.235), and stagnant performance in T2, T3, and T4, ranging from 23.235 to 23.667. Pairwise comparisons in control group (Table 7) showed that although the gap between the low-baseline and high-baseline groups narrowed at T1 (MD = –6.931, p < 0.001, Cohen's d=1.83), it remained statistically significant at all subsequent time points: T2 (MD = –1.687, p = 0.019, Cohen's d=0.45), T3 (MD = –1.945, p = 0.007, Cohen's d=0.51) and T4 (MD = –2.005, p = 0.005, Cohen's d=0.53). The result suggests that, the use of STEM interventions helps to close initial gaps in social-emotional skills.

Table 7. Pairwise comparisons of children's SEC between high-SEC_T1 and low-SEC_T1 children in the experimental and control groups at different time points

Group	Time	Low group	High group	Mean Difference	SE	df	Sig.	95% confidence interval	Cohen's d
EG	T1	19.391	25.681	-6.29	0.727	743.537	<0.001	[-7.718,-4.863]	1.66
	T2	22.484	24.766	-2.282	0.727	743.537	0.002	[-3.709,-0.854]	0.60
	T3	23.812	26.021	-2.209	0.727	743.537	0.002	[-3.636,-0.781]	0.58
	T4	25.781	26.66	-0.878	0.727	743.537	0.228	[-2.306,0.549]	0.23
CG	T1	18.952	25.882	-6.931	0.716	743.537	<0.001	[-8.336,-5.526]	1.83
	T2	21.548	23.235	-1.687	0.716	743.537	0.019	[-3.092,-0.282]	0.45
	T3	21.29	23.235	-1.945	0.716	743.537	0.007	[-3.35,-0.54]	0.51
	T4	21.661	23.667	-2.005	0.716	743.537	0.005	[-3.41,-0.6]	0.53

*Significant differences, p< .05.

Do boys and girls differ in their developmental responses to kindergarten STEM activities?

To investigate whether there are differences in the developmental trajectories of social-emotional competence between boys and girls, we included gender as a fixed categorical predictor in a linear mixed-effects model, along with its two-way interaction with "time" and "group," as well as the three-way interaction of "group × time × gender."

The fixed effects results are presented in Table 8. The main effect of gender was not significant (F = 1.344, p = 0.248), which means, averaged over all time points and groups, there was no significant difference in overall social-emotional competence between boys and girls. The Time × Gender interaction term was not significant (F = 0.327, p = 0.806), which means that when all groups were analyzed together, there was no difference in the rate of change over time between boys and girls. The Group × Gender interaction was not significant (F = 1.427, p = 0.234), suggesting that the overall group-level advantage of STEM intervention compared to conventional instruction was not significantly moderated by gender. The three-factor interaction (group × time × gender) was not statistically significant (F = 0.652, p = 0.582), indicating that there were no significant differences in the development of social-emotional competencies between genders at different groups and time points.

Table 8. Fixed-effects test statistic for the model

	Molecular degrees of freedom	Degrees of freedom in the denominator	F	Sig.
Intercept	1	219.923	14359.602	<0.001
Gender	1	219.923	1.344	0.248
Time * Gender	3	482.414	0.327	0.806
Group * Gender	1	219.923	1.427	0.234
Group * Time * Gender	3	482.414	0.652	0.582

*Significant differences, p< .05.

Although the interaction term was not statistically significant, the estimated marginal mean of the boys and girls at each time point (

Figure 3.) showed very similar development patterns under all experimental conditions, further supporting the conclusion that the moderating effect was not significant. In the experimental group, boys tended to grow steadily from 21.755 at T1 to 26.075 at T4 (+4.32), and girls almost exhibited the same cumulative increase from 22.328 at T1 to 26.224 at T4 (+3.90). The developmental trajectories of boys and girls were essentially parallel from T1 to T4, and paired comparisons of gender differences at each time point were not statistically significant (P > 0.05). In the control group, boys' scores were almost stable from 21.589 at T1 to 22.143 at T4 (+0.55). While girls' scores were stable, the scores ranged only slightly between 22.561 and 22.982 over the four time points (+0.42). Like the experimental group, paired comparisons within the control group (Table 9) showed no statistically significant gender differences at any time point (P > 0.05, Cohen's d<0.100).

Figure 3. Developmental trajectories of kindergarten children's social emotional competences with different genders in the experimental and control groups

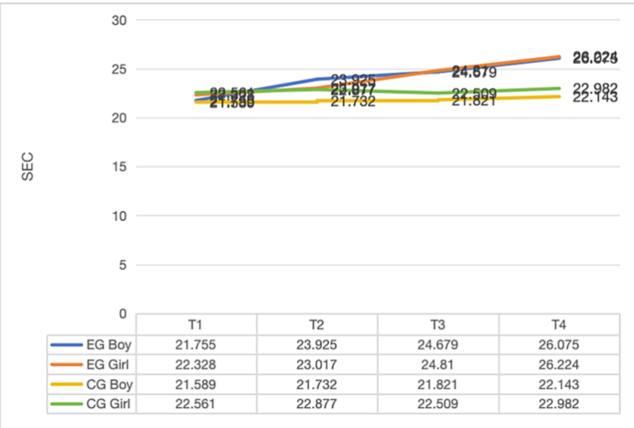


Table 9. Pairwise comparisons of children's SEC between boys and girls in the experimental and control groups at different time points

Group	Time	Boy	Girl	Mean Difference	SE	df	Sig.	95% confidence interval	Cohen's d
EG	T1	21.755	22.328	-0.573	0.797	690.793	0.472	[-2.138,0.992]	0.027
	T2	23.925	23.017	0.907	0.797	690.793	0.255	[-0.657,2.472]	0.043
	T3	24.679	24.81	-0.131	0.797	690.793	0.869	[-1.696,1.434]	0.006
	T4	26.075	26.224	-0.149	0.797	690.793	0.852	[-1.713,1.416]	0.007
CG	T1	21.589	22.561	-0.972	0.789	690.793	0.218	[-2.521,0.577]	0.047
	T2	21.732	22.877	-1.145	0.789	690.793	0.147	[-2.694,0.404]	0.055
	T3	21.821	22.509	-0.687	0.789	690.793	0.384	[-2.237,0.862]	0.033
	T4	22.143	22.982	-0.84	0.789	690.793	0.288	[-2.389,0.71]	0.041

*Significant differences, p< .05.

Discussion

Longitudinal effects of kindergarten STEM activities on children's social–emotional competence

The results shown here suggest that children who participated in the structured STEM program had a longer-term improvement in overall SEC than children who participated in regular classroom instruction. More importantly, we found that the benefit of STEM participation accumulates slowly over the intervention period and remains at the 4-week follow-up. We do not expect an immediate effect or short-lived effect; rather, a gradual divergence in developmental paths between the two groups.

One interesting finding is that statistically significant differences between groups occur in the middle of the intervention. The effect size in this timeframe is small. This pattern should be understood cautiously. The small effect size indicates that children did not have a rapid development change within four weeks, but rather that the STEM program began to change the rate at which SEC developed. This is consistent with developmental views that view social–emotional competence as a gradual development of skills formed by repeated educational experiences rather than isolated learning experiences (Denham & Ferrier, 2024). A group difference arises early rather than being a sign of significant short-term progress.

Another important observation is that the difference between the STEM and control groups increased by the end of the intervention and remained visible at the follow-up. Children in control groups showed a little improvement in the follow-up period, suggesting that normal development and regular kindergarten experience contributed to the growth of SEC over time. These results do not suggest that STEM replaced typical developmental processes; rather, they suggest that participation in a structured STEM program leads to additional developmental gains than those observed in regular school children.

These results are consistent with previous intervention studies, which found positive effects of integrated STEAM learning on children's social–emotional development. For example, Başaran and Bay (2023) found that project-based STEAM helped preschool children achieve better collaboration learning outcomes. Yalçn and Erden (2021) reported continued development benefits after an eight-week design-based STEM program. Sung et al. (2023) observed positive effects of integrated STEAM for young children's self-regulation and social behavior. However, the literature has not been completely consistent. Monkeviciene et al. (2020) used a large-scale survey of preschool teachers who reported little improvement in children's social competence following STEAM implementation. Rather than contradictory results, these differences may reflect significant differences in research design, intervention intensity, and outcome measurement.

The present study also contributes to the growing literature by providing evidence for the developmental pattern of the effects rather than simply documenting post-intervention differences. Previous preschool STEM studies have mostly used cross-sectional or pretest–posttest designs, making it difficult to determine when developmental differences emerge or whether they persist beyond program completion. By incorporating four waves of assessment, we can conclude that changes in children's overall SEC were gradual rather than immediate and remained observable four weeks after the intervention. Nevertheless, since we did not include classroom process measures or observations on children's interactions, we cannot determine which features of STEM instruction contributed to the developmental differences. Future research combining longitudinal intervention designs and classroom process measures could help clarify how STEM supports children's social–emotional development.

Developmental trajectories among children with different baseline levels of social–emotional competence

In this paper, we did not find statistical evidence that baseline SEC moderated the longitudinal effects of the STEM program. Although baseline SEC was a strong predictor of children's performance over the four assessments, neither the Group × Baseline interaction nor the three-way Group × Time × Baseline interaction reached statistical significance. Therefore, we do not support the hypothesis that children with lower initial SEC benefited more from the STEM program than children with higher initial SEC. This indicates that in the sample, the longitudinal advantage of STEM participation seemed to be similar between different baseline levels of SEC.

The descriptive trajectory also contains some observations that may inform future work, but should not be taken as evidence. In the STEM group, children with lower baseline SEC showed a higher absolute increase in scores over the study period than children with higher baseline SEC, leading to a gradual reduction of the initial gap. By the follow-up assessment, the difference between the two subgroups was no longer statistically significant in pairwise comparisons. However, children with lower baseline SEC in the control group showed modest improvement over time, but the gap between lower and higher baseline children remains statistically significant throughout the study period. This description should be read cautiously. Since the formal moderation test was not statistically significant, the apparent convergence observed in the STEM group cannot be considered as evidence of a compensatory intervention effect. There are several other explanations. Children with lower initial scores naturally have more opportunities for improvement because they start low; children with relatively high baseline scores may not have seen much growth on the DESSA-mini scale. Second, regression towards the mean may have contributed to the convergence observed, especially when children were classified into subgroups according to their baseline scores. Therefore, the reduction of the within-group performance gap shouldn't be considered as evidence that the STEM program reduced developmental inequality specifically.

Our results differ from previous studies showing stronger intervention benefits among children with lower initial social–emotional competence, which suggested that children entering interventions with lower SEC may achieve greater subsequent improvement in supportive settings(Group, 2011). Other longitudinal intervention studies have reported relatively consistent intervention effects among children with different baseline characteristics, suggesting compensatory effects may not occur uniformly in different settings (Cipriano et al., 2023; Durlak et al., 2011; R. D. Taylor et al., 2017). This is not contradictory evidence, but may reflect differences in the intervention content, program duration, participant characteristics, and outcome measurement(Cipriano et al., 2023). Compared with highly targeted SEL programs targeting children with high-risk children, we evaluated a universal STEM curriculum delivered to all children in regular kindergarten classrooms. Universal intervention may improve children's overall development, without necessarily generating different benefits for particular subgroups(Greenberg et al., 2017).

In summary, we conclude that baseline SEC was still important for children's overall level of social–emotional competence during the study period, but statistically, there was not enough evidence to conclude that it changed the effectiveness of the STEM intervention. Future studies with a larger sample size and statistical power may be more suited to determine whether differences exist in developmental paths between children with different initial SECs. Incorporating latent growth modelling or growth mixture modelling may also help identify differences in developmental paths that cannot be observed with standard interaction analyses.

Developmental trajectories among boys and girls

The main effect of gender and the interaction between gender were not statistically significant in this study. Boys and girls were equally SEC (and similarly progressed) in this study. Furthermore, the absence of a significant Group × Time × Gender interaction suggests that the benefit of a STEM program was not different across boys and girls. The absence of a gender moderation effect is theoretically informative because previous studies have not shown gender differences in young children's social–emotional development and responses to STEM environments.

Developmental studies have frequently reported that girls outperform boys on certain dimensions of social–emotional competence during early childhood, particularly in emotional understanding and behavioral regulation (Denham, 2023; OECD, 2021). Few preschool intervention studies have suggested that boys and girls may respond differently to integrated STEM or STEAM curricula. For example, Bers (2022) identified gender-specific developmental pathways in children's social–emotional development.

But we did not expect this, and boys and girls developed very similarly for both the STEM and control groups. This is not to say gender is irrelevant for children's social–emotional development. It indicates that the boy/girl did not benefit from STEM differently in this particular intervention. Gender differences may arise only under certain instructions, in certain social–emotional domains, or for longer durations than the ones we studied.

The differences between our results and studies with gender-specific effects may be related to differences in research design and outcome measurement rather than to genuine differences in children's development. First, we assessed children's overall SEC using the DESSA-mini total score rather than individual domains of social–emotional competence. Previous studies with gender differences have often focused on particular developmental dimensions such as emotional regulation, behavior adjustment, or peer interaction rather than general competence. Therefore, differences in gender in individual domains may not necessarily translate into significant differences in the overall composite score. Second, differences in age, cultural context, program characteristics, and intervention duration may also contribute to differences. As recent reviews have noted, gender differences in preschool STEM outcomes are mixed, and no consistent conclusion is reached between intervention studies (Wan et al., 2021).

Another consequence of the results is that the longitudinal benefits of the program were broadly comparable for boys and girls. Though the study was not designed to evaluate gender equity directly, we concluded that the program had similar benefits regardless of gender. But this conclusion should be taken into account with respect to the limitations of the present study. Since small samples were taken and gender was considered as the second moderator, the study may have had limited statistical power to detect small moderation effects. Larger samples and multidimensional assessments of SEC would be useful to determine whether gender differences arise in particular aspects of children's social–emotional development or under different forms of STEM instruction.

Conclusions

Children in the 8-week kindergarten STEM program had a quasi-experimental longitudinal study of SEC development. Compared with children receiving regular classroom instruction, children in the STEM group had more longitudinal improvement in overall SEC over the 4 assessments. The intervention effect was present during the program and continued at the 4th week follow-up. However, the improvement after the intervention should be interpreted cautiously. Children in the control group also showed modest improvement over time, suggesting that the STEM program provided additional growth beyond typical classroom experiences rather than replacing children's normal development. Children with different baseline SEC did not find statistically significant differences in overall scores. We found no difference in baseline SEC or gender with respect to the effectiveness of the intervention. These results indicate that the developmental advantage of the STEM program was broadly similar for children with different initial SEC and boys and girls.

The study is interesting in two ways. First, although most previous studies have been based on cross-sectional or simple pretest–posttest comparisons, we use 4-wave measures to measure children's overall SEC over the intervention and in short-term follow-ups. This longitudinal approach provides more detailed insight into developmental change than a single post-intervention comparison alone. Second, by looking for possible moderation effects of baseline SEC and gender, we extend our knowledge of developmental heterogeneity in kindergarten STEM interventions. Although no moderation effects were observed, we can argue that the overall developmental benefit of the program was not restricted to specific subgroups of the sample.

The results also have practical implications. For kindergarten teachers, the results suggest that adding structured STEM activities to regular classroom practice may provide a further educational context for children's social–emotional and cognitive development. Teachers may not view STEM only as a means of promoting science or mathematics, but may consider its role for wider child development goals. For curriculum developers and school leaders, the results emphasize the importance of designing sustained and not one-off STEM experiences, since the developmental differences accumulate gradually over the intervention period. While we did not study specific classroom processes, the results should not be interpreted as evidence that some instructional strategy or STEM activity contributes to the observed developmental gains. Future curriculum development should therefore be accompanied by systematic evaluation of implementation quality and classroom interaction processes.

There are several limitations to the interpretation of the results. First, the quasi-experiment is ecologically valid but does not allow causal reasoning with the same confidence as a fully randomized controlled trial. Second, the study relied solely on teacher-reported DESSA-mini scores, which can lead to common source bias and only assess children's overall SEC and not specific competencies. Therefore, we cannot determine whether aspects of SEC, like emotional regulation, interpersonal skills, or responsible decision-making, evolved differently over time. Third, although originally a mixed-methods project, we report only quantitative results and therefore do not explain the classroom processes behind the observed developmental trajectories. Fourth, all participating kindergartens were public institutions located in one region of China. This may limit the generalization of results to other cultures and educational settings. Fifth, teachers of the intervention group received professional training before the intervention; although this training was part of the intervention, it did not affect children's development independent of the impact of the STEM curriculum itself. Third, although procedures were implemented to ensure consistency of the intervention, implementation fidelity was not evaluated quantitatively, meaning that it was difficult to determine to what extent variation of program delivery had a significant effect on children's development. Future work should use larger multisite random studies, incorporate multiple sources of SEC assessment (teacher, parent, observational, and child), qualitative evidence of classroom interaction, and monitor implementation fidelity to understand how and under what conditions kindergarten STEM programs support children's social–emotional development.

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Authors' and translators' details:

Jingfang Zhang	p120183@siswa.ukm.edu.my	Autor
Kamariah Abu Bakar	kamariah_abubakar@ukm.edu.my	Autor
Nurazidawati Mohamad Arsad	azidarsad@ukm.edu.my	Traductor