



# Does the Inclusion of Science Content and Skills in Preschool Curricula Matter?

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Accepted: 30 June 2025 / Published online: 21 August 2025  
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## Abstract

This study investigated the potential relations between the level of science content in early learning curricula and science achievement scores in fourth grade. A multilevel analysis of data from the 2015 Trends in International Mathematics and Science Study (TIMSS), involving 180,651 participants, revealed a long-term relationship between science learning opportunities in preschool and higher science achievement by fourth grade. The findings of this study suggest that science content coverage in preschool, and possibly the related early science learning experiences associated with it, might not be consequential for children's later science achievement, particularly for boys, in countries with high science content coverage. High-quality elementary science learning opportunities might offset a lack of early science learning opportunities.

**Keywords** TIMSS · Preschool curriculum · Science achievement · Secondary data analysis

Researchers, educators, and policymakers have identified gender and income-based disparities as major challenges to student achievement in K-12 STEM education (National Science Board, 2022). The National Assessment of Educational Progress findings from 2009 to 2019 highlighted a broad and persistent science achievement gap between children from lower and higher-resourced families, with a narrowing but persistent gender-based science achievement gap in middle and high school grades favoring boys (National Center for Education Statistics, 2019).

These observed science achievement disparities among children from the elementary grades and beyond appear to be primarily explained by the initial achievement gap in children's general knowledge about physical, biological, and social science upon kindergarten entry (Koerber & Osterhaus, 2019; Morgan et al., 2016; Saçkes et al., 2013). Therefore, researchers have suggested that efforts to address science achievement disparities should be implemented during the early childhood years (Kohlhaas et al., 2010; Morgan

et al., 2016, 2024; Saçkes et al., 2011). Such early intervention efforts should be informed with evidence from studies examining the role of prior math and reading skills, school and teacher quality, and curricula in these science achievement disparities (Quinn & Cooc, 2015). The current study focuses on one aspect of the early learning curricula, the science content coverage (i.e., science concepts and skills included within the preschool curricula) and its association with later science achievement.

A limited number of research studies have examined the relationship between academic content coverage during the early childhood years and children's academic achievement. These studies demonstrated that exposure to early learning curricula that included advanced academic concepts and skills was associated with higher academic achievement in mathematics and literacy and improved socio-emotional outcomes in kindergarten (Bassok & Latham, 2017; Claessens et al., 2014; Engel et al., 2016; Kluczniok et al., 2016; Le et al., 2019). Children who experienced early learning curricula that included literacy or mathematics concepts and skills performed almost a half standard deviation higher than children who were exposed to curricula that did not target these concepts and skills (Jenkins et al., 2018; Nguyen et al., 2018). The content coverage of the curricula, what is being taught in educational settings, has also been identified as a strong predictor of the academic achievement of students in upper elementary grades and beyond both in national and

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international contexts (Matsubara et al., 2016; Schmidt et al., 2015; Sousa & Armor, 2010; Willms, 2010). To date, the association between curricular academic content coverage and young children's academic achievement has only been examined within the context of mathematics and literacy achievement in kindergarten, and these studies used national-level data that encompassed a short duration. Studies that used local or national data to examine the relations between science content coverage in curricula and students' academic achievement focused only on upper elementary grades or above. Studies utilizing international data have the potential to inform policymakers and educators in making evidence-based decisions to develop educational policies and institute curriculum improvements related to the teaching and learning of science. However, very few studies have focused on a potential link between the science concepts and skills in early learning curricula and children's long-term science achievement using international level data (Saçkes & Trundle, 2024).

Therefore, this study used the Trends in International Mathematics and Science Study (TIMSS) data sets to examine the potential relationship between the inclusion of science concepts and skills in early learning curricula and children's later science achievement. Here we argue that countries with early learning curricula that include science concepts and skills might be more likely to demonstrate higher science achievement performance on international large-scale assessments. In our previous study, we tested this hypothesis with a limited sample size using country-level science achievement scores and country-level covariates (Saçkes & Trundle, 2024). In the present study, we tested this hypothesis within the context of TIMSS data sets using child-level science achievement scores and covariates. More specifically, we tested whether the content coverage of science in early learning curricula is associated with children's fourth-grade TIMSS science achievement scores, after controlling for gender, preschool attendance status, and socioeconomic status (SES). We also tested the interaction between preschool attendance status and the science content coverage in the preschool curriculum and the interaction between gender, preschool attendance status, and science content coverage in the preschool curriculum. We expected that the science content coverage in preschool would be a statistically significant predictor of children's fourth-grade science achievement (Hypothesis 1). We expected the interaction between preschool attendance status and science content coverage to be statistically significant, indicating that children who attended preschool tended to get higher scores in countries with high science content coverage (Hypothesis 2). We also expected the interaction between gender, preschool attendance status, and the science content coverage in the preschool curriculum not to be significant, indicating that the interaction between

preschool attendance status and science content coverage is not dependent on a child's sex (Hypothesis 3).

## Effectiveness of Early Science Instruction

Young children enter preschool and kindergarten full of wonder and curiosity about the natural world. Because the early childhood years provide a wealth of opportunities to nurture young children's interest in science, research in early childhood science education has expanded rapidly in recent years (Siry et al., 2023). The results of these studies indicate that science teaching, as it is currently implemented with our youngest learners, might be ineffective at producing long-term impacts on children's science learning. For example, studies that used data from the Early Childhood Longitudinal Study (ECLS-K), which included a nationally representative cohort of children who entered kindergarten in 1998 in the United States, reported that the frequency and duration of early childhood teachers' instruction on science concepts and skills in kindergarten were not significant predictors of children's third-grade science achievement (Saçkes et al., 2011). Likewise, the frequency of teaching life science, earth and space science, and physical science concepts in kindergarten was not associated with the progress in children's performance on third-grade to eighth-grade science achievement tests (Saçkes et al., 2013).

Results from studies that analyzed the second wave of the Early Childhood Longitudinal Study data, which included a nationally representative cohort of U.S. children who entered kindergarten in 2011, revealed that the situation remained unchanged. Although statistically significant, the duration of science teaching in kindergarten was a practically insignificant (less than 0.03 standard deviation) predictor of children's end-of-kindergarten science achievement scores. The number of science concepts and skills covered in kindergarten also did not significantly predict science achievement (Curran & Kitchin, 2019). Kindergartners who received preschool education, particularly center-based, tended to obtain higher scores, about 0.06 SD, on teacher-rated science ability at kindergarten entry. Nevertheless, the science achievement difference, as measured by standardized science achievement tests, between children who attended preschool and those who did not was not significant at the end of kindergarten. These findings suggest that preschool education is, at best, marginally associated with science achievement at kindergarten entry, but this association appeared to fade out 8 months after entering kindergarten (Curran, 2019). Collectively, the findings of studies that used U.S. national data sets demonstrated that early science instruction remains ineffective in producing short to medium-term effects on children's science achievement.

Early science education's short to medium term influence was also examined in Chinese and Australian contexts where the timing of science instruction differs (Tao et al., 2012a, b). In China, science education is not provided until third grade, while in Australia, early science education begins in preschool. Chinese and Australian children's science performances were comparable on a third-grade assessment, which suggests early science education was not associated with third-grade science performance in these contexts. The income-based difference in science achievement scores was evident in both countries, favoring children in higher income families (Tao et al., 2012a). A comparison of sixth graders' science performances indicated that children from high-income families were similar in both countries. Australian children from low and medium-income families, however, outperformed their Chinese peers based on science assessment scores. These findings suggest that early science education might have a medium-term effect on children from low and medium-income families (Tao et al., 2012b).

Previous studies indicated that children from families with a higher SES continue to expand their knowledge of the natural world over the summer between kindergarten and the first grade, with close to a quarter of a standard deviation higher than children from families with a low SES (Burkam et al., 2004). Children's knowledge about the natural world develops more during the summer than in-school time, indicating a limited influence of early experience supporting science learning in typical kindergarten classrooms (Burkam et al., 2004). These overall results suggest that science learning opportunities provided in typical kindergarten classrooms, at best, negligibly impact children's immediate and later science achievement.

In contrast to typical preschool and kindergarten settings, where the teaching and learning of science is often neglected, the implementation of content-specific curricula that target science concepts and skills produces better science learning outcomes. For example, inquiry-based, hands-on science activities that involve a high level of teacher scaffolding increased the frequency of preschoolers' usage of science concepts and causal connectives in their responses (Peterson & French, 2008). Interactive read-aloud and retellings of informational picture books, accompanied by hands-on science activities, were effective in improving four-year-old preschoolers' science vocabulary (Leung, 2008). Explicit science vocabulary instruction during shared reading in a virtual classroom enhanced children's science vocabulary development (Gibbs & Reed, 2023). Shared book reading interventions improved low-income preschoolers' science vocabulary close to one standard deviation (Gonzalez et al., 2010). Home and school-based scientific inquiry and literacy-integrated activities that focused on specific life

science concepts were effective in developing kindergartners' scientific literacy and motivation to learn science (Mantzicopoulos et al., 2013; Patrick et al., 2009). A science curriculum designed for pre-kindergartners was found to be ineffective in improving children's science achievement scores on a science assessment that included life, earth, and physical science concepts (Kinzie et al., 2014). In contrast, children who participated in the Balanced Learning Curriculum, which used a play-based early learning modeling and integrated science, technology, engineering, arts, and mathematics (STEAM) concepts and skills, demonstrated a substantial increase, 0.36 standard deviation, in their standardized science achievement scores from the fall to spring assessments (Saçkes et al., 2020). Low-income children and girls benefited more from content-specific curricula than their peers from high-income families and boys (Assel et al., 2007; Mantzicopoulos et al., 2013; Patrick et al., 2009; Saçkes et al., 2020).

The majority of studies that examined the effectiveness of science content-specific curricula on young children's learning of science found that robust and intentional exposure to science concepts and skills in early childhood classrooms supported children's development of science vocabulary, concepts, and inquiry skills (Mantzicopoulos et al., 2013; Patrick et al., 2009; Peterson & French, 2008; Saçkes et al., 2020). However, these studies were conducted with small sample sizes, covered limited science content, and did not examine the long-term retention of acquired science concepts and skills. Therefore, the long-term impact of the curricular interventions and the generalizability of the findings to a larger population of younger children remain limited.

## Socio-Economic Status and Gender Based Disparities in Early Science Achievement

The detrimental academic consequences of poverty on children's science achievement in elementary and upper grades have long been documented. For example, the National Assessment of Educational Progress 1996 findings indicated that children in fourth, eighth, and twelfth grades who were from low-income families had close to 1 SD lower science achievement scores than their peers in families with average or above average incomes. Children with college-educated parents and parents with a positive attitude toward science had 0.5 SD higher science achievement scores. Children from low-income families with few resources at home and parents who did not graduate from college exhibited greater science achievement disparities (Von Secker, 2004).

Studies with younger children also identified a substantial income-based science achievement gap among young children. Findings of studies based on a nationally

representative cohort of U.S. children who entered kindergarten in 1998 found very large SES-based differences in the achievement levels of children at the beginning of kindergarten, with children from low SES families scoring one standard deviation lower on science achievement tests than children from high SES families (Lee & Burkam, 2002). Family SES for was a strong predictor of children's science knowledge at kindergarten entry, with a 1 standard deviation change in family SES corresponding with a 0.39 standard deviation change in children's science knowledge (Morgan et al., 2016).

Furthermore, kindergartners' initial science knowledge and SES were strong predictors of their pre-kindergarten, end of kindergarten, and third-grade science achievement test scores as well as the growth in their science performances from third grade to eighth grade (Morgan et al., 2016; Saçkes et al., 2011, 2013). Children from high-income families were rated by their teachers as more competent in using science process skills, and these children had higher science achievement scores in third grade than children from low-income families, with these SES-based disparities in science achievement reaching over a half standard deviation (Saçkes, 2013).

Children from higher SES families tended to obtain higher scores on the third-grade achievement test than their peers from lower SES families, and children from higher resourced families continued to obtain higher scores on fifth and eighth-grade science assessments (Saçkes et al., 2013). More specifically, a 1 standard deviation change in family SES corresponded with a 0.30 standard deviation change in children's third-grade science achievement and a 0.02 standard deviation change in children's science achievement from third to eighth grade (Morgan et al., 2016). The science achievement gap between children from low and high SES families follows a cumulative model of achievement growth, indicating a widening gap by the end of middle school (Morgan et al., 2016; Saçkes et al., 2013).

Studies that utilized the second wave of Early Childhood Longitudinal Study data set, which is based on a nationally representative cohort of US children who entered kindergarten in 2011, revealed that SES-related science achievement gaps persist (Curran, 2017; Curran, 2019; Morgan et al., 2023). These studies reported that kindergartners from high-income families performed 1 standard deviation higher on science achievement tests than their peers from lower-income families. While the science achievement gap among children in low and median-income families was about a 0.80 standard deviation, this gap was about a 0.20 standard deviation among children in median and high-income families. The science achievement gap appears to be wider for children from families below the median income. Moreover, the income-based science achievement disparity was

larger than the corresponding reading and mathematics achievement disparities. The observed income-based science achievement trend in kindergarten was also evident in first grade (Curran, 2017). Children's science achievement in kindergarten was a strong predictor of the subsequent gap in advanced science achievement during the elementary grades. Kindergartners from high-income families and boys were more likely to demonstrate advanced science achievement during the elementary school years (Morgan et al., 2023).

Gender was identified as another source of variation in children's science achievement. Gender based early science achievement disparities between boys and girls are not uniform, and the reported performance differences between boys and girls were marginal. While some studies reported that girls outperformed boys (Saçkes, 2013; Saçkes et al., 2020; Patrick et al., 2009), other researchers reported that boys performed better (Saçkes et al., 2011, 2013), and some studies reported no difference at all (Kinzie et al., 2014; Leibham et al., 2013).

Findings of studies that were based on a nationally representative cohort of U.S. children who entered kindergarten in 1998 and 2011 demonstrated that the achievement difference on pre- and end-of-kindergarten science tests between boys and girls was marginal, favoring boys. This observed science achievement difference between girls and boys became more prominent at the third-grade assessment, and boys continued to outperform girls on the fifth and eighth-grade science assessments (Saçkes et al., 2011, 2013). Girls were evaluated by their teachers as more skilled (approximately a 0.20 SD higher) in using scientific thinking skills than were boys at the end of kindergarten. However, boys performed approximately a 0.40 standard deviation higher on the third-grade science achievement test than girls (Saçkes, 2013).

Although there is no reported gender difference in science achievement during kindergarten, the science achievement gap between boys and girls appears to emerge by the end of first grade (Curran & Kellogg, 2016). The emerging science achievement disparities between boys and girls at kindergarten entry became more pronounced at first grade, reaching almost a quarter of a standard deviation by third grade and remaining relatively stable by the end of middle school (Saçkes et al., 2011, 2013; Quinn & Cooc, 2015). Boys' and girls' science knowledge was comparable upon kindergarten entry. Yet, the boys, on average, performed over a 0.12 standard deviation higher than girls on a third-grade assessment, and their performances continued to grow with an additional 0.02 standard deviation by the end of middle school (Morgan et al., 2016).

Collectively, findings of studies with young children emphasized a noticeable science achievement gap among

boys and girls in kindergarten, which begins to be more pronounced at first grade and becomes more evident on the third-grade science assessments (Curran & Kellogg, 2016; Kähler et al., 2020; Kohlhaas et al., 2010; Morgan et al., 2016; Saçkes et al., 2011, 2013). Science achievement disparities between boys and girls increase as children move from elementary school to middle school (Liou et al., 2023). In contrast, income-based science achievement gaps among children from low and high-income families are evident at the beginning of kindergarten and get gradually larger as children move from elementary school to middle school (Curran, 2017, 2019; Kähler et al., 2020; Morgan et al., 2016, 2024; Saçkes et al., 2011, 2013).

### Preschool Attendance and Science Achievement

In addition to the research literature that focused on income and gender-based science achievement gaps, a body of research literature examined the link between preschool attendance and subsequent academic achievement (Bailey et al., 2017; Barnett, 2011; Cortázar et al., 2020; Heckman, 2006). These studies examined the effect of preprimary education at either local or national levels, and the studies mainly focused on mathematics and literacy achievement, grade retentions, and graduation rates (McCoy et al., 2017). A limited number of research studies examined the potential relation between preprimary attendance and children's later science achievement on national and international large-scale assessments.

One study focused on fourth-grade Flemish children who received preschool education, and the results indicated that these students performed marginally higher on national science achievement tests (Sierens et al., 2020). A recent study examined the impact of Chile's national public Early Childhood Care and Education program on children's academic achievement as measured by national tests in fourth, tenth, and twelfth grades. This study found that children who attended preschool performed marginally higher (0.06 SD) on science achievement tests in the tenth grade than their peers who did not attend preschool (Cortázar et al., 2020). The association between attendance in Quebec preschool education programs and later science achievement on national and international assessments was not statistically significant (Baker et al., 2019). A comparison of the academic performances of fourth-grade Turkish children on the 2015 and 2019 TIMSS cycles and 2012, 2015 and 2018 PISA cycles demonstrated that preschool attendance was significantly related to children's science performances on the fourth-grade TIMSS assessments when their SES was controlled. The highest reported advantage was on the

2015 TIMSS assessment where children who attended preschool performed about a 0.28 SD higher than their peers who did not attend preschool. This effect declined to a 0.13 SD on the 2019 TIMSS assessment. Preschool attendance was marginally related to children's fourth-grade science achievement on the 2012 PISA assessment, with a practically insignificant effect size. Preschool attendance was unrelated to children's science performances on the 2015 and 2018 PISA assessments (Suna & Ozer, 2022).

Likewise, similar studies that examined the PISA 2015 data set indicated that, when the SES status of children is considered, the differences in science achievement between children who attended preschool and those who did not attend preschool were not statistically significant (Balladares & Kankaraš, 2020; Buldu & Olgan, 2020). A more recent study that investigated the 2018 PISA science assessment results of 73 countries reported that children who attended preschool obtained a 0.09 SD higher science achievement score than their peers who did not attend preschool. This effect was larger (0.20 SD) for children who attended preschool for two or more years (Richter et al., 2021). In sum, the evidence regarding the short-term and long-term influence of preschool attendance on children's science achievement is scarce. The available evidence suggests that the associations between preschool attendance and children's later science achievement on national and international assessments is, at best, marginal.

### Early Learning Curriculum

Curricula for young learners may be defined as the intentional and incidental learning and development opportunities that are provided within learning environments (Colliver, 2022; Trundle & Smith, 2017). The content of these opportunities is often described as learning areas or goals in curriculum documents (Anders et al., 2016; Siraj-Blatchford, 2008). Curricular documents, among other factors (e.g., parental preferences, teachers' background and beliefs, classroom resources), influence whether children have access to early science learning opportunities in preschool classrooms (Greenfield et al., 2009; Saçkes, 2014). Children are more likely to have opportunities to develop an understanding of science concepts and develop science-related skills if these concepts and skills are included in the curriculum (Matsubara et al., 2016).

Previous studies demonstrated that, regardless of children's SES and prior pre-K experience, exposure to advanced concepts and skills such as measurement and computation, rather than basic content such as counting to 10 and naming basic geometric shapes, is associated with higher academic achievement in kindergarten (Claessens et al., 2014).

In typical kindergarten classrooms, however, children are exposed to concepts and skills they were already taught during the preschool years. Curricula for young learners typically include basic rather than advanced concepts and skills, and these basic concepts and skills are repeatedly presented to children, particularly to children from low-income families (Cohen-Vogel et al., 2021). Therefore, opportunities to present advanced science concepts and skills are often missed in typical preschool classrooms.

The International Association for the Evaluation of Educational Achievement (IEA) uses a model that defines the curriculum at three levels. The *intended curriculum* refers to the concepts and skills planned for children to learn. In contrast, the *implemented curriculum* refers to the concepts and skills actually taught to children, and the *attained curriculum* refers to the concepts and skills children demonstrate they learned via assessment (Houang & Schmidt, 2008). International large-scale assessments provide data about the attained curricula of countries, and researchers may use these data to examine the potential link between the attained and intended curricula. To date, the link between the intended and the attained curricula has only been established at the elementary and middle school levels (Matsubara et al., 2016; Schmidt et al., 2001). The possible contribution of the intended preschool curriculum to children's later science achievement has yet to be examined. The present study aims to use the TIMSS data to examine the extent to which the inclusion of science concepts and skills in preschool curricula might be related to children's long-term science achievement.

## Methods

### Participants

The sample for this study consisted of 180,651 children from 37 countries who participated in the 2015 round of TIMSS. Over 312,000 students, including nationally representative samples of approximately 4,000 students from 57 countries and 7 benchmarking entities, participated in the fourth-grade assessments during the TIMSS 2015 cycle. Countries that had no preschool curricula at the state or national level and countries where preschool attendance data either were not reported or the attendance data were available for less than 50% of the students were excluded from the analysis (see <https://timss.bc.edu/timss2015/> for more information).

### Measures

**Science Achievement Scores** The fourth-grade science achievement scores from the TIMSS 2015 data set were used

as outcome measures. The organization of the fourth-grade science assessment framework includes two dimensions (e.g., content and cognitive), with the content dimension being comprised of three domains: Life science (45%), physical science (35%), and Earth science (20%). The cognitive dimensions include three domains: Knowing (40%), applying (40%), and reasoning (20%) (Mullis & Martin, 2013). The fourth-grade science achievement assessment included a pool of 176 multiple-choice and constructed-response items, and students responded to 20 to 28 science items in 36 min (Martin et al., 2016; Martin et al., 2020; Mullis & Martin, 2017). Examples of science items can be accessed from [https://timssandpirls.bc.edu/timss2015/downloads/T15\\_FW\\_AppC.pdf](https://timssandpirls.bc.edu/timss2015/downloads/T15_FW_AppC.pdf). The psychometric properties of each science achievement item were examined using Classical Test Theory-based item difficulty level and discrimination index as well as one-parameter Rasch model-based difficulty indexes. The science assessments had an international median Cronbach's alpha reliability of 0.78. The TIMSS data set includes five plausible values for each student within their fourth-grade science achievement scores. These plausible values for fourth-grade science achievement scores were used as outcome measures in the current analysis.

**Preschool Science Content Coverage** The country-level measure of the preschool science content coverage score was generated using a scoring rubric designed by the researchers in a previous study (Saçkes & Trundle, 2024). A total of 37 countries' curricula and policy documents, which were in effect during the academic year of 2010–2011 (the years fourth grade sample attended preprimary education), were accessed and retrieved (a total of 179 documents) from the websites of ministries or departments of education or websites of European Commission National Policies Platform Eurydice (<https://eacea.ec.europa.eu/national-policies/eurydice/>) and United Nations Educational, Scientific, and Cultural Organization (<https://unesdoc.unesco.org/>). Countries' early learning curricular documents and policy documents targeting preschool and kindergarten children were reviewed, examined, and scored following the document analysis method and the curriculum analysis framework (Bowen, 2009; Van den Akker, 2003). The analytic procedure used to score the early learning curriculum documents focused on the analysis of the content of the documents to empirically represent the extent to which science was targeted as a learning area and the extent to which science process skills and concepts, topics, and themes specific to Earth and space science, life science, and physical science domains were included.

The scoring rubric included five components that indicated the inclusion of: (1) "Science as a standalone domain

in the curriculum,” (2) “Science process skills,” (3) “Learning outcomes specific to Earth and space science concepts,” (4) “Learning outcomes specific to life science concepts,” and (5) “Learning outcomes specific to physical science concepts” (Saçkes & Trundle, 2024). Each component was scored 0 to 2 (0=none, 1=partial inclusion, 2=full inclusion), with a total score ranging from 0 to 10. To examine the reliability of the scoring rubric, randomly chosen curricular documents (a total of 95 documents from 24 countries) were examined and scored independently by two researchers. The inter-rater agreement between the two sets of curricula scores was calculated using Cohen’s weighted kappa. The kappa coefficient was 0.72 (95% CI=0.55–0.88), indicating high inter-rater agreement between the two coders (Cohen, 1968).

**Child’s Sex** The information regarding students’ sex was obtained from the ITSEX variable. In the unweighted data set, the percentage of boys was 51.1%, and the percentage of girls was 48.9%. The percentage of missing data was minimal ( $n=28$ ). We used a hot-deck method to impute the missing data (Myers, 2011). The imputed sex variable was used in the analyses.

**Preschool Attendance** For the student-level analysis, the data regarding whether the students participated in preschool education was collected from the ASBH05AB variable. This variable indicated whether the child attended pre-primary education-ISCED Level 0-including kindergarten for children age 3 or older before first grade. The percentage of children who attended preschool was 75%, and the percentage of children who did not was 14.8% in the unweighted data set. The percentage of missing data for preschool attendance status was slightly over 10% (10.2%). The missing data were imputed using hot-deck imputation (Myers, 2011). This imputed Preschool Attendance variable was used in the analyses.

**Socio-Economic Status** The Home Resources for Learning Scale was used as a proxy for the child-level SES. This variable is labeled as ASBGHRL in the TIMSS data set. The Home Resources for Learning scale consisted of five items, two of which were reported by the students (“Number of books in the home” and “Number of home study supports”), and the remaining three were reported by the parents (“Number of children’s books in the home,” “Highest level of education for either parent,” and “Highest level of occupation for either parent”) (Martin et al., 2016). SES scores ranged from 3.69 to 15.04, with a mean of 10.10 and a standard deviation of 1.93 for the unweighted sample data. The percentage of missing data for SES was slightly over 10% (11.19%). The missing data for the SES variable were

imputed using the Expectation-Maximization estimation method (Croninger & Douglas, 2005).

Based on the imputed Home Resources for Learning Scale scores, two measures were constructed: Child SES and School SES. The Child SES variable was calculated by centering the ASBGHRL variable at children’s respective country mean scores to represent the extent to which children have higher or lower SES scores in comparison to their peers in the same country. To calculate the School SES scores, initially, the mean ASBGHRL scores for each school were calculated by aggregating the ASBGHRL scores of those children within each school. Then, these scores were centered at their respective school-level country mean to represent to what extent schools have higher or lower SES scores in comparison to schools within the same country.

**Gross National Income Per Capita** We used gross national income (GNI) per capita as a measure of the country-level SES in the analysis. The GNI per capita represented the measure of average income earned by a person in a country. The GNI data were obtained from the TIMSS 2015 Encyclopedia, which is primarily based on the World Bank’s World DataBank (<https://timssandpirls.bc.edu/timss2015/encyclopedia/introduction/demographics-of-the-timss-2015-countries/>). The raw GNI scores of countries ranged from 3070 USD to 92,200 USD, with a mean and median of 28,132 USD and 22,513 USD, respectively. The GNI variable was standardized with a mean of 0 and a standard deviation of 1. This standardized GNI variable was used in the analysis.

## Analytical Approach

Data were analyzed using the SPSS Complex Samples General Linear Model software. This analysis allowed for the computation of statistics and standard errors from samples obtained through multistage designs and within the framework of a linear regression model (IBM Corporation, 2017; Siller & Tompkins, 2006). Due to the complex sampling design used by TIMSS, the impact of design effects and sampling weights was considered by using the appropriate stratification (IDCOUNTRY), clustering (SCHOOLID), and weighting (SENWGT) variables. We used six independent variables (Child Sex, Preschool Attendance, Country SES (GNI), School SES, Child SES, and Preschool Science Content Coverage) and the interactions between preschool attendance and science content coverage and the interactions between sex, preschool attendance and science content coverage within the General Linear Model to test the hypothesized relation between preschool science content coverage and fourth-grade science assessment scores. A total of five complex samples

general linear model analyses were conducted using five plausible values as outcomes. The parameter estimates and covariance matrices resulted from these five analyses were recorded and combined using Rubin's rule (van Ginkel & Kroonenberg, 2014). The pooled parameter estimates were reported in Table 1.

## Results

We initially examined the science content coverage scores of the study countries. The results showed that science was included as a distinct learning and development area in the curricula of only 9 of the 37 countries (24.3%) included in the study. Fifteen countries (40.5%) did not include science as a distinct learning and development area in their preschool curricula but included it in other learning

and development areas. About one-third of the countries (35.1%) included in the study did not include science in their preschool programs.

Only five countries (13.5%) did not include scientific process skills in their preschool curricula. Almost 90% of the countries included science in their preschool education curricula, either partially (20 countries) or comprehensively (12 countries). Concepts related to Earth and space sciences were not included in preschool curricula in almost half of the countries (48.6%). The number of countries that partially included concepts related to Earth and space sciences in their curricula was 15 (40.5%), and the number of countries that included them comprehensively was 4 (10.8%). Concepts related to the life sciences were found to be the most frequently included concepts in countries' preschool curricula. Of the 37 countries whose preschool programs were studied, only six (16.2%) did not include any life science concepts. In contrast, more than half (56.8%) partially included life science concepts, and more than a quarter (27%) included life science concepts comprehensively. The physical sciences were the least included area in the curricula. Fifteen countries (40.5%) did not include any concepts related to the physical sciences in their curricula. Almost half of the countries (48.6%) had some coverage of concepts related to physical sciences in their curricula. Concepts related to the physical sciences were found to be comprehensively included in the curricula of only four (10.8%) countries (See Appendix Table 2 for science content coverage scores of the countries).

The results of the Complex Samples General Linear analysis indicated that all tested parameters were statistically significant predictors of fourth-grade science scores. The covariate of child's sex ( $B=-1.535$ ,  $t=-2.03$ ,  $p=.042$ ), Country SES ( $B=2.36$ ,  $t=3.21$ ,  $p=.0001$ ), School SES ( $B=10.86$ ,  $t=12.00$ ,  $p=.0001$ ), Child SES ( $B=16.07$ ,  $t=67.97$ ,  $p=.0001$ ), and Preschool attendance status ( $B=32.18$ ,  $t=26.82$ ,  $p=.0001$ ) were statistically significant predictors of fourth-grade science scores. Boys obtained lower science achievement scores than girls, yet this observed science achievement gap between boys and girls was marginal. Country, school, and child level SES were significant predictors of science achievement. Children from countries with higher GNI per capita, schools with higher SES, and affluent families were more likely to obtain a higher score on the fourth-grade science achievement test. Children who attended pre-primary education were more likely to obtain a higher score on the fourth-grade science achievement test than their peers who did not attend.

**Table 1** Pooled estimates and standard errors for the model predicting TIMSS 2015 science achievement scores

Parameter	Estimate	Std. Error			
			t	df	p.
Intercept	516.953	1.074	481.414	8.393	0.0001
Child Sex (Boys)	-1.535	0.754	-2.034	643.185	0.042
Preschool Attendance (Attended)	32.181	1.200	26.820	432.180	0.0001
Preschool Science Content Coverage	6.498	0.285	22.782	592.478	0.0001
Country SES	2.361	0.737	3.205	1658.316	0.001
School SES	10.861	0.905	12.003	49364.576	0.0001
Child SES	16.069	0.236	67.970	17.405	0.0001
Preschool Attendance (Not Attended)*	7.756	0.680	11.411	139.233	0.0001
Preschool Science Content Coverage					
Child Sex (Boys)*	5.010	0.803	6.238	4253.522	0.0001
Preschool Attendance (Not Attended)*					
Preschool Science Content Coverage					
Child Sex (Boys)*	1.575	0.357	4.411	829.764	0.0001
Preschool Attendance (Attended)*					
Preschool Science Content Coverage					

The preschool science content coverage was a statistically significant predictor of fourth-grade science scores ( $B=6.49, t=22.78, p<.001$ ), suggesting the first research hypothesis was supported. Children who lived in countries with higher science content coverage were more likely to obtain a higher score on the fourth-grade science achievement test than their peers who lived in countries with lower science content coverage in the preschool curriculum.

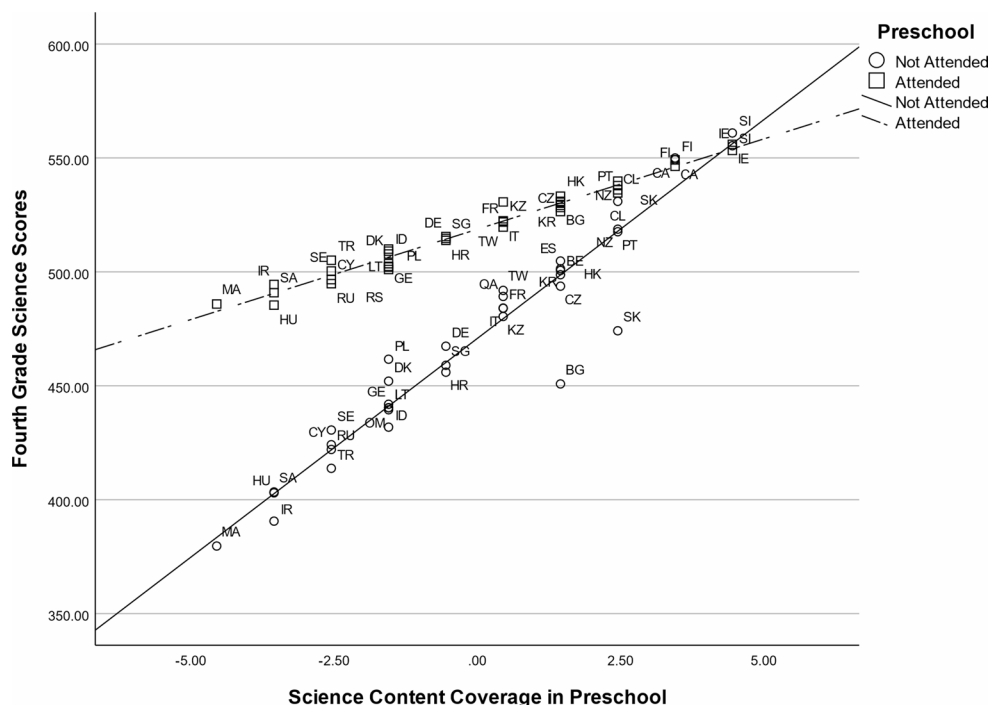
All tested interactions were statistically significant predictors of fourth-grade science scores. The interaction between Preschool Attendance (not attended) and Preschool Science Content Coverage was statistically significant ( $B=7.75, t=11.41, p=.0001$ ), suggesting that the gap on the fourth-grade science achievement test between the children who attended preschool and did not attend preschool was getting smaller in countries where Preschool Science Content Coverage scores were higher (See Fig. 1). This result indicated that our second research hypothesis was not supported. The Child Sex (Boys)\* Preschool Attendance (not attended) \* Preschool Science Content Coverage interaction also was statistically significant ( $B=5.01, t=6.23, p=.0001$ ), suggesting our third hypothesis was not supported. Boys who did not attend preschool tended to obtain higher scores on the fourth-grade science achievement test in countries with higher preschool science content coverage scores (See Figs. 2 and 3).

### Discussion

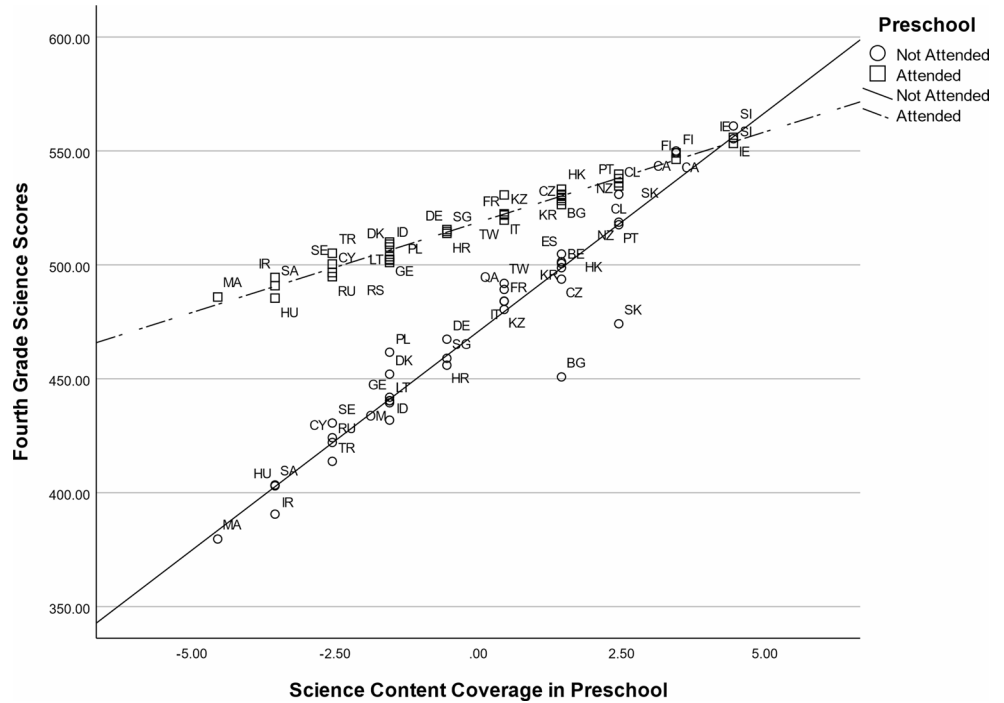
We tested three hypotheses within the scope of this study. The results indicated that the first hypothesis was supported. The main effect of preschool science content coverage was a significant predictor of students’ fourth-grade science achievement scores, even after controlling for sex, SES (country, school, and child level), and preschool attendance statuses. Further examination of interaction terms, including sex and preschool attendance statuses with preschool science content coverage scores, revealed that the association between science content coverage of preschool curricula and students’ science achievement depends on children’s preschool attendance status and sex.

These results suggest that our second hypothesis was not supported. We expected that the science achievement gap between children who attended preschool and those who did not attend would be narrower in countries with lower preschool science content coverage and wider in countries with higher preschool science content coverage. As illustrated in Fig. 1, we observed a trend that is opposite to our expectation. In general, children who attended preschool tended to obtain higher scores on the fourth-grade science achievement test than their peers who did not receive preschool education. However, the interaction between preschool attendance status (not attended) and preschool science content coverage was positive, indicating that

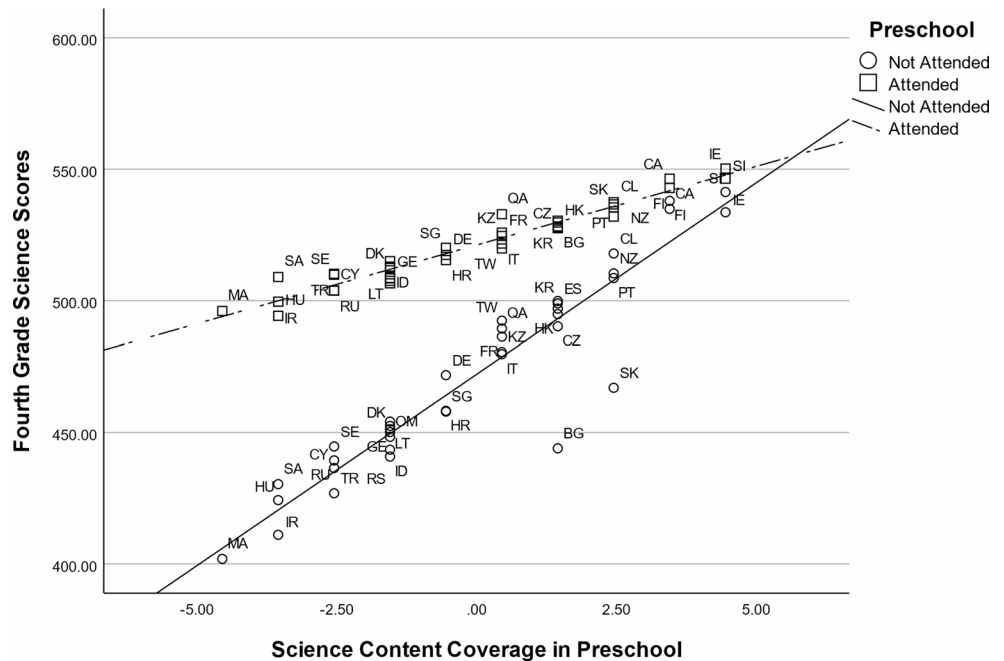
**Fig. 1** Preschool attendance and preschool science content coverage scores interaction



**Fig. 2** Preschool attendance and preschool science content coverage scores interaction for boys



**Fig. 3** Preschool attendance and preschool science content coverage scores interaction for girls



whether they attended preschool or not, children’s fourth-grade science achievement scores increased as the level of science content coverage of their countries’ preschool curricula increased. In other words, in countries with a higher level of science content coverage in the preschool

curricula, children, whether they attended preschool or not, tended to obtain higher scores on the fourth-grade science achievement test than their peers from countries with lower levels of science content coverage. These findings suggest that countries with science-rich preschool

curricula may also have robust elementary school science curricula that support their learning of science and compensate for not participating in preschool. The impact of early learning opportunities on later academic success might not be uniform. While early educational opportunities may play a more important role in some educational settings, learning opportunities in elementary school may play a more important role in other educational settings (Reardon, 2019).

This trend could be further explained by one of the five temporal patterns of educational opportunity illustrated by Reardon (2019). The observed patterns in the results suggest that early childhood and elementary opportunities to learn science vary considerably across countries and are positively correlated within the countries (Reardon, 2019). Countries with high levels of science content coverage in their preschool curricula may also have high-quality science curricula in upper grades. Lack of early science learning opportunities appears to be compensated for with high-quality science learning opportunities in later grades. Indeed, evidence from a recent study with 2937 children supports this possibility, at least in the German context (Kähler et al., 2020). In this longitudinal study, the researchers found that children who attended science-focused kindergartens obtained higher science achievement scores than children who attended non-science-focused kindergartens. However, science achievement disparities observed among children attending science-focused and non-science-focused kindergartens had disappeared by the third year of elementary school. The authors suggest that the science education opportunities provided in elementary schools reduced the science achievement gap observed in kindergarten (Kähler et al., 2020). Exposure to rich science learning opportunities in early elementary grades might benefit all children regardless of their preschool attendance status (Bailey et al., 2020). Further studies should examine the possible alignment or misalignment of science content coverage in preschool and elementary school curricula and the association with students' science achievement.

Our last hypothesis was also not supported. We expected that the interaction between preschool attendance status and the science content coverage would not depend on a child's sex. To the contrary, the interaction of sex, preschool attendance status, and science content coverage indicated that boys who did not attend preschool exhibited similar performances to boys who attended preschool. They performed better than their respective female peers in countries with a higher level of science content coverage.

These findings suggest that boys might benefit more from exposure to rich science learning opportunities in early elementary grades than do girls. There is no reported gender gap in science achievement during preschool and kindergarten (Curran & Kellogg, 2016). Studies suggest that the emerging science achievement disparities between boys and girls at kindergarten entry became more pronounced at first grade, reaching almost a quarter of a standard deviation by third grade and remaining relatively stable by the end of middle school (Morgan et al., 2016; Saçkes et al., 2011, 2013; Quinn & Cooc, 2015). The findings of the present study suggest that the differential effect of science learning opportunities provided in elementary grades on boys and girls might be one of the factors that play a role in the observed gender gap in science achievement. Further studies should focus on the quality and quantity of science learning opportunities provided in elementary grades to identify the possible causes of the gender-based science achievement gap and the interest that emerges in late elementary grades and beyond.

The overall results of the present study imply that the science content coverage in preschool curricula does matter for some children but not others. In countries with low to moderate science content coverage in preschool curricula, children who attended preschool persistently demonstrated higher science achievement performances than their peers who did not attend preschool. In contrast, countries with high science content coverage in preschool curricula for children, particularly boys who did not attend preschool, demonstrated similar science achievement performances compared to their peers who attended preschool. In other words, the advantage of attending preschool on science achievement faded by the fourth grade. This pattern held true, at least in the domain of science achievement, in countries with high science content coverage in preschool curricula. Studies demonstrated that developmental or academic advantages gained as a result of participating in preschool education programs might not be enduring and begin to fade out over the next several years (Bailey et al., 2017; Hogrebe & Strietholt, 2016; Kähler et al., 2020; Lipsey et al., 2018). Exposure to a high-quality elementary curriculum or learning experience might be one of the factors that is responsible for the fade-out phenomenon previously reported in the literature (Kähler et al., 2020). Children who did not have a chance to attend preschool and received early science learning opportunities might reach, even outperform, their peers in elementary grades, where a high-quality elementary science curriculum and learning experience are provided.

There are some limitations of the current study that warrant caution in the interpretation and the generalizability of the findings. We reviewed and examined the early learning curricular documents to empirically represent the extent to which they targeted science as a content learning area. We also examined the extent to which the curricula included science process skills, concepts, topics, and themes specific to Earth and space, life, and physical science. Due to a lack of relevant information in the TIMSS data sets, we were unable to examine the efficacy of the teachers' implementation of the curricula in preschool classrooms. The science teaching practices in preschool are likely to mediate between the quality of curricular documents in terms of inclusion of science and children's science achievement. The observed association of the curricula content coverage and science achievement might change with data regarding the science teaching practices in preschool classrooms.

Local and national level variations in policies and mandates regarding early childhood education services may result in inconsistent adoption and implementation of early learning curricula and standards (Whitaker et al., 2022). Most countries implement a national preschool curriculum nationwide (i.e., Türkiye) while some countries, such as Germany, only have curricular frameworks. The extent to which local practices adopt and implement these curricular documents remains unclear (Kluczniok et al., 2016). Therefore, the results of the present study should be interpreted with caution for countries that have no country level common preschool curriculum.

The current study focuses on one aspect of the early learning curricula, the science content coverage and its association with later science achievement. Theoretical and pedagogical approaches adopted in the curricula likely influence children's learning and the durability of the acquired skills and knowledge (Jenkins et al., 2019; Preschool Curriculum Evaluation Research Consortium, 2008). Therefore, variations in the theoretical foundations and pedagogical approaches of the preschool curricula in countries that participate in international assessments

could be reviewed, and the possible associations with these curricula characteristics with immediate and later students' achievement could be examined. Moreover, further studies could focus on the relations between the content coverage of other academic areas, including mathematics and literacy in preschool curricula and later students' achievement. The current study included data from the TIMSS 2015 cycle. Similar studies should use more recent TIMSS assessment cycles (e.g., 2019 and 2023) to examine whether participating countries' preschool curricula have changed regarding science content coverage and to determine if the inclusion of science in preschool curricula still matters.

The current study was motivated by the premise that the observed science achievement disparities among children from elementary grades and beyond are mainly due to the initial achievement gap in children's early science knowledge upon kindergarten entry (Koerber & Osterhaus, 2019; Morgan et al., 2016, 2024; Saçkes et al., 2013). Thus, efforts to address science achievement disparities should be implemented during preschool. The overall results of the present study support this premise and highlight the importance of two factors in addressing income and gender-based disparities in learning science and pursuing science-related careers—supporting home learning contexts of children in less-resourced households and fostering girls' understanding of socio-cultural and psychological aspects of science. In order for early exposure to high-quality science curricula to be an effective policy tool, curricula should be designed to provide cognitive, motivational, and material resources to support the home science learning contexts of children from less-resourced families. Curricula should also provide opportunities for young girls to question the gender norms and stereotypes associated with science to foster their interest in science and appreciation of the many ways science careers can involve helping others. Any interventional efforts that do not include such design elements would likely be unable to produce the intended outcomes: addressing income and gender-based disparities in learning science and pursuing science-related careers.

## Appendix

**Table 2** Science content coverage scores

Country	Science as a Stand-alone Domain	Science Process Skills	Earth and Space Science	Life Science	Physical Science	Science Content Coverage Scores
Bulgaria	2	0	2	2	0	6
Chile	1	2	1	2	1	7
Chinese Taipei	1	1	1	1	1	5
Croatia	0.0	2	0	1	1	4
Cyprus*	1.	1	0	0	0	2
Czech Republic	1	2	1	1	1	6
Denmark	1	1	0	1	0	3
Finland	2	2	1	2	1	8
France	1	1	0	2	1	5
Georgia	1	1	0	1	0	3
Germany	1	1	1	1	0	4
Hong Kong, SAR	2	2	1	1	0	6
Hungary	0	0	1	0	0	1
Indonesia	0	1	0	1	1	3
Iran, Islamic Republic of	0	0	0	1	0	1
Ireland	1	2	2	2	2	9
Italy	1	2	0	1	1	5
Kazakhstan	1	1	1	1	1	5
Korea, Republic of	2	1	1	1	1	6
Lithuania	0	1	0	1	1	3
Morocco	0	0	0	0	0	0
Oman	0	1	0	1	1	3
New Zealand	1	2	1	1	2	7
Poland	0	1	1	1	0	3
Portugal	1	2	1	1	2	7
Qatar	2	1	0	1	1	5
Russian Federation	0	1	0	0	1	2
Saudi Arabia	0	0	0	1	0	1
Serbia	0	2	0	0	1	3
Singapore	2	2	0	0	0	4
Slovak Republic	2	1	2	2	0	7
Slovenia	2	1	2	2	2	9
Spain	1	1	1	2	1	6
Sweden	0	1	0	1	0	2
Türkiye	0	1	0	1	0	2
Belgium (Flemish)	1	1	1	2	1	6
Canada (Ontario)	2	2	1	2	1	8

\*Data in this table referring to “Cyprus” represent the southern part of the island. There is no single authority representing both the Turkish and Greek Cypriot communities on the island. Türkiye recognizes the Turkish Republic of Northern Cyprus (TRNC) and data representing children living in the TRNC are not available.

**Authors' Contributions** The authors contributed equally to the manuscript.

**Funding** details: This study is supported by Balıkesir University Scientific Research Projects grant BAP2018/032.

**Data availability statement:** The data that support the findings of this study are available on request from the corresponding author.

## Declarations

**Competing Interests** The authors report there are no competing interests to declare.

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