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SUPPORTING EARLY MATHEMATICAL SKILLS OF MULTILINGUAL CHILDREN

Bridging the gap

Katri Luomaniemi

TURUN YLIOPISTON JULKAISUJA – ANNALES UNIVERSITATIS TURKUENSIS
SARJA – SER. B OSA – TOM. 729 | HUMANIORA | TURKU 2025

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Dedicated to my primary school teachers Soile and Mauri Vesanto, who taught me the importance of reading and writing, and to my Vaari, who was always so proud of me.

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ABSTRACT

The aim of this dissertation was to provide a deeper understanding on how to support multilingual children's mathematical skills in early childhood education and care (ECEC). Research has shown that multilingual children tend to have weaker mathematical skills than their monolingual peers as early as the first grade. However, the diverse multilingual settings in which mathematical teaching and learning occur today as well as the traditional monolingual perspective in pedagogical practices pose a challenge in terms of providing effective support. The purpose of this dissertation is to offer new perspectives on supporting mathematical skills in ECEC that would broaden the traditional practices to be equal to all learners including multilingual children.

The dissertation consists of three studies and a summary section. The aim of the first study was to investigate how the Count How Many -intervention (CHM) supports the early numeracy and oral language skills of multilingual children. The CHM intervention is intended to promote spontaneous focusing on numerosity (SFON) and to enhance skills related to counting and cardinality understanding. Although the intervention was not initially designed for multilingual children, its engaging, accessible, and hands-on early numeracy activities were expected to be effective also for multilingual children, as these activities allow participation even with a limited vocabulary. A prior study conducted with children whose first language is Finnish indicated that the intervention effectively supports early numeracy and oral language development (Hannula-Sormunen et al., 2020). In Study I, the effectiveness of the intervention was investigated for the first time with multilingual children.

A total of 48 children participated in the Study I, of whom 16 were multilingual. The multilingual children participated in the CHM intervention. Pairwise-matched monolingual children were selected for the two control groups. One of the control groups (n = 16) participated in the same intervention as the multilingual children, while the other control group (n = 16) underwent the early literacy intervention Let's Read and Talk. Children's numeracy and oral language skills were measured at pretest before the intervention, at posttest after the six-week intensive phase, and at a delayed posttest after the five-month rehearsal phase. No statistically significant differences were found between the groups in the measurements. Thus, the results

showed similar development of numeracy skills and oral language skills in the multilingual group in comparison to matched monolingual groups of children.

Even though the CHM intervention appeared to hold promise as being beneficial to multilingual children's numeracy skills, Study I suggested that a deeper investigation into effective support strategies for multilingual children's mathematical skills within ECEC would be valuable. Therefore, the following studies focused on identifying research-based recommendations to enhance early mathematical skills in multilingual children (Study II) and reviewing the former early mathematical interventions implemented with multilingual children (Study III).

In the Study II, research-based recommendations were compiled from previous literature following the principles of thematic synthesis. Articles presenting recommendations for supporting the early mathematical skills of multilingual children were searched from the international and national databases. Only articles that explicitly focused on recommendations for promoting early mathematical skills within ECEC context were included. Ultimately, five articles published between 2011 and 2020 were included in the synthesis. The articles were reviewed according to the three-phase protocol of thematic synthesis, first coding the articles, then forming descriptive themes based on the coding of the recommendations, and finally forming an analytical model based on the descriptive themes. According to the analytical model, ECEC professionals can support the early mathematical skills of multilingual children by (1) making mathematical activities culturally relevant, (2) becoming aware of their own preconceptions about learning mathematics and language, and shifting the perspective from weaknesses to strengths, and (3) enabling versatile ways to participate in math talk on a regular basis. Synthesizing the recommendations complements the limited research literature published in Finnish on supporting multilingual children's early mathematical skills. The recommendations were reflected to Finland's national core curriculum for ECEC. Thus, the results of this study can be used also to support the pedagogical planning in ECEC.

The systematic review and meta-analysis conducted in the third study aimed to investigate the current state of early mathematical intervention research involving multilingual participants. The systematic review included 24 articles that explored early mathematical interventions with multilingual children aged 3 to 5 years. The results revealed that numeracy emerged as the predominant focus of these interventions, followed by geometric, measurement, and patterns. In examining specific instructional features related to multilingual participants, the most commonly employed approach was the use of mathematical language, while the use of children's home language(s) and culturally responsive instructional approach were less utilized.

Of the 24 studies included in the systematic review, 17 provided sufficient data to be included in the meta-analysis. The average weighted effect size ($g = 0.46$, 95% *CI* 0.32, 0.59) of the interventions involving multilingual participants was small according to Cohen's (1988) criteria. No significant differences were observed between interventions utilizing mathematical language, home language, or culturally responsive instructional approach and those interventions that did not employ these pedagogical practices. The average effect size of the interventions with multilingual

participants was smaller compared to former meta-analyses where the participants were mainly monolingual children. The findings suggest that current early mathematical interventions may not adequately meet the needs of multilingual children and could benefit from further development.

Overall, the findings of the dissertation suggest that the recommendations developed to support multilingual children's early mathematical skills have not yet been used to their full potential. In the future, it would be important to explore the impact of the recommended practices in ECEC on the development of early mathematical skills in multilingual children. The findings of this dissertation provide a broad theoretical basis not only for the development of interventions for multilingual children, but also for ECEC professionals to guide the pedagogical planning aiming to support the development of mathematical skills in multilingual children. Furthermore, the findings can be utilized in professional development for ECEC professionals and in current pre-service education, when the goal is to provide research-based information on how to support the early mathematical skills of multilingual children.

KEYWORDS: Early childhood education and care, multilingualism, mathematics

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TIIVISTELMÄ

Tämän väitöskirjan tavoitteena on laajentaa ymmärrystämme siitä, miten monikielisten lasten matemaattisia taitoja voidaan tukea jo varhaiskasvatuksessa. Monikielisillä koulutulokkailla on havaittu olevan heikommat matemaattiset taidot kuin heidän yksikielisillä ikätovereillaan. Haasteen matemaattisten taitojen tukemiselle asettaa kuitenkin valtava heterogeenisyys monikielisissä matemaattisissa oppimisympäristöissä sekä näiden oppimisympäristöjen rakentuminen perinteisten yksikielisten pedagogisten käytänteiden varaan. Tämän tutkimuksen tarkoituksena on tarjota uusia näkökulmia matemaattisten taitojen tukemiseen varhaiskasvatuksessa. Nämä näkökulmat laajentavat perinteisiä käytäntöjä huomioimalla erityisesti monikieliset oppijat ja mahdollistavat näin kaikille lapsille tasa-arvoisemmat lähtökohdat koulupolulle astumiseen.

Väitöskirjatutkimus rakentuu kolmesta tutkimuksesta sekä yhteenveto-osuudesta. Ensimmäisen tutkimuksen tavoitteena oli selvittää, miten Laske, kuinka monta -interventio kehittää monikielisten lasten varhaisia matemaattisia ja kielellisiä taitoja. Laske, kuinka monta -interventio on kehitetty edistämään spontaania huomion kiinnittämistä lukumääriin sekä laskemiseen ja kardinaalisuuteen liittyviä taitoja kuten lukumääräisyyden tajua sekä kardinaalisuuden periaatteen ymmärtämistä. Interventiota ei alun perin suunniteltu erityisesti monikielisten lasten taitojen kehittämiseen, mutta sen käytännönläheisten, visuaalisten ja toiminnallisten aktiviteettien ajateltiin toimivan myös monikielisten lasten kohdalla. Kun interventiota aiemmin testattiin suomea äidinkielenään puhuvien lasten kanssa, tulokset osoittivat, että intervention avulla voidaan tehokkaasti tukea lasten varhaisia matemaattisia ja kielellisiä taitoja (Hannula-Sormunen, et al., 2020). Tässä tutkimuksessa tutkittiin intervention toimivuutta ensimmäistä kertaa monikielisillä lapsilla.

Tutkimukseen osallistui yhteensä 48 lasta, joista 16 oli monikielisiä. Monikieliset lapset osallistuivat Laske, kuinka monta -interventioon. Kahteen kontrolliryhmään valittiin yksikielisiä lapsia, jotka vastasivat iältään ja matemaattisilta taidoiltaan monikielisiä lapsia. Toinen kontrolliryhmistä (n = 16) osallistui samaan interventioon kuin monikieliset lapset, kun taas toinen kontrolliryhmä (n = 16) kävi läpi kielellisten taitojen kehittämiseen tarkoitetun Luetaan jutustellen -intervention. Lasten matemaattisia ja kielellisiä taitoja mitattiin alkumittauksessa ennen interventiota, loppumittauksessa kuuden viikon intensiivivaiheen jälkeen sekä

viivästetyssä loppumittauksessa viiden kuukauden harjoitteluvaiheen jälkeen. Mittauksissa ei löydetty tilastollisesti merkitseviä eroja ryhmien välillä vaan tulokset osoittivat, että monikielisten lasten matemaattiset ja kielelliset taidot kehittyivät kontrolliryhmien lasten kanssa samankaltaisesti.

Ensimmäisen tutkimuksen tulokset siis osoittivat, että Laske, kuinka monta -interventiolla voidaan kehittää myös monikielisten lasten matemaattisia taitoja. Tämä herätti kuitenkin myös kiinnostuksen syventää tietoa siitä, miten näitä taitoja voitaisiin entistä paremmin tukea varhaiskasvatuksessa. Seuraavissa tutkimuksissa tavoitteena olikin selvittää, millaisia tutkimusperustaisia suosituksia on olemassa monikielisten lasten varhaisten matemaattisten taitojen tukemiseen (Tutkimus II) sekä millaisia varhaisten matemaattisten taitojen interventioita monikielisten lasten kanssa on toteutettu aiemmin (Tutkimus III).

Toisessa tutkimuksessa tutkimusperustaisia suosituksia koottiin aiemmasta tutkimuskirjallisuudesta temaattisen synteesin periaatteita noudattaen. Artikkeleita, jotka esittelivät suosituksia monikielisten lasten varhaisten matemaattisten taitojen tukemiseen, haettiin suurimmista kansainvälisistä ja kansallisista tietokannoista. Lopulta aineisto muodostui viidestä aikavälillä 2011–2020 julkaistusta artikkelista. Aineistoon otettiin mukaan ainoastaan sellaisia artikkeleita, joiden suositukset olivat selkeästi suunnattuja varhaisten matemaattisten taitojen tukemiseen varhaiskasvatusympäristössä. Artikkelit käytiin läpi temaattisen synteesin kolmivaiheisen protokollan mukaisesti siten, että ensin artikkeleiden yksittäiset suositukset koodattiin, jonka jälkeen koodauksen perusteella suosituksista muodostettiin deskriptiivisiä teemoja. Kolmannessa vaiheessa muodostettiin analyyttinen malli, joka pohjautui deskriptiivisiin teemoihin. Analyyttisen mallin mukaan varhaiskasvatuksen ammattilaiset voivat tukea monikielisten lasten varhaisia matemaattisia taitoja (1) tekemällä matemaattisesta toiminnasta kulttuurisesti merkityksellisiä, (2) tiedostamalla omat ennakkokäsityksensä matematiikan ja kielen oppimisesta ja siirtämällä näkökulman heikkouksista vahvuuksiin ja (3) mahdollistamalla monipuoliset tavat osallistua matematiikkakeskusteluun säännöllisesti. Suositusten kokoaminen yhteen täydentää vähäistä suomenkielistä tutkimuskirjallisuutta monikielisten lasten varhaisten matemaattisten taitojen tukemisesta. Suosituksia peilattiin myös Varhaiskasvatussuunnitelman perusteisiin ajatuksena mahdollistaa näin suositusten käyttö pedagogisen suunnittelun tukena varhaiskasvatuksessa.

Kolmannen tutkimuksen systemaattisen katsauksen ja meta-analyysin tarkoituksena oli kartoittaa ja analysoida monikielisten lasten varhaisia matemaattisia taitoja tukevien interventiotutkimusten nykytilaa. Systemaattiseen katsaukseen sisältyi yhteensä 24 varhaisten matemaattisten taitojen interventiotutkimusta, joissa osallistujina oli 3–5-vuotiaita monikielisiä lapsia. Systemaattisessa katsauksessa havaittiin, että matemaattisista osa-alueista interventioissa painotettiin eniten numeerisia taitoja. Seuraavaksi suosituimpia painotusalueita olivat geometria, mittaaminen sekä sarjoittaminen. Erityisesti monikielisiin osallistujiin liittyvistä pedagogisista menetelmistä interventioissa painottui matemaattisen kielen käyttö, kun taas lasten kotikielen käyttöä sekä kulttuurisesti vastuullista pedagogista lähestymistapaa hyödynnettiin interventioissa vähemmän.

Kokonaisaineistosta (24 tutkimusta) yhteensä 17 tutkimusta kuvasi aineiston sillä tarkkuudella, että tutkimus voitiin sisällyttää meta-analyysiin. Meta-analyysissa analysoitiin interventioiden vaikutusta monikielisten lasten matemaattisiin taitoihin.

Interventioiden efektikokojen keskiarvo *g* oli 0.46 (95 % luottamusväli 0.32–0.59). Cohenin (1988) kriteereillä vaikutusta voidaan siis kuvata pieneksi. Tilastollisesti merkitseviä eroja ei havaittu niiden interventioiden välillä, jotka käyttivät matemaattista kieltä, lasten kotikieltä tai kulttuurisesti vastuullista pedagogista lähestymistapaa verrattuna interventioihin, joissa niitä ei käytetty. Meta-analyysin vaikutuskoko oli pienempi verrattuna aiempiin meta-analyyseihin, joissa osallistujina oli pääasiallisesti yksikielisiä lapsia. Tulokset viittaavat siihen, että varhaisia matemaattisia taitoja tukevat interventiot eivät nykyisellään huomioi monikielisten lasten tarpeita parhaalla mahdollisella tavalla vaan interventioita voitaisiin edelleen kehittää.

Väitöskirjan tulosten mukaan näyttäisi siltä, että monikielisten lasten varhaisten matemaattisten taitojen tukemiseen kehitettyjä suosituksia ei vielä ole osattu hyödyntää parhaalla mahdollisella tavalla. Tulevaisuudessa olisikin tärkeää tutkia, miten suositusten mukainen toiminta varhaiskasvatuksessa vaikuttaisi monikielisten lasten varhaisten matemaattisten taitojen kehittymiseen. Väitöskirjan tulokset tarjoavat laajan teoreettisen pohjan paitsi monikielisille lapsille suunnattujen varhaisten matemaattisten taitojen interventioiden kehittämiselle myös tueksi varhaiskasvatuksen ammattilaisille pedagogiseen suunnitteluun, kun tavoitteena on tukea monikielisten lasten varhaisten matemaattisten taitojen kehittymistä. Tutkimustuloksia voidaan hyödyntää myös varhaiskasvatuksen ammattilaisille suunnatussa täydennyskoulutuksessa sekä nykyisessä opettajankoulutuksessa, kun tavoitteena on tarjota tutkimusperustaista tietoa siitä, miten monikielinen pedagogiikka voidaan yhdistää matemaattisten taitojen tukemiseen varhaiskasvatuksessa.

ASIASANAT: varhaiskasvatus, monikielisyys, varhaiset matemaattiset taidot

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29.5.2025

Katri Luomaniemi

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Tables

Figures

List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

I Luomaniemi, K., Mattinen, A., McMullen, J., Sorariutta, A., & Hannula-Sormunen, M. (2021). The Effects of a SFON-Based Early Numeracy Program on Multilingual Children's Early Numeracy and Oral Language Skills. *Journal of Cognitive Education and Psychology*, *20*(2), 138–160 https://doi.org/10.1891/JCEP-D-20-00006.

II Luomaniemi, K., Kankaanpää, S. & Hannula-Sormunen, M. (2023). Suosituksia monikielisten lasten varhaisten matemaattisten taitojen tukemiseen – Temaattinen synteesi. [Recommendations for supporting multilingual children's early mathematical skills - Thematic synthesis]. *Journal of Early Childhood Education Research 12*(3), 23–63. https://doi.org/10.58955/jecer.126173.

III Luomaniemi, K., Gegenfurtner, A., Kankaanpää, S., Lehtinen, E., McMullen, J. & Hannula-Sormunen, M. (2025). The effects of early mathematical interventions for 3–5-year-old multilingual children: A systematic review and a meta-analysis. PsyArXiv. https://doi.org/10.31234/osf.io/78zme_v2.

The original publications have been reproduced with the permission of the copyright holders. In all publications, Luomaniemi contributed to the conceptualization, data analysis and interpretation and was responsible for writing the first drafts of the manuscripts. All co-authors participated in the conceptualization, provided critical feedback and contributed to all manuscript revisions. Study III is under review in Educational Research Review and is available as a preprint in PsyArXiv.

Declaration of generative AI and AI-assisted technologies: In preparing of this dissertation Luomaniemi used AI-tool Grammarly to paraphrase and improve the readability, subsequently reviewing and editing the content, thereby taking full responsibility for the final publication.

1 Introduction

Mathematics is a hierarchical set of skills, meaning that later skills build on earlier ones. Previous research has established that the building blocks of mathematical skills are built before school age, highlighting the importance of early childhood education and care (ECEC) in learning of mathematical skills (Claessens & Engel, 2013; Clements & Sarama, 2020; Duncan et al., 2007; Fuson, 1988). Children in today's society encounter variety of languages prior entering school. Already in 2010 it was estimated that more than fifty percent of the global population used multiple languages in their daily lives (Grosjean, 2010). The number of multilingual children participating in ECEC is steadily increasing, but the practices and materials that support learning are often designed for monolingual environments where children are proficient in the instructional language of ECEC (Castro & Prishker, 2019). Consequently, they may not address the diverse needs of multilingual learners, potentially hindering their academic outcomes (Goldenberg et al., 2013). In the current research, a multilingual child is defined as a child who uses two or more languages on a daily basis (Grosjean, 2010) and whose home language is different from the one used in ECEC (Musanti & Celedón-Pattichis, 2013).

Education plays an important role in promoting equality and preventing exclusion. ECEC in particular is an environment where pedagogical solutions can increase children's equal opportunities to succeed in their future learning path and contribute positively to society as whole (Arvola, 2021; Kangas et al., 2021, 2023). Research has shown that mathematics, in particular, is crucial in human life. It serves as an invaluable tool for gaining insight into and analyzing the world around us and provides essential skills that open up numerous educational and career opportunities (Lehtinen et al., 2022; National Research Council, 2009). Investing in and fostering children's mathematical skills during ECEC can lead to long-lasting advantages across various fields and disciplines. Promoting mathematical thinking in ECEC can therefore be seen as part of equity work aimed at ensuring equal educational rights for all children.

Research shows that limited proficiency in the language of instruction is associated with underperforming in mathematics (NCES, 2017; OECD, 2016). This issue is especially prominent among children from low-income backgrounds

(Sarnecka et al., 2018), and the differences in mathematical skills between multilingual and monolingual children can be observed already in first grade (Ukkola & Metsämuuronen, 2019). This calls for targeted interventions to support multilingual learners already in ECEC. However, there is a paucity of research focused on supporting the learning of ECEC-aged multilingual children (Arvola et al., 2017; McCabe et al., 2013). This gap in empirical studies has resulted in a scarcity of research-based pedagogical tools to enhance the mathematical skills of multilingual children in ECEC.

The aim of this research is to provide a comprehensive insight into how the early mathematical skills of multilingual children can be supported. Even though the multilingual contexts in which the mathematical teaching and learning is happening today is extremely diverse, the findings of this dissertation could serve as the foundation when designing future interventions or planning the pedagogical activities in ECEC's daily life. The empirical part of the current research has been conducted in Finland, where monolingual practices in education has been the norm for the last decades (Alisaari et al., 2019, 2024; Suuriniemi & Satokangas, 2023). The current research offers new insights to early math practices that broaden the traditional monolingual perspective and can contribute to preservice education and professional development for both future and current ECEC professionals[1].

[1] In the current thesis, "ECEC professionals" refers to the pedagogical professionals working in ECEC. In Finland, this includes ECEC teachers and childcarers. To become an ECEC teacher in Finland, one must hold a degree from a university or a university of applied sciences, such as a Bachelor of Education, Master of Education, or Bachelor of Social Sciences. Childcarer in ECEC is required to have at least an upper secondary level qualification in social welfare and healthcare (Education Finland, 2025).

2 Multilingual children as early math learners

At present, considerable knowledge exists regarding the early mathematical skills of monolingual children, as there is already a robust body of research from the 1970s that has successfully explained, for example, the development of children's counting skills (Gelman & Gallistel, 1978). There are also meta-analyses with positive results on the effects of early mathematical interventions on monolingual children's mathematical skills. For example, when examining the effects of early numeracy interventions on preschool, kindergarten, and first-grade monolingual students, Nelson and McMaster (2019) reported an overall effect size of g = 0.64 (95% CI = 0.52, 0.76). They found 34 intervention studies and included those that encompassed students with disabilities or who were at risk of math difficulty. Wang and colleagues (2016) conducted a meta-analysis examining the effectiveness of early mathematical interventions (N = 29) in monolingual participants. They also found an overall effect size (Cohen's d = 0.62, $p < .001$, effect size range 0.50–0.75) that can be defined as moderate to large according Cohen's (1988) criteria. These findings show that there are several early mathematical interventions conducted on monolingual participants and that the interventions have been effective in supporting children's mathematical skills.

In the current thesis, these two meta-analyses are used as examples of "meta-analyses with monolingual participants". The primary reason for their selection is that both meta-analyses focus on early mathematical interventions and provide a general effect size for the included interventions. However, it is essential to note that the interventions included in these meta-analyses were typically conducted in naturalistic settings. This means that the participants were often not exclusively monolingual. Despite this, the meta-analyses did not differentiate between the effects observed in monolingual and multilingual children. Consequently, even though there could have been multilingual participants, the interventions were primarily designed from a monolingual perspective, and the majority of the participants in these meta-analyses were monolingual children.

There is relatively little research on how learning multiple languages affects the development of mathematical skills during early childhood compared with

substantial studies on monolingual children's early mathematical skills (Bonifacci et al., 2016; Cross et al., 2009; Richards-Tutor et al., 2016). Research on school-aged children has indicated that the development of mathematical skills in multilingual children is often less advanced than that of their monolingual peers or does not reach national norms (Harju-Luukkainen & McElvany, 2018; Ukkola & Metsämuuronen, 2019, 2021). There are significant differences in the mathematical skills of children at the beginning of first grade (FINEEC, 2020; Ukkola & Metsämuuronen, 2019). In a study conducted in 2020, the Finnish Education Evaluation Center (FINEEC) found that students with above-average math skills in the beginning of first grade demonstrated fluency in decimals and were able to identify three-digit numbers. The most advanced students could perform addition and subtraction with numbers up to 100. Some were fluent in solving double-digit equations and could also formulate correct mental calculations from verbally described situations. The weakest students understood some everyday mathematical concepts, such as more and less, but recognizing number symbols was difficult for many (FINEEC, 2020).

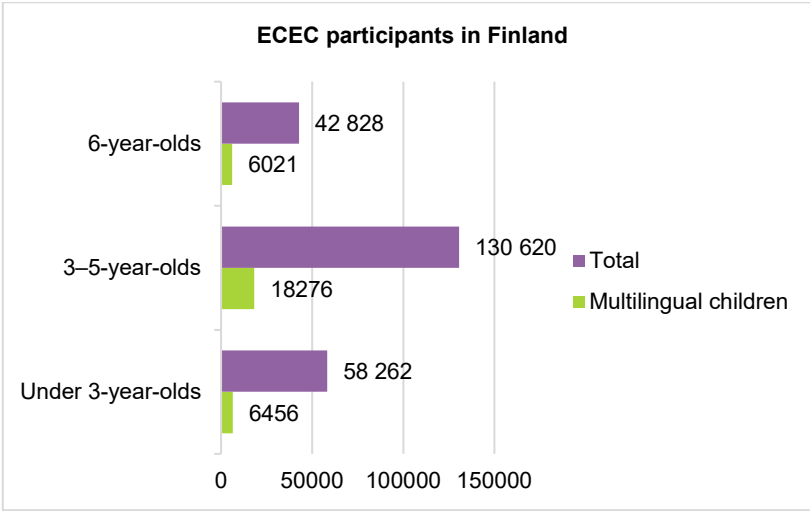
In the same FINEEC study (2020), five risk factors predictive of low starting levels in mathematics and mother tongue at the beginning of first grade were identified. The lower-than-average starting level in mathematics was associated with (1) a decision to receive intensified or special support, (2) having Finnish or Swedish as a second language, (3) learning difficulties in the immediate family, (4) a low educational background of caregivers, and (5) being born in the last months of the year. The accumulation of risk factors had a major impact on the children's test scores at the baseline. Having several risk factors predicted a low starting level, which could be up to 200 points lower than for students without risk factors in their lives. The range of the starting-level points was 52–1021 (FINEEC, 2020).

Multilingualism does not automatically pose a challenge to learning mathematical skills, but poor command of the language of instruction in school or early childhood education and care (ECEC) increases the risk of underachievement (NCES, 2017; OECD, 2016). Moreover, if a multilingual child comes from a family with low socio-economic status (Sarnecka et al., 2018) or has other risk factors from the aforementioned list (FINEEC, 2020), it becomes evident that the child needs a high-quality ECEC environment in which ECEC professionals are aware of research-based methods to support the child's skills before school starts. It is also crucial to recognize that every multilingual child's language background is unique. Not all multilingual children are at risk of learning difficulties. Fluency in two or more languages is often associated with high academic performance (Portes & Rumbaut, 2001). Research has also indicated that improved proficiency in two languages can lead to positive gains in the mathematical skills of children with math difficulties (Lee Swanson et al., 2019). Bonifacci et al. (2016) and Alt et al. (2014) showed that multilingual children were behind their monolingual peers only when

the math tasks included a verbal component. If the language load was reduced (Alt et al., 2014) or if the tasks measured purely nonverbal numerical skills (Bonifacci et al., 2016), the multilingual children performed equally well as their monolingual peers. The ages of the children in Alt et al.'s (2014) study ranged from 6.75 to 9.1 years, whereas the children in Bonifacci et al.'s (2016) study were preschoolers, with a mean age of 4.9 years.

These findings support the work of other studies in this area linking language development with math performance. However, even though it is clear from earlier research that early language and literacy skills and early mathematical skills develop together (Purpura & Reid, 2016; Schleppegrell, 2007), fostering children's general language skills does not directly improve their mathematical performance (Hannula-Sormunen, Nanu, et al., 2020; Jordan et al., 2012). However, targeting support to enhance their mathematical language does lead to positive outcomes in their math skills (Purpura et al., 2017, 2021). One explanation is that general language interventions rarely target math-related vocabulary or words used in math instruction (Harmon et al., 2005). Previous studies (Clements & Sarama, 2020; Hannula-Sormunen et al., 2020) with mostly monolingual participants have shown that when early mathematical skills are supported through research-based interventions that include playful activities and focus on mathematizing everyday situations, there is also a positive impact on language skills and executive function development. In other words, playful mathematical interventions may be beneficial for the mathematical and language learning of young multilingual children (Fuson et al., 2015). However, it seems that this approach remains a largely unutilized opportunity in ECEC.

This dissertation focuses on supporting the early mathematical skills of multilingual children participating in ECEC, with a specific focus on children over 3 but under 6 years old. This age group has been selected for three reasons: (1) it constitutes the largest cohort of multilingual ECEC participants in Finland (see Figure 1, Vipunen – Education Statistics Finland, 2023); (2) it is a particularly critical period for the development of foundational mathematical skills, including understanding numbers and quantity, counting, cardinality, and geometric and spatial reasoning (Fuson et al., 2015; Gelman & Gallistel, 1978; Wynn, 1998); and (3) although there is an expanding body of research dedicated to supporting the mathematical skills of school-aged multilingual children (Sharma & Sharma, 2023), a notable gap remains in the literature concerning the enhancement of mathematical skills among multilingual children who participate in ECEC (Cross et al., 2009; Richards-Tutor et al., 2016). It should be noted that, in this dissertation, the term "under-school-aged children" refers to children who are under 7 years old. This is because the dissertation is set in Finland, where children enter primary school in the year they turn 7 years old.



Note. Multilingual children = Mother tongue other than Finnish, Swedish or Sami

Figure 1. Participants in Finnish ECEC in year 2023 (Vipunen – Education Statistics Finland, 2023).

Multilingual children have often been described using various terms in the literature, and there is no universally accepted term to define this diverse group of language learners. The term "multilingual children" is used throughout this study to refer to children who use two or more languages on a daily basis (Grosjean, 2013) and whose home language is typically other than the majority language(s) of the country (Musanti & Celedón-Pattichis, 2013). Other common terms found in previous literature on children learning two or more languages, either simultaneously or sequentially, include dual language learners, second language learners, emergent bilinguals, language minority students, and, in English-speaking countries, English learners, English language learners, or limited English proficient students. The term "multilingual" is used in this study because it is short and clear, and acts as an umbrella term for all children who learn more than one language during childhood (Grosjean, 2010). The concept of a "multilingual child" also reflects the idea that the terms we use can influence a person's identity (Alisaari & Rakkolainen-Sossa, 2022). This term views language from an equal and positive perspective, asserting that no language is foreign or secondary. Instead, the use of multiple languages is seen as an asset, regardless of the level of language proficiency.

Just as we learn to identify potential challenges that multilingualism could pose to early mathematics learning, we must also acknowledge the advantages that come with being proficient in multiple languages. Viewing a child as a capable problem solver who can think mathematically in several languages can help reduce the negative perceptions often associated with multilingual children who may not yet be

proficient in the instructional language of ECEC. The discourse around multilingual children in the context of mathematics education should move from seeing risks and deficits to asset-based discourse in which children's different language and cultural backgrounds are recognized and valued (De Araujo et al., 2018).

2.1 Previous reviews on early mathematical interventions with multilingual learners

There is a consensus among researchers about the importance of early interventions, especially in mathematics, in which the new learning area is largely grounded on the previously learned. In other words, children may struggle to count objects accurately if they have not yet understood the one-to-one counting principle. These early interventions may prevent children from falling even more behind, as the mathematical content becomes more challenging during the future school years (Nelson, 2017).

There has been a consistent finding in previous reviews of research on early mathematical interventions for multilingual participants: a limited number of studies have been conducted on this topic. For example, Richards-Tutor et al. (2016) conducted a research synthesis including interventions for at-risk English learners from kindergarten to grade 12 (approximately 5–18-year-old students) and did not find any mathematical interventions. Buysse et al. (2014) found one study (Pasnak et al., 2006) focusing on mathematical skills in their search for educational interventions for under 6 years old multilingual children. Consequently, these reviews did not provide results regarding support for multilingual children's mathematical skills. In their study summarizing the literature on learning and teaching mathematics for young children, Cross et al. (2009) found that "surprisingly little research has examined the mathematics performance of English language learners." In accordance with previous studies, Bonifacci et al. (2016) reported that literacy development has often been the focus of research conducted with language minority students. However, the development of early mathematical skills has reached much less attention among researchers interested in the learning of young multilingual children. Despite previous studies longing for more research on the subject, a few reviews have presented intriguing findings. These findings will be explored in the following sections.

De Araujo et al. (2018) highlighted the use of children's cultural resources and the fostering of asset-based discourses in mathematics education. They conducted a review of mathematics teaching and learning with K-12 (approx. 5–18-year-old) English learners. Of the 75 studies they found, only six focused on under 6-year-old English learners. However, their review provided important insight into how instructional practices often reflect the deficit perspective of multilingual

children and their families. This deficit view, in which knowing languages other than English is seen as a limitation, could actually hinder the learning of multilingual children. Therefore, the discourse on multilingual children's mathematical learning should be changed to an asset-based discourse, in which children are seen and treated as capable problem solvers whose language and cultural background serve as a resource. This perspective presented by Araujo et al. aligns with culturally responsive mathematics teaching (Abdulrahim & Orosco, 2020; Aceves & Orosco, 2014; Gay, 2018), in which the materials used in mathematics teaching are culturally relevant, prompting the presentation and discussion of mathematical ideas, and tailored to serve learners' diverse abilities. Culturally responsive teachers appreciate children's culture, language, and heritage and integrate students' experiences and cultural knowledge into mathematics instruction. These pedagogical practices of culturally responsive teaching correspond with the principles of linguistically responsive teaching (LRT) established by Lucas and Villegas (2011, 2013). The LRT framework provides a comprehensive approach to education that aims to support multilingual learners and is widely used in current studies concerning multilingual pedagogies, especially in Finland (e.g., Alisaari et al., 2024; Alisaari & Heikkola, 2020; Alisaari & Rakkolainen-Sossa, 2022; Heikkola et al., 2024), while culturally responsive mathematics teaching specifically focuses on pedagogical practices within the mathematics domain.

Another interesting finding is from Banse's (2021) review in which the use of children's home language was emphasized in all four domains investigated. Banse's review focused on examining how to support dual language learners (DLLs) in math, science, literacy, and socio-emotional development in early childhood. As stated in previously described reviews (Buysse et al., 2014; De Araujo et al., 2018; Richards-Tutor et al., 2016), Banse also noticed that mathematics was the least investigated domain, as there were only four studies focusing on supporting DLL's math learning (Burchinal et al., 2012; Castro & Prishker, 2019; Clements et al., 2011; Foster et al., 2019). Banse's findings are widely supported in research on multilingual pedagogies (e.g., Aerila et al., 2024; De Sousa & Lennon, 2024; García, 2017; Repo et al., 2024) and in studies specifically focusing on multilingual children's math learning. For example, in Rubio et al.'s (2024) longitudinal study on home language use in the mathematics classroom of students during their fourth, fifth, and sixth class (9–12-year-old students), they noticed that when the teacher used the students' home language, the students started to use the home language more often. This led to the students feeling secure and comfortable in the classroom, which was associated with improvement in the mathematics assessment and, more importantly, growth in mathematics self-efficacy and interest. When bringing the phenomenon into the ECEC context, pedagogical translanguaging is often used as a term to describe how children should be given the possibility of utilizing all of their communicative

potential when learning new pedagogical content (see Repo et al., 2024). This approach encourages teachers to support and promote the use of all of children's linguistic resources, including their home language, during learning activities (Kirsch & Seele, 2020).

Whereas previous reviews have focused on systematically reviewing prior research and discussing the findings in a more qualitative manner, Arizmendi et al. (2021) conducted a meta-analysis that provided quantitative results on the effectiveness of language-focused interventions in English learners' math performance. In their study, language-focused interventions were defined as those that focused on teaching math vocabulary and understanding math terminology. The results of the meta-analysis, including six randomized group study designs, showed that the effect of the interventions on students' math performance was small ($g = 0.26$). The interventions conducted in kindergarten (Doabler et al., 2016, 2019; Foster et al., 2018) were found to be more effective than those conducted in the third grade or middle school. The researchers suggested that the strongest effect size in kindergarten interventions could have been derived from linguistically and cognitively less demanding mathematical content. The small effect size in Arizmendi et al.'s (2021) meta-analysis should be interpreted cautiously, as the number of studies was limited. Although the effect size in the meta-analysis was small, it was one of the first meta-analyses to examine the role of mathematical language in multilingual children's mathematical performance.

There is a consensus among researchers that mathematical language plays a critical role in predicting mathematical development. Mathematical language can be defined as key ideas, concepts, and terms that are required to understand and participate in mathematical activities, to describe mathematical ideas, and to participate in mathematical discussions (Han & Ginsburg, 2001; Purpura et al., 2017). Turan and De Smedt's (2024) recent study found that preschool-aged (6-year-old) multilingual children relied on mathematical language as much as their monolingual peers when solving mathematical problems related to numerical competencies and measurement. This finding adds to the evidence base highlighting the importance of mathematical language when enhancing the early mathematical skills of multilingual children (Cummins, 1979; Moschkovich, 2013).

Two important themes have emerged from the studies discussed so far. First, it seems that there is a paucity of research regarding multilingual children's early mathematical skills (Banse, 2021; Bonifacci et al., 2016; Buysse et al., 2014; Cross et al., 2009; Richards-Tutor et al., 2016). Second, despite the scarcity of research, some interesting findings regarding the methods for supporting multilingual children's early mathematical skills are supported by several researchers. For future studies and for practitioners working in ECEC with multilingual children, it is necessary to gather existing research to provide an overall picture of what is currently

known about supporting multilingual children's early mathematical skills. Therefore, this dissertation makes an important contribution to research by summarizing recommended practices for supporting the mathematical skills of under-school-aged multilingual children. Additionally, it provides a comprehensive overview of the current state of early mathematical intervention research concerning multilingual children.

2.2 Pedagogical planning in Finnish ECEC – The need for research-based materials for supporting multilingual children's early mathematical skills

International migration is reflected in the growing number of multilingual children in Finnish early childhood education and care (Vipunen – Education Statistics Finland, 2023). The children usually come from families with immigrant parents, and Finnish-born children and their parents use their native language at home. Thus, many children can be exposed to the majority language of the country for the first time when they enter ECEC (Bergeron-Morin et al., 2023). Children's low proficiency in ECEC's instructional language may cause challenges for ECEC professionals to support and find methods to make them feel like part of the group and offer positive learning experiences (Bergeron-Morin et al., 2023). Consequently, children's diverse language backgrounds are increasingly influencing pedagogical planning in ECEC conducted by ECEC professionals.

Pedagogical planning is performed by ECEC teachers. It refers to designing future pedagogical activities that are later implemented together with the children. There are guiding documents and issues that should be acknowledged when planning pedagogical activities. One is the national core curriculum for ECEC (2022), which is a national norm and serves as a guiding document for ECEC providers preparing the local curricula. ECEC professionals are obligated to follow the values, objectives, and contents of the local curriculum. In addition, every child has an individual ECEC plan created by ECEC professionals. Although the national core curriculum (2022) is obligatory and provides the underlying values and the content of competencies children should learn in ECEC, it still leaves room for ECEC professionals to plan daily pedagogical practices and activities within the child group.

The pedagogical activities should also acknowledge children's current interests and their level of competence in certain skills. The content of daily pedagogical activities is usually an indication of ECEC professionals' professional skills, pedagogical content knowledge, strengths, and their own interests in the pedagogical field. ECEC teachers are allocated 13% of their weekly working time (i.e., 5 hours)

for pedagogical planning, evaluation, and formulating individual ECEC plans (OAJ, 2023). The underlying factors affecting pedagogical planning are illustrated in Figure 2. With only 5 hours a week dedicated to pedagogical planning and many things to consider, pedagogical planning can sometimes pose challenges to the hectic world of ECEC. Therefore, it is important that ECEC professionals have easy-access, research-based information regarding multilingual children's learning.

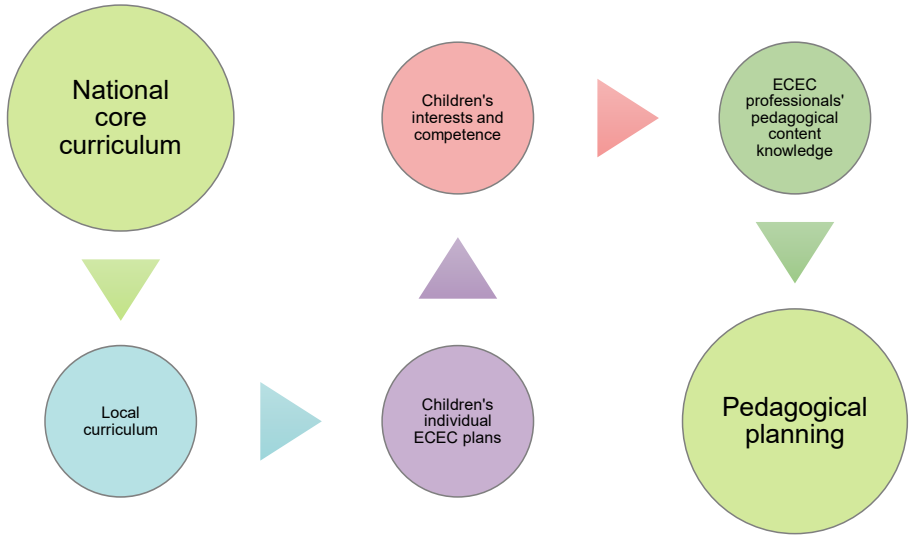


Figure 2. Documents and issues that guide pedagogical planning in early childhood education and care.

The national core curriculum (2022) defines the content of learning that should be supported in ECEC. Five different learning areas are specified in the curriculum in which mathematical thinking skills are embedded in one of the areas called "exploring and interacting with my environment." The other learning areas are the "rich world of languages," "diverse forms of expression," "me and our community," and "I grow, move, and develop." These learning areas are embedded in daily life in ECEC and supported in the mutual interactions between ECEC professionals and children. This differs from school teaching, in which specific subjects typically have designated time slots for instruction. Children's initiatives supplement the pedagogical planning made by ECEC professionals, and pedagogy is emphasized in all activities, not just the guided and pre-planned pedagogical activities. This, again, emphasizes the role of pedagogical content knowledge that ECEC professionals have. Pedagogical content knowledge facilitates the sensitivity to grasp the spontaneous learning moments provided by children's notions or initiatives (Mattinen, 2006).

Concerning the support for multilingual children's learning in ECEC, ECEC professionals usually emphasize children's language and early literacy skills more than early mathematical skills (Phillips & Meloy, 2012; Wang et al., 2016). This is understandable, especially with children who do not speak ECEC's instructional language at home and therefore require intensive support to adapt to their new environment. In addition, high-quality research-based materials, tips, and tools already exist to support multilingual children's language skills in Finnish early childhood education (see, e.g., Ota koppi website and handbook 2020; Kielipeda 2020; Language comparison tool 2022; Competencies for linguistically and culturally responsive ECEC guide 2017). These materials have been developed to complement the national core curriculum for ECEC (2022). Similar research-based materials would be needed to support the development and assessment of the mathematical skills of multilingual children. However, research concerning the educational support of multilingual children under school age is scarce (Arvola et al., 2017; McCabe et al., 2013; Pontier et al., 2020) and tends to be fragmented, making it challenging to access relevant studies. As previously stated, the time allocated for pedagogical planning in ECEC is limited. Whereas research-based, easy-access materials are available to support the language skills of multilingual children, there is a noticeable lack of resources focused on enhancing their early mathematical skills. Recognizing the critical role that early mathematical skills play in a child's future development, it seems unfair for these children to miss out on high-quality pedagogical support simply because suitable materials have not been developed to support ECEC professionals in their pedagogical planning. Thus, this dissertation aims to fill the gap in the literature by summarizing the existing research findings and providing pedagogical strategies and tools for ECEC professionals to facilitate pedagogical planning when supporting multilingual children's early mathematical skills.

3 Early mathematical skills in ECEC

The importance of early mathematical skills has been shown in several previous studies. According to previous research, early mathematical skills predict not only future mathematical skills but also literacy skills such as reading fluency and general academic skills, graduation from high school, college entry, and career outcomes (Claessens & Engel, 2013; Davis-Kean et al., 2022; Duncan et al., 2007; Fuson et al., 2015; Koponen et al., 2016; Purpura & Ganley, 2014). A strong evidence base shows that, prior to school age, a variety of mathematical skills are already developing from initial to basic and then to more sophisticated (Clements & Sarama, 2020; Jordan et al., 2010; Parviainen, 2019; Purpura & Lonigan, 2013; Sorariutta et al., 2017). When children master foundational skills, it is easier to succeed in more advanced topics. The stronger children's skills are at the start of school, the better their chances of effectively learning mathematics throughout their primary school years.

From a broader point of view, mathematics can be understood as a complex conceptual system with precise rules, abstract theories, structures, and formulas. However, when the view is zoomed into mathematics education for young children, it becomes evident that math is discovered through everyday situations "by finding the mathematics in, and developing mathematics from, children's activity" (Clements & Sarama, 2020). This discovery occurs through shared reflective observations, verbal interactions, and playful engagement between children and their guardians, educators, or peers (Mattinen & Hannula-Sormunen, 2017). In the Finnish national core curriculum for ECEC (2022), children are seen as exploratory, playful, self-expressive, and observant learners. In accordance with this approach to learning, ECEC's pedagogical activities that aim to support children's mathematical thinking skills should be playful and direct children to mathematical observations and ideas. Ultimately, providing opportunities for playful mathematical activities that bring joy to children creates a positive attitude toward mathematics and promotes inclusion and a sense of belonging for multilingual children (see, Kangas et al., 2023).

There are some misconceptions that could have influenced the support for multilingual children's mathematical skills in ECEC. Traditionally, in ECEC's pedagogical planning and daily activities, a strong emphasis has been placed on

language and literacy skills (Lee & Ginsburg, 2009; National Research Council, 2009). Conversely, mathematics has received much less attention (Phillips & Meloy, 2012; Wang et al., 2016) and is sometimes even been viewed as a subject that children will learn once they reach school age (Lee & Ginsburg, 2009). Regarding multilingual children, there has been a misconception that children should be fluent in the instructional language of ECEC to be able to learn mathematical skills (National Research Council, 1997). Sometimes ECEC professionals could have been concerned that time spent supporting mathematical skills would detract from the practice of language or social skills, which could have led to multilingual children being excluded from mathematical activities altogether (Clements et al., 2018). However, previous studies have found that supporting early mathematical skills through research-based interventions that use everyday situations also develops language and executive function skills (Clements & Sarama, 2020; Hannula-Sormunen et al., 2020). Another misconception is that mathematics is seen as a separate entity from language and culture. It has been thought that mathematics, because of its own symbols, is easy to assimilate, regardless of language proficiency (Francis et al., 2006). However, aspects of mathematical thinking, such as understanding abstract concepts or explaining the reasoning that led to the solution, require the ability to describe one's own thinking verbally. Therefore, it is important that ECEC professionals understand that language and mathematical skills develop hand in hand (Purpura & Napoli, 2015).

The current thesis aims to refute these misconceptions by providing research-based knowledge on how to support multilingual children's mathematical skills in ECEC. An essential part of supporting these skills is the content knowledge of ECEC professionals. When ECEC professionals deepen their understanding of mathematical concepts and build their confidence in their teaching abilities, they become more optimistic about children's learning potential (Chen et al., 2014; Parviainen et al., 2023, 2024). As the focus of this dissertation is on supporting 3–5-year-old multilingual children's mathematical skills, the next chapters aim to describe the mathematical skills that typically develop at this age range and should therefore be supported in ECEC.

It is important to recognize that although the mathematical development of multilingual children may be slower than that of their monolingual peers (Harju-Luukkainen & McElvany, 2018; Ukkola & Metsämuuronen, 2019; Xue et al., 2012), this does not affect the content of the mathematical skills that these children are learning in ECEC. Moschkovich (2012) highlighted that teachers of young multilingual children should follow general recommendations for high-quality mathematics instruction by offering mathematical experiences that cause productive struggles and treating all children as capable problem solvers. As multilingual children are extremely diverse in their linguistic and cultural backgrounds, it is

important to gain information about their previous mathematical experiences at home or at ECEC and to view their first language and cultural background as a resource and asset in mathematical learning situations (De Araujo et al., 2018; Moschkovich, 2012).

3.1 Early mathematical skills

Early mathematical skills have traditionally been classified into the domains of numbers and geometry (e.g., National Research Council, 2009; Tsamir et al., 2011) However, Clements and Sarama (2007, 2020) broadened the perspective to encompass spatial thinking and mathematical reasoning processes. In this dissertation, early mathematical skills are organized into three categories, as proposed by Parviainen (2019). These categories are based on a comprehensive literature review in which Parviainen examined the mathematical skills that have been studied in previous research. The literature review comprised 134 articles published between 2003 and 2018 that focused on early mathematical skills within early childhood education. Through data-driven qualitative content analysis, Parviainen formed three categories: (1) numerical skills, (2) spatial thinking skills, and (3) mathematical thinking and reasoning skills. Of these categories, numerical skills were the most investigated, as 62 of the 134 studies focused on numerical learning, 54 studies focused on spatial thinking skills, and only 18 studies were concerned with mathematical thinking and reasoning skills (Parviainen, 2019).

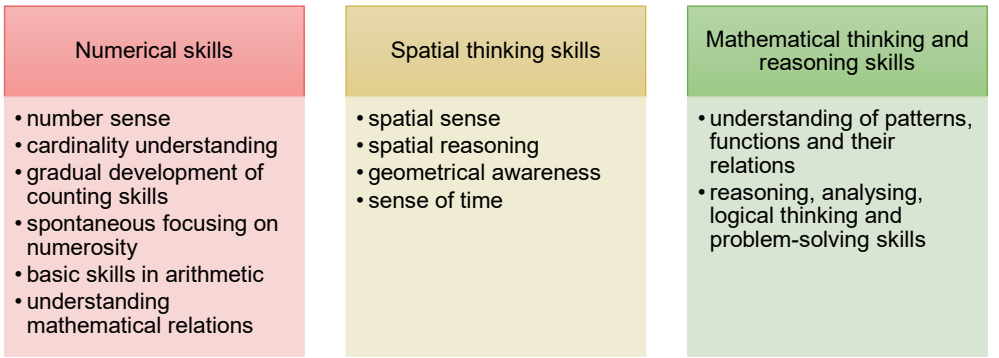


Figure 3. Early mathematical skills relevant to the current thesis based on Parviainen (2019).

Figure 3 does not comprehensively describe all early mathematical skills (for a comprehensive and holistic model of early mathematical skills, see Parviainen, 2019; 2024). The mathematical skills illustrated in Figure 3 are derived from Parviainen's (2019) study, but they are limited to skills relevant to the current thesis. In the

following paragraphs, each skill is briefly described to clarify its significance in the development of children aged 3–5 years.

Regarding the **numerical skills** category, number sense refers to quantity and number knowledge (Clements & Sarama, 2007) and can be categorized into symbolic and non-symbolic number sense (Aunio & Räsänen, 2016). Research (Aunio & Räsänen, 2016; Jordan et al., 2008; Libertus et al., 2011) has shown that a strong number sense enhances the learning of formal mathematical concepts. In the age group of 3–5-year-old children, one of the most relevant numerical skills is the gradual development of counting skills, including the understanding of cardinality (Bermejo, 1996; Fuson, 1988, 1991). The development of cardinality recognition skills begins with recognizing exact numbers by subitizing, which refers to the instant comprehension of 1–4 items in a set simultaneously without counting (Clements, 1999; Clements & Sarama, 2007; Starkey & Cooper, 1995). Another skill for recognizing the exact number of items is verbal counting. According to Fuson (1988) and Gelman and Gallistel (1978), children's verbal counting skills are fundamental for building an understanding of the natural number concept and later numeracy skills.

Children's early counting attempts often involve randomly pointing at objects and reciting number words, lacking a true understanding of the quantities they represent (Fuson, 1991; Geary & van Marle, 2016). A major step in learning to count accurately is understanding the cardinal principle. This principle means that the last word in a counting sequence indicates the total number of items in the set (Wynn, 1990) and how in any counting list, in any language, the third word consistently represents 3, while the 10th word represents 10 (Sarnecka et al., 2015). The cardinal principle belongs to the five counting principles outlined by Gelman and Gallistel (1978). The other four principles are one-to-one, stable order, abstraction, and order-irrelevance. To count correctly and specifically to use counting effectively, children need to understand and integrate all of these principles.

In addition to these principles, Hannula and Lehtinen (2005) proposed that spontaneous focusing on numerosity (SFON) functions as a significant subprocess in any counting action. SFON refers to the phenomenon in which children independently direct their attention to the exact number in a set of items or incidents without any deliberate guidance or prompting and use this information in their action (Hannula et al., 2010). Prior to enumerating a set of items, it is essential to focus on the precise aspect of exact numerosity in that set. Thus, this focused attention is required for accurate number recognition and counting.

Basic arithmetic skills include learning to compose and decompose numbers and the basics of addition and subtraction (Clements & Sarama, 2007; Krajewski & Schneider, 2009; Parviainen, 2019). In addition, understanding mathematical relations refers to comparing and ordering skills, which means that children

recognize that a group of items can differ in quantity and learn how to determine ordinality and sequence sets (Clements & Sarama, 2020; Gelman & Gallistel, 1978).

Parviainen (2019, 2024) categorized **spatial thinking skills** into three areas: spatial reasoning, geometric awareness, and a sense of time. Spatial reasoning includes skills such as mapping and discriminating directions and locations (Clements & Sarama, 2011). Understanding shapes, conservation, volume, and mass requires geometrical awareness skills (Parviainen et al., 2023). A sense of time refers to learning about the concept of time (Parviainen, 2019). Along with learning about spatial relations, geometry, and time, children's knowledge of the principles of measuring should also be developed. Studies (Clements et al., 2022; Clements & Sarama, 2007; Lyytinen, 2014) have shown that during ECEC (ages between 3 and 6 years), children's spatial thinking skills develop gradually from simple to more sophisticated and accurate as the children grow and their language abilities develop.

Mathematical thinking and reasoning skills encompass abilities such as reasoning, problem solving, logical thinking strategies, recognizing patterns, and understanding the relationships among functions (Parviainen et al., 2023). The development of these skills is fundamentally rooted in understanding concepts such as part–whole relations and place–value system (Aunio & Räsänen, 2016). Children's cognitive development coincides with the development of their mathematical thinking and reasoning skills. As children grow older, they become more sophisticated in their ability to apply analytical thinking and various logic and reasoning strategies to solve mathematical problems (Vanluydt et al., 2021; Warren et al., 2016). Recent studies have demonstrated that complex mathematical thinking and reasoning skills, such as patterning (Papic et al., 2011) and proportional reasoning, can actually be supported in ECEC, which is at a much younger age than previously believed (Vanluydt et al., 2021).

Many similarities can be found between these aforementioned early mathematical skills and the skills described in the Finnish national core curriculum for ECEC (National Agency of Education, 2022). The national core curriculum for ECEC uses the term "mathematical thinking skills" as an umbrella concept. By categorizing the skills according to Parviainen's (2019) three skill categories, the following skills described in the core curriculum could be included in the numerical skills: development of the number concept, noticing numerosities from surroundings, and later combining them into number words and number symbols, number sequence skills, and number naming skills. Concerning spatial thinking skills, the following skills are described in the national core curriculum (National Agency of Education, 2022): paying attention to shapes in surroundings, measuring, practicing concepts related to position and relations, examining objects and shapes, geometric thinking, and the concept of time. The skills described in the national core curriculum that are related to mathematical thinking and reasoning skills are

discerning and describing mathematical observations in various ways, such as using their bodies or images; classifying, comparing, and ranking things and objects; discovering and producing regularities and changes; constructing and deducing; and solving mathematical problems related to the learning environment.

The variety of early mathematical skills was presented to describe the skills that could be supported in ECEC and to highlight how early math is much more than just simple shapes and learning to count. The building blocks of essential mathematical skills are established between the ages of 3 and 5 years, a critical period for the development of number sense, cardinality understanding, counting, and geometric and spatial reasoning (Fuson et al., 2015; Gelman & Gallistel, 1978; National Research Council, 2009; Wynn, 1990). Even though early mathematical skills were presented in three different categories, it should be noted that they do not develop independently from each other; instead, the skills within different skill categories develop simultaneously and are connected with one another (Parviainen, 2024).

3.2 Everyday mathematical experiences in ECEC

There are significant differences in the number of mathematical experiences that children acquire before starting formal schooling (Fuson et al., 2015). These experiences arise in everyday situations in which children develop mathematical concepts by exploring their everyday environment (Ginsburg & Seo, 1999; Hannula et al., 2005; Ramani et al., 2015), such as going down the slide one more time, playing with different kinds of manipulatives such as Legos or puzzles, or conducting experiments, such as testing whether the toilet paper roll is long enough to reach the kitchen from the toilet. Hannula and Lehtinen (2005) made an interesting finding that some children are more aware of numerosities in their surroundings than others, calling this tendency spontaneous focusing on numerosity (SFON). In the next 20 years, this finding has been proven and extended by other studies all over the world (Verschaffel et al., 2020) to several different mathematical aspects, such as quantitative relations (McMullen et al., 2013), multiplicative relations (Määttä et al., 2022), Arabic number symbols (Rathé et al., 2019), numerical order (Harju et al., 2022; 2024), and magnitudes (Viarouge et al., 2018). Altogether, the central idea in the research on mathematical focusing tendencies is that in everyday situations in which there is no specific external guidance, children must first pay attention to elements that can be quantified or mathematically represented before they can apply their mathematical knowledge (Verschaffel et al., 2020). The term “spontaneous” refers to this process; children are not guided to focus on mathematical features. More importantly, in this context, “spontaneous” does not indicate the unintentional acquisition of skills or knowledge, nor does it imply an inherent nature to their origins (Hannula, 2005; Lehtinen & Hannula, 2006).

These spontaneous focusing tendencies and awareness of their existence play an important role in supporting children's mathematical skills in ECEC. Children with a higher tendency to spontaneously focus on mathematical features are more likely to engage in more self-initiated practice, which can be seen as developmentally relevant, as numerous opportunities for learning or practicing mathematical skills arise outside of formal educational contexts (Hannula & Lehtinen, 2005; McMullen et al., 2019). This self-initiated practice provides these children with a significant advantage in learning formal mathematical concepts later in school (Hannula et al., 2005; Hannula & Lehtinen, 2005; McMullen et al., 2019; Verschaffel et al., 2020). Therefore, it is important for ECEC professionals to encourage children to view the world through mathematical lenses from an early age. By doing so, they can help prevent significant gaps in mathematical skills before children enter school, fostering a strong foundation for future learning.

As previously stated, focusing on mathematical features is not evident among all children. However, it is important to recognize that this tendency is not an innate ability that cannot be influenced. Previous intervention studies (Braham et al., 2018; Hannula et al., 2005; Hannula-Sormunen, Nanu, et al., 2020; Mattinen, 2006; Mattinen et al., 2006) have indicated that children's focusing tendencies can be enhanced by modifying their play and activity environments as well as through guidance from adults. These studies revealed that such practices often lead children to develop mathematical skills more broadly beyond just the specific activities involved in the interventions. These findings highlight the role of ECEC in providing mathematical experiences in which children practice their mathematical thinking skills in meaningful situations (Björklund & Palmér, 2024).

This brings us to mathematizing, which is described as seeing the world through mathematical lenses and identifying everyday situations and problems in which mathematical thinking is needed, useful, and meaningful to children (Clements & Sarama, 2013; Freudenthal, 1968). When mathematizing the world around them, children create models of real-life situations with mathematical objects, such as numbers and shapes, and engage in mathematical actions, such as counting and transforming shapes while exploring the structural relationships between these elements. This understanding aids them in solving problems. For example, when children build a tunnel out of pillows and the teacher asks whether the tunnel is large enough for her to fit in, in order to solve the problem, children must think about the number and shape of the cushions, compare the tunnel's size with the teacher's size, and test their solution by letting the teacher crawl through the tunnel.

This example was originally described in Björklund and Palmer's empirical study (2024) examining how mathematizing is made possible in Swedish ECEC. It is a perfect example of a mathematical problem in children's world that cannot be solved without mathematical thinking. Naming shapes and number symbols during

book reading or building a puzzle could enhance mathematical vocabulary, but the key for ECEC professionals to facilitate children's mathematizing is to use everyday situations close to the children's world and experiences and create mathematical play in which mathematical skills and knowledge are relevant and necessary to solve a problem (Freudenthal, 1968). These true problem-solving situations facilitate mathematizing and mathematical discussions in which children learn to communicate their mathematical thinking and reasoning.

Fuson et al. (2015) summarized effective teaching–learning practices in teaching with curriculum focal points. The two main roles of teachers are "(1) to expect and support children's ability to make meaning and mathematize the real world and (2) to create a nurturing and helping math talk community". The transition from home to ECEC can be a significant milestone for children. While many children may find this experience exciting, it can also be challenging for some, particularly if they are unfamiliar with the language spoken in the ECEC setting. Therefore, the goal of ECEC professionals is to create a caring and nurturing atmosphere in which the professionals' senses are tuned in to listen and discuss children's mathematical ideas sensitively. The math talk community is a safe place where children support each other not only in everyday language but also in engaging in mathematical discourse (Celedón-Pattichis, 2018). The idea of supporting children's ability to communicate their mathematical ideas is also supported by Cross et al.'s (2009) study, which highlighted representing, problem solving, reasoning, connecting, and communicating as some of ECEC's mathematical learning goals.

In sum, fostering and enabling everyday mathematical experiences could be one of the keys to narrowing the gap in children's mathematical skills before school starts. ECEC is an excellent environment for facilitating children's mathematical focusing tendencies and self-initiated practice through mathematizing the children's everyday experiences in a caring atmosphere where math talk is cherished. Research on the development of children's mathematical skills (Aunola et al., 2004; Duncan et al., 2007; Jordan et al., 2009) has shown that children who start behind in mathematics tend to stay behind their peers throughout their academic journeys. Therefore, the pedagogical practices in ECEC are vital for guiding children toward a successful educational journey and laying a strong foundation for their future.

3.3 The current methods for supporting mathematical skills in ECEC

Mathematics is deeply connected with the cultural practices surrounding children's learning environments. The transmission of cultural practices (e.g., counting objects) occurs through child–adult interactions in which the shared attention of the adult and the child is focused on mathematical features (Mattinen, 2006; Mattinen & Hannula-

Sormunen, 2017). This means that the child has the opportunity to learn from the adult the necessary knowledge and skills to process and exploit numbers and other mathematics in the child's own activities. The learning of early mathematical skills, such as the conceptual understanding of numbers and other mathematical concepts, does not occur without guidance. In other words, the learning of early mathematical skills is not self-evident or does not occur automatically as a child grows. For example, recognizing and expressing numbers in words and symbols and learning the relationships between them take several years and require much practice (Fuson, 1988). It is important to facilitate mathematical awareness of the ECEC environment and ECEC professionals because the surrounding culture and the child's growing environment significantly affect learning (Hannula-Sormunen et al., 2018).

The national core curriculum for ECEC (National Agency of Education, 2022) guides and supports the development of children's mathematical thinking skills by encouraging and providing opportunities for children to explore and observe. Interactive and playful situations are essential in which the adult takes a variety of initiatives from the child and makes use of the mathematical opportunities offered by the learning environment and materials that appeal to children. Children are also encouraged to describe their mathematical observations in various ways, such as using their bodies, devices, or images. The national core curriculum for ECEC (National Agency of Education, 2022) also noted that support for skills should take into account children's current level of mathematical competence. The guiding principles from the national core curriculum are summarized in Figure 4.

The national core curriculum does not explicitly consider the influence of children's linguistic and cultural backgrounds, or their varying levels of language proficiency, on the methods for supporting children's mathematical thinking skills. However, since 2018, Finland's national core curriculum for ECEC has acknowledged the increasing multilingual population, aiming to foster children's linguistic development and curiosity about languages and cultures (Aerila et al., 2024). The intention is that these principles should be reflected in all learning areas, but the effective implementation of this curriculum relies on ECEC professionals' readiness to modify their approaches in accordance with these language policies (Repo et al., 2024) and apply them throughout different learning areas, such as mathematical thinking skills. This dissertation aims to bridge the gap between the national core curriculum language pedagogies and practical applications by supporting ECEC professionals' pedagogical planning by gathering previous intervention research and research-based recommendations that focus on enhancing multilingual children's early mathematical skills

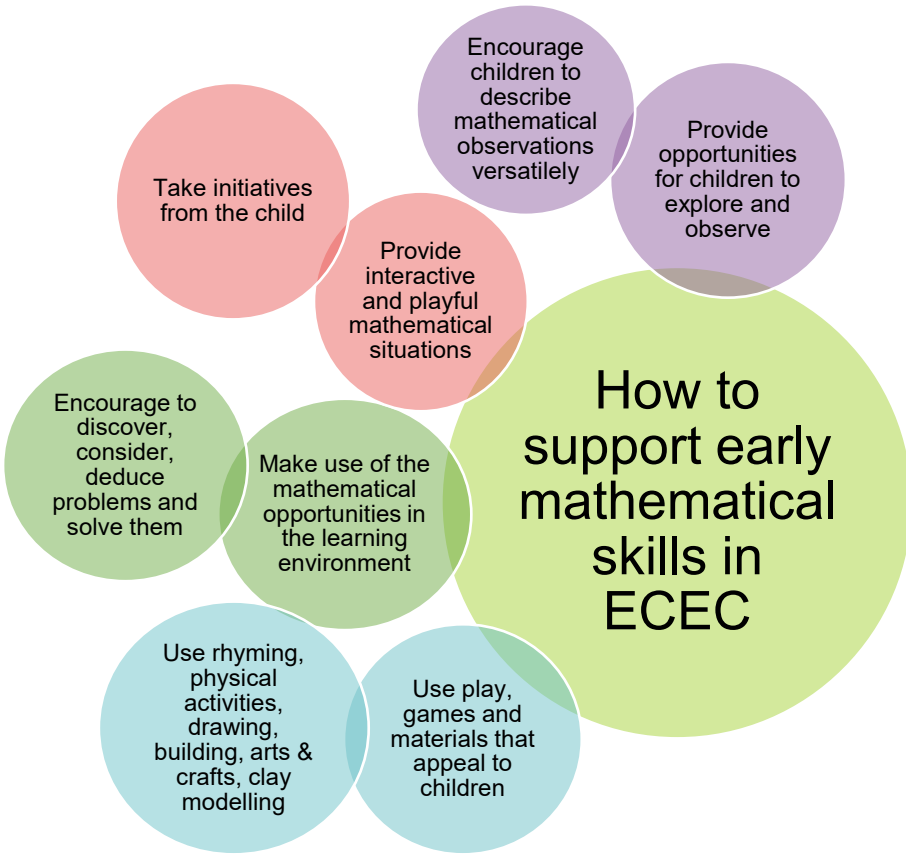


Figure 4. How to support early mathematical skills in ECEC according to national core curriculum (National Agency of Education, 2022).

4 Theoretical underpinnings – From monolingual practices to the multilingual perspective

Although this study focuses on supporting early mathematical skills, current theoretical perspectives on language learning and multilingual pedagogy should be considered because children learn not only mathematical content but also language skills. The interdisciplinary nature of research in mathematics education with multilingual children is challenging. This study is based on Moschkovich's (2002) situated and socio-cultural approach, which considers learning mathematics when children speak more than one language as "participation in a community where students learn to mathematize situations, communicate about these situations, and use resources for mathematizing and communicating" (p. 197). Multilingual children with their diverse linguistic and cultural backgrounds bring their own meanings to the representations in everyday learning situations in ECEC settings. These meanings must be made apparent and negotiated. Thus, participating and communicating in mathematical learning situations not only constitute learning mathematics but also involves using social, linguistic, and material resources.

The underlying theoretical perspective in this study is based on sociocultural theory (Vygotsky, 1978), according to which cognitive development, including mathematical development, is shaped by culturally constructed practices, tools, and symbols. Consequently, mathematical understanding is fostered through social interactions and practices, which then enhance mathematical development. The current study examines effective pedagogical practices that enhance early mathematical learning among multilingual children. The term "pedagogical practice" in this study refers to actions related to supporting and learning early mathematical skills within the ECEC context, which encompasses the daily experiences of both ECEC professionals and children (see Musanti & Celedón-Pattichis, 2013). In this context, the terms "pedagogical practice" and "instructional practice" are used interchangeably.

Culture and mathematical learning are closely connected, as both are influenced by everyday experiences (Hannula-Sormunen et al., 2018). These everyday experiences are situations in which cognitive development occurs through

collaborative learning opportunities with more knowledgeable peers or experts, a concept known as the zone of proximal development (Vygotsky, 1978). ECEC professionals who adopt multilingual pedagogical practices use scaffolds that help learners utilize their cultural backgrounds and strengths in developing their skills (Abdulrahim & Orosco, 2020; Aerila et al., 2024; Lucas & Villegas, 2013; Repo et al., 2024).

ECEC practices in Finland and internationally are often based on a monolingual perspective (Aerila et al., 2024; Kirsch & Seele, 2020). However, the monolingual perspective hinders the learning of multilingual children because it does not acknowledge the cultural and linguistic strengths and experiences of multilingual children (Abdulrahim & Orosco, 2020; Alisaari et al., 2019; Castro & Prishker, 2019; Kirsch et al., 2020). Traditionally, language practices in ECEC aim for children to learn the official languages of their countries, with less attention paid to supporting children's home languages (Kirsch et al., 2020). This could be due to ECEC professionals finding multilingual practices challenging to implement because they usually require complex knowledge of multilingual pedagogy. This knowledge must be integrated with an understanding of child development and general ECEC pedagogy (Aerila et al., 2024; Bergeron-Morin et al., 2023; Repo et al., 2024). Furthermore, a multilingual perspective should be applied across various content areas, including the development of early mathematical skills. Incorporating this perspective into daily pedagogical work inevitably demands additional effort, interest, and time.

In this dissertation, multilingual pedagogy refers to an educational approach or perspective that values and utilizes different languages as resources for learning. In ECEC groups in which systematic multilingual pedagogy is applied, children's linguistic repertoires are recognized and incorporated regularly into daily activities, promoting the flexible use of diverse languages to enhance educational experiences and outcomes (Aerila et al., 2024; Kirsch et al., 2020). This approach also emphasizes cooperative relationships with children's families, especially those from minority language backgrounds, to support children's linguistic strengths and respect multilingual identities. What often goes unrecognized in the discussion on multilingual children is how families and children's diverse languages bring richness to ECEC groups and facilitate the learning experiences of other children (Bergeron-Morin et al., 2023). Bialystok's (2018) review of bilingual education explored its effects and outcomes and found that effective multilingual programs provide cognitive advantages over monolingual instruction. In sum, monolingual pedagogy and practices seem to work for monolingual children, whereas multilingual pedagogy and its practices benefit both multi- and monolingual children (Kirsch et al., 2020).

The knowledge and research-based materials for easing ECEC professionals' work in multilingual child groups are still difficult to find and require more work and effort from ECEC professionals, who might be challenged to find time for the daily basic care and education of the children. Although the national core curriculum for ECEC (National Agency of Education, 2022) aims to promote language awareness by supporting children's linguistic repertoires, their linguistic identities, and their curiosity about languages, texts, and cultures, it does not provide much practical guidance on how to implement language awareness in practice. It also lacks strategies for integrating language awareness into different learning areas, such as mathematical thinking skills.

In summary, it seems that improvements in ECEC's pedagogical practices are essential. However, there is an undeniable need for research-based information and the availability of comprehensive educational resources. This includes both pre-service and in-service training, along with improved resources related to multilingual pedagogy, including supporting early mathematical skills (see, e.g., Aerila et al., 2024; Harju-Autti et al., 2022). It is important to recognize that as these multilingual children are learning the instructional language of ECEC, as well as their home language(s), they are developing into multilingual citizens, and this will undoubtedly be an asset for their future (Musanti & Celedon-Pattichis, 2013).

5 Research aims

The purpose of this dissertation is to expand our understanding on how to support early mathematical skills of multilingual children in ECEC. The dissertation brings insights to mathematics learning in today's multilingual ECEC contexts through conducting an intervention study in Finnish ECEC setting, synthesizing recommendations provided by former research on how to support early mathematical skills, and reviewing former international early mathematical intervention studies. The specific focus of all the studies is on ECEC-aged multilingual children.

The first part of the dissertation aims to determine if it is possible to improve the early numeracy and oral language skills of multilingual children through an intervention originally designed for monolingual children (Study I). The second part focuses on existing literature to synthesize and present research-based recommendations on how to support the early mathematical skills of multilingual children (Study II) and to explore previous research to assess the current state and effectiveness of early mathematical interventions conducted with multilingual participants (Study III). This second part of the dissertation complements the results of the empirical part by identifying and summarizing research-based methods for supporting the early mathematical skills of multilingual children. The overarching aim of the present dissertation is to broaden the perspective of future early mathematical interventions, pre-service teacher education, professional development as well as daily practices in ECEC to better acknowledge and support the early math learning of multilingual children.

In addition to these general goals, each study had more specific research questions:

RQ1: How effective was the CHM intervention, originally designed for monolingual children, in supporting multilingual children's early numeracy and oral language skills? (Study I)

RQ2: What insights does the existing research provide on supporting multilingual children's early mathematical skills in ECEC?

- What research-based recommendations are there for supporting the mathematical skills of multilingual children in ECEC? (Study II)

- What is the current state of intervention research, and what is the average effect size of early mathematical interventions conducted with multilingual children in ECEC? (Study III)

6 Data and methods

The present dissertation comprises three studies, each offering a relevant perspective on supporting the mathematical skills of multilingual children in ECEC setting. Quantitative methods were used in Study I as the effectiveness of early numeracy program Count How Many was tested with multilingual participants. Study II was more qualitative as the recommended practices for supporting early mathematical skills of multilingual children were described, synthesized and analyzed. Study III integrated both qualitative and quantitative methods through conducting a systematic review and a meta-analysis. The systematic review described the former early mathematical intervention studies and the meta-analysis examined how effective the interventions had been for multilingual children's mathematical skills. In the current thesis, an early mathematical intervention was defined as a planned procedure, which changes the existing pedagogical practice in ECEC setting and has the intention to foster children's early mathematical skills (see, Mononen, 2014). Table 1 summarizes the data and methods used in the studies.

Table 1. Data and methods.

STUDY	AIMS	DATA	N	ANALYSES
I. The effects of a SFON-based early numeracy program on multilingual children's early numeracy and oral language skills	To examine how early numeracy intervention supports multilingual children's early numeracy and oral language skills.	5 numeracy and 2 oral language measures. 3 measurement points: Pre-test, post-test, and delayed post-test.	*N* = 48 Multilingual children *n* = 16 Monolingual children *n* = 32	Descriptive statistics ANOVAs to test group differences
II. Recommendations for supporting multilingual children's early mathematical skills - A thematic synthesis	To synthesize and analyze recommendations presented in previous research for supporting multilingual children's early mathematical skills	Studies focused on providing recommendations for supporting multilingual children's early mathematical skills based on previous research and expert opinions.	5 articles	Three-stage procedure of thematic synthesis: (1) coding, (2) descriptive themes, (3) analytical model
III. The effects of early mathematical interventions for 3–5-year-old multilingual children: A systematic review and a meta-analysis	To examine the current state of research on supporting multilingual children's early mathematical skills	Early mathematical intervention studies with 3–5-year-old multilingual participants	Systematic review: 24 articles Meta-analysis: 17 articles	A systematic review and a meta-analysis

6.1 Study I

The first study was quasi-experimental, indicating that participants were assigned to groups according to non-random criteria instead of random assignment (Maciejewski, 2020). In Study I, the primary criterion for group assignment was the children's home language. Previously unanalyzed data were used from a larger research project that developed and evaluated the effectiveness of two early numeracy interventions Count How Many (CHM) and One, two, how many (see Hannula-Sormunen et al., 2020). The CHM intervention was designed for 3–5-year-old children, whereas the One, two, how many -intervention was aimed at under three-year-old children. Hannula and colleagues (2020) focused on monolingual Finnish-speaking participants and showed that the CHM program improved their early numeracy skills. Study 1 in this dissertation focused on the multilingual participants who were not included in the larger study and examined how effective the intervention was for their early numeracy and oral language skills.

6.1.1 Participants

The study involved a total of 48 participants from five ECEC centers in a medium-sized city in Finland. The participants were divided into three subgroups. One subgroup consisted of 16 multilingual children (4.5 years; SD = 9.7 months) who took part in the CHM intervention. Among this group of children, a total of 14 different home languages were identified. Eight parents reported speaking Finnish and another language at home, while eight parents indicated that they did not use Finnish at home.

The second subgroup, consisting of 16 participants, also took part in the CHM intervention. The children in this group were Finnish-speaking monolingual children, who were 4.5 years old on average, with a standard deviation of 9.0 months. The third subgroup, comprising 16 participants, participated in an early literacy program called Let's Read and Talk (LRT). Similar to the second subgroup, the children (4.4 years, SD 9.2 months) in this group were also Finnish-speaking monolinguals. The children in these two control groups were pairwise-matched with the multilingual children in the first subgroup based on their age, and pretest scores of SFON tendency and cardinality-related skills.

6.1.2 Description of the CHM and LRT interventions

CHM intervention offers repeated experiences where the children's focus is guided into numerosity, recognizing and using exact numbers and practicing counting skills. The aim is that the focusing on numerosity would eventually transfer from these guided experiences to novel situations, even when explicit guidance is not provided. This would result as an increased self-initiated practice, ultimately giving children an advantage when they begin studying formal mathematics in school (Hannula et al., 2005; Hannula & Lehtinen, 2005; McMullen et al., 2019; Verschaffel et al., 2020).

The early numeracy skills are practiced in guided playful activities as well as in various situations throughout the ECEC day. The purpose is to expand the mathematics from the structured, fun and playful small-group activities to be a part of everyday experiences in ECEC. From the mathematical content areas, CHM focuses especially on SFON, counting and cardinality understanding. The focus is on these skills, because they are the basis for later school mathematics, and on the other hand, those are the skills that are needed regularly in everyday life (Fuson et al., 2015; Gelman & Gallistel, 1978; Hannula-Sormunen et al., 2018; Wynn, 1998).

The Let's Read and Talk intervention supports children's vocabulary and listening comprehension skills through dialogic reading (see, Whitehurst et al., 1988), where the main aim is to make the children storytellers instead of passive listeners. In addition to picture book reading situations, listening comprehension and

vocabulary skills were practiced in everyday activities that emerged from children's own interest or in situations, which provided an opportunity to joint reflection (Lindfors et al., 2025; Sorariutta et al., 2024).

In both of the interventions, it was extremely important that the interventionists were aware of the children's zone of approximal development (see, Vygotsky, 1978) and sensitive to children's questions, actions and ideas. The activities were scaffolded to meet the level of children's numeracy skills in the CHM intervention or literacy skills in the LRT intervention. The activities followed the same structure in both of the interventions. The core in both interventions consisted of the guided small group activities. Additionally, there were whole group activities and importantly, the content of the interventions was embedded in the everyday situations, routines and activities throughout the ECEC day.

6.1.3 Procedure

The schedule and design of the study is described in Figure 5. Both interventions started with professional development workshops for the ECEC professionals who worked as interventionists and delivered the intervention activities in the ECEC centers. As described in Figure 5, professional development continued throughout the intervention and was delivered by the researchers. In the team meetings, the ECEC professionals had the opportunity to discuss about the activities as well as reflect their own guidance as the researchers brought up the well-guided episodes from the video-recorded small group activities. The baseline testing was done in October before the interventions. The posttest was administered seven weeks after the pretest and the delayed posttest was conducted five months later. The test situation consisted of seven tasks and two short breaks and lasted an average of 20 minutes. During the breaks children could relax and do simple exercises such as fly like butterflies to help them focus for the next task.

The interventions started with intensive phase, which in CHM intervention lasted for 6 weeks and in LRT intervention 5 weeks. The intensive phase included small-group (3–7 children) activity, that occurred every other week and was implemented 3 times a week lasting 15–30 minutes. The small-group sessions included a playful activity, such as Count How Many box, Count How Many board and Vegetable market. The ECEC professionals had structured guidelines to carry out the activities aimed at triggering and promoting the focus on numerosity. This was achieved by asking "how many" -questions, counting and recounting, and adjusting the number of objects in the guided activities as well as in the ECEC environment. The ECEC environment was also mathematized through the strategic placement of SFON baits, which facilitated opportunities for children to explore and engage in counting activities. These baits can be easily created by arranging similar toys or countable

objects in a symmetrical manner, making the set of objects visible against the background and appealing for children to notice. After the small group week, the following week always focused on applying the skills rehearsed in the small group to everyday situations during the ECEC day.

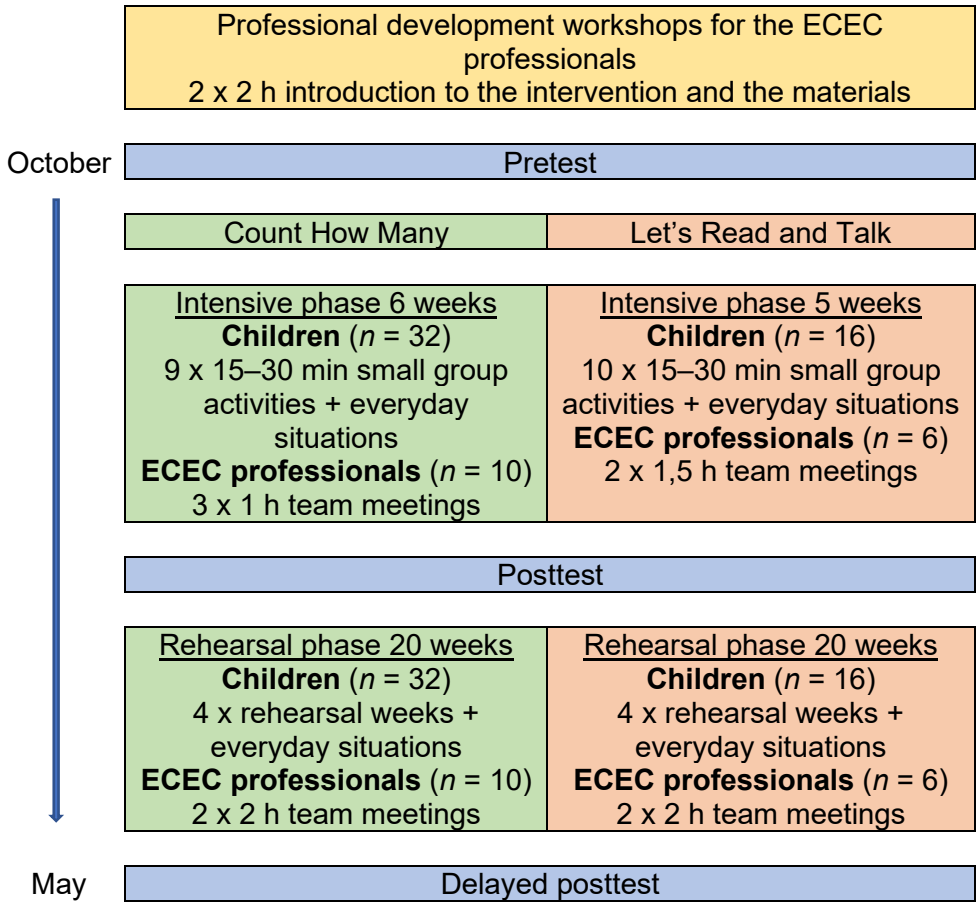


Figure 5. Schedule of the data collection, professional development training and intervention phases (Luomaniemi et al., 2021).

The rehearsal phase followed the intensive phase and lasted for five months. This was planned to prevent the fade-out effect, which often happens after a short intervention period (Bailey et al., 2016). The main goal of the rehearsal phase was to maintain the good practices from the intensive phase, especially keeping the object counting and noticing numerosities integrated in the daily ECEC routines. During the 20-week period, there were four special weeks when one of the guided small-group activities was implemented twice a week. The purpose of the special weeks was to support the ECEC professionals maintain their sensitivity to interact

mathematically with the children during the daily routines, such as morning gatherings, unguided play, dressing for outdoor activities, eating situations or moving from one place or activity to another. As a result, counting and enumeration activities become enjoyable and frequent parts of the day in ECEC.

6.1.4 Numeracy measures

SFON (Spontaneous focusing on numerosity) was assessed through three different tasks: an imitation task with disappearing objects (Hannula & Lehtinen, 2005), a selection task (Hannula et al., 2005), and an imitation task with visible objects (Hannula et al., 2005). The procedure was consistent across all measurement points. Novel effect was created by changing the materials used in the parallel tasks. When measuring spontaneous (i.e., not guided or prompted) mathematical tendencies, it is crucial to avoid all contextual hints about mathematics during the tasks. This ensures that if a child describes some mathematical aspect (e.g., numerosity) when performing the task, it can be assumed that the mathematical notion was self-initiated (Hannula & Lehtinen, 2005; McMullen et al., 2019). SFON-tasks used with 3–5-year-old children are characterized by the use of small numbers and clear visual instructions. This ensures that all children are capable of successfully execute the task by focusing on the numerical aspects in the task. In other words, the demand for mathematical skills is not overly high.

In the imitation task, the experimenter shows the child an example of what to do and asks the child to imitate exactly what was done. When the task involves visible objects, the child can see the materials throughout the task. For example, the experimenter might put two handfuls of gravel on a toy truck and ask the child to replicate the action. In contrast, in the imitation task with disappearing objects, part of the materials will "disappear" during the task. For example, the experimenter might give toy berries to a toy parrot's mouth, and the berries disappear into the parrot's stomach, making a bumping sound. The child will earn one point for the task if they focus spontaneously on the numerosity, which can be demonstrated through quantifying acts, either verbally or nonverbally.

The selection task differs from the imitation tasks in that the child is asked to actively select something rather than imitate the experimenter's actions. For example, in the first trial, the experimenter asks the child to choose a shoebox for a paper creature. The boxes have different numbers of shoes (3, 1, 2 and 4) on the lids and the creature has either one or two legs. The experimenter shows the child the shoe boxes one by one and asks the child to give the creature its own shoe box. The child gets a point for focusing on the numerosity and indicating it verbally or non-verbally.

Other numeracy measures were Give-a-number task (Wynn, 1990) and Number sequence production task. Give-a-number task was designed to assess children's

understanding of cardinality. In the task, children were asked to place a certain number of small objects on the table, with numbers ranging from 2 to 32. The child was provided with a box of items containing 10 more items than the requested number. Number sequence production task was utilized to assess children's verbal counting skills. The children were asked to count to as high a number as they could and to stop at a maximum of 50.

6.1.5 Language measures

The children's language abilities were assessed using the WPPSI-III vocabulary task (Wechsler, 2009) and the NEPSY II story comprehension task (Korkman et al., 2008). In the vocabulary task, the child was first asked to name five well-known items in pictures and then to provide an explanation of the meanings of various words. The number of words depended on the child's performance; if the child answered three consecutive questions with zero points, the task would end. In the story comprehension task, the experimenter displayed a picture and read a short story related to it. The children were then asked to retell as many details of the story as they could remember. After this, the experimenter posed guided questions about the elements that the children did not mention while retelling the story.

6.1.6 Statistical analyses

All analyses were performed using IBM SPSS Statistics version 25. Descriptive statistics, including frequencies, means, and standard deviations, were utilized to summarize the data. To analyze if the groups differed in pretest measures or background variables a one-way ANOVA was used. Repeated measures ANOVA was used to examine the differences in the development of mathematical and language related measures by condition across three timepoints. Cronbach's alpha was used to estimate the reliability of the measures. Descriptive methods were used in the further analysis to explore the relationship between the language backgrounds of multilingual children and their outcomes in the numeracy and oral language measures.

6.2 Study II

The first study provided important information about how an intervention designed for monolingual learners works with multilingual participants. Although the results could be interpreted as promising, it was clear that there was room for improvement in the intervention to support multilingual children's early mathematical skills. Therefore, Study II was planned to find promising practices or recommendations

concerning ECEC-aged multilingual children's mathematics learning. In the future, these practices could then complement the activities and professional development used in the original intervention to better foster the early mathematical skills of multilingual children.

6.2.1 Data collection

The data collection procedure followed the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-analyses) guidelines (Page et al., 2021). The preliminary search was made in Google Scholar. Afterwards, six international electronic databases were used: Web of Science, Scopus, JSTOR, PsycInfo, ERIC, and Academic Search Premier. In addition to international databases, the search was made also in two Finnish databases Arto and Melinda. The international search yielded six articles that met the inclusion criteria. The search was continued by reviewing the reference list of these six articles and by conducting a snowball search using Google Scholar's "articles related to the topic" search. After reviewing the six selected articles, the study by Musanti and Celedón-Pattichis (2013) was decided to be excluded. This decision was made because the 2018 article by Celedón-Pattichis, which was also included in the synthesis, utilized the 2013 study as a source. Furthermore, both studies cited 13 of the same sources. The 2018 article also offered more recent data, leading us to include only that study. As a result, the total number of articles included in the synthesis was five.

6.2.2 Study selection

The study was included if it was in English or Finnish and focused on the recommendations specifically developed to support multilingual children's early mathematical skills. No date constraint was set due to the limited research on the topic. The study was included if the recommended practices were intended to be implemented in ECEC instead of school or home setting. The study was excluded if the recommendations were not the main focus of the study, if the recommendations were not specifically designed to support early mathematical skills, or if the recommendations were clearly aimed at children over the age of 7 or the target age group was not clearly stated.

6.2.3 Analysis procedure

Thematic synthesis (Thomas et al., 2017; Thomas & Harden, 2008) was selected as the analysis method, as it allows qualitative material to be organized and analyzed in detail. Thematic analysis is a more commonly used method than synthesis, which

is often employed to analyze data in individual original studies. In a thematic synthesis, the same type of analysis is used to combine the results or content of several studies. The method not only describes the included studies but also facilitates a deeper interpretation of various aspects of the research topic. The method has a precise order in the analysis process and following the steps ensures that the interpretations and conclusions made during the analysis can be traced back to the original text throughout the process.

The data-driven thematic synthesis was conducted using the Nvivo (12) program in three steps. Initially, the articles were coded line by line, with each recommendation in the article serving as its own unit of analysis. Two researchers coded the recommended articles, with one article being collaboratively coded to create a coding table based on the article. Subsequently, each person independently coded the remaining four articles. If a recommendation did not align with any existing code, new codes were added to the coding table as needed throughout the process. The inter-coder reliability was .83.

In the second step, the codes were organized into descriptive themes. The goal was to stay true to the original articles by forming themes according to the terms and wording used in the articles, without analyzing or interpreting the recommendations. The codes were grouped into larger entities by two researchers. These entities were then named as descriptive themes based on their content. Finally, the descriptive themes were combined into larger categories that combined the themes.

In the third stage of the analysis, analytical themes were constructed based on the descriptive themes. The aim was to highlight recommendations for guiding pedagogical planning, specifically those relevant to the everyday life of Finnish early childhood education and care. When constructing the analytical themes, special attention was paid to the objectives outlined in the Finnish national core curriculum for ECEC (National Agency of Education, 2022) for developing mathematical thinking.

6.3 Study III

Research on developing early mathematical skills in multilingual children under school age is limited (Bonifacci et al., 2016; Cross et al., 2009; Richards-Tutor et al., 2016) as also noted during Studies I and II. Furthermore, the existing research seemed to be fragmented, and to our knowledge, had not been compiled comprehensively before. Therefore, it was important to systematically gather the existing research to provide a better understanding of what is known. The objective of the systematic review was to summarize research on early mathematical interventions for multilingual children aged 3 to 5. In addition to summarizing the existing research, the aim was to combine the results statistically and estimate the

effectiveness of the interventions. This involved conducting a meta-analysis of studies that provided sufficient data for effect size calculations (Schmid et al., 2020).

6.3.1 Data collection

The systematic review and meta-analysis were designed following the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-analyses) guidelines (Page et al., 2021). Relevant studies were located through a systematic database search in December 2020, followed by supplementary searches in March 2021 and July 2023. In addition to Google Scholar, six different electronic databases were used: Web of Science, Scopus, JSTOR, PsycInfo, ERIC, and Academic Search Premier. To find all relevant studies, the search was not limited to peer-reviewed journals. Researchers on the field were contacted to obtain unpublished data or request more specific information of the data in their published studies. Web pages from different ECEC research communities, such as Eriksson Institute, were also reviewed.

6.3.2 Study selection

In order for a study to be included in the systematic review, it had to be an intervention study involving multilingual participants aged 3 to 5 years, either as the target group or as a subgroup. The intervention had to specifically target early mathematical skills and be implemented in ECEC settings. For a study to be eligible for the meta-analysis, it needed to meet all the criteria mentioned before and provide sufficient data for calculating effect sizes. Studies that did not provide sufficient data for this calculation were only included in the systematic review. Colandr tool (Cheng et al., 2018) was used for the screening process. The tool enables two reviewers to select the studies individually.

First, titles and abstracts were examined to narrow down the 465 studies found in the initial search. A total of 370 studies were excluded because they did not meet the inclusion criteria. In the second phase, the full text of 90 articles was reviewed (full text was not available in 3 studies and the language in the full text was other than English in two of the studies). A backward and forward citation search was made for the relevant documents and 24 researchers were conducted to provide more detailed data. The final number of included intervention studies for the systematic review was 24. Of these 24 studies, 17 provided sufficient data for the meta-analysis.

6.3.3 Analysis procedure

The analysis procedure was started by summarizing the purpose of the study, the contents of the intervention and the key findings. This was done to get a comprehensive picture of all the studies included. The information retrieval was then continued with coding the basic information of the studies (the year of publication, study location, type of publication, and study design), participant characteristics (the age range or the grade reported, the number of participants, the type of control group, the term used for multilingual children, and the definition of the term), general intervention characteristics (language of instruction, interventionist, group size, the intensity of the intervention, and if the intervention was designed specifically for multilingual children), mathematical content, instructional features, specific instructional features related to multilingual participants (the use of mathematical language, children's home language, and cultural responsiveness), and outcome measures (selecting the primary measure).

The rationale for the specific instructional features related to multilingual participants (the use of mathematical language, children's home language, and cultural responsiveness) stems from summarizing the previous reviews and expert opinions in the field (Banse, 2021; Celedón-Pattichis, 2018; Clements et al., 2018; De Araujo et al., 2018; Moschkovich, 2013). These three instructional features recurred throughout the studies as methods to support multilingual children's mathematical skills. These features were coded, because one of the goals of the study was to examine whether current intervention research already utilizes these instructional features, which former research recognizes as supporting practices for enhancing young multilingual learners' mathematical skills.

6.3.4 Statistical analyses

A random-effects model was used in the meta-analysis because it accounts for a range of true effect sizes, rather than presuming that a single true effect size is representative of all interventions (Borenstein et al., 2009). This choice was suitable for our analyses due to the expected significant variability between studies based on their conduct and the characteristics of the samples used in each study. Comprehensive Meta-Analysis Software Version 4 (Borenstein et al., 2022) was used to calculate effect sizes.

Hedges' g was used to describe the effect sizes of the standardized mean differences between groups. Hedges' g is similar to Cohen's d but is more appropriate for analyzing small samples. Table 2 describes the statistical tests used in the meta-analysis.

Table 2. Overview of the statistical tests used in the meta-analysis.

Statistical test	Purpose
The mean effect size (Hedge's g), the 95% confidence interval of the average treatment effect, the 95% prediction interval	To assess the mean effect size and the variability of the effects
Q test	To examine the variation in the distribution of effect sizes
I^2	To determine the extent of variability in effect sizes due to heterogeneity, as opposed to sampling error
'Remove one study' procedure	To control for the impact of outliers
A funnel plot	To analyze the symmetry of treatment effects around the underlying true effect
Egger's test	To statistically evaluate the asymmetry of a funnel plot
Classic fail-safe n analysis	To determine the number of missing studies needed for the mean effect size to no longer be statistically significant

Several moderators were used in the further analysis including intervention design (for multi- or monolingual children), control group characteristics, sample size, group size, duration of the intervention, instructional approach (traditional versus computer-based), and the nature of mathematical content. A mixed-model procedure was employed to assess the effects of these moderators. Furthermore, to evaluate the influence of specific intervention features related to multilingual participants, effect sizes were also calculated for the use of mathematical language, home language and culturally responsive instructional approach.

6.4 Ethical considerations

The purpose of this dissertation is to describe and bring insights to mathematics learning in today's multilingual ECEC contexts by conducting an intervention study in Finnish early education settings, synthesizing recommendations provided by former research, and reviewing former international early mathematical intervention studies. The ethical considerations are presented first for the empirical part, which involves ECEC-aged children (Study I), followed by the review-type studies where the data consists of previous research (Studies II and III).

6.4.1 Study I

Participation in the intervention study was entirely voluntary for all involved parties. Informed consent was obtained from the guardians of the participants, along with a

verbal assent from the participants for the use of their data. Due to some guardians not speaking Finnish, the research permission form was also provided in English ($n = 3$), Arabic ($n = 2$), and Russian ($n = 2$). The study utilized a design that included an experimental group participating in early numeracy intervention and two active control groups participating either in early numeracy or early literacy intervention. This arrangement provides benefits to both the experimental group and the control groups, as the interventions support the development of children's different cognitive skills. The ethical guidelines of the University of Turku were followed, and both ethical board of Turku University and all required levels of ECEC administration gave permission for conducting the Study I.

Given the sensitive nature of the video data, special care was taken to protect anonymity of the subjects. The video-recorded test situations were transcribed into text files and coded to SPSS. The names appearing in the video-recordings were replaced by pseudonyms, and invented numerical identifiers were used in the research materials to identify the subjects. Video recordings will be destroyed 10 years after their completion (December 31, 2026). Anonymized files and forms are stored in the data archive of the Faculty of Education.

Video recordings or parts of video recordings were not used in research publications and were not shown in any public context (such as scientific conferences) unless the written permission of all persons appearing in the video and their guardians was requested. Direct excerpts from text files produced from research material that had been anonymized has been used in scientific presentations.

The ethical principles of research in the humanities and social and behavioral sciences presented by the Finnish Advisory Board on Research Integrity (2019), General Data Protection Regulation (European Parliament Council of the European Union, 2016), Data policy of the University of Turku (2016) were followed in all data collection, analysis and publishing in this project.

6.4.2 Study II and III

Unlike the intervention study, the thematic synthesis (Study II) and the systematic review and the meta-analysis (Study III) did not collect personal, sensitive or confidential information from participants. Thus, a permission from the ethical board was not needed. However, we ethically considered the quality of evidence reported in the included recommendation studies ($N = 5$) in Study II, and intervention studies ($N = 24$) in Study III. Both studies followed the TENK guidelines by Finnish National Board on Research Integrity (2019).

It was recognized that studies yielding significant positive results are more likely to be published than studies that report null or negative findings. (Franco et al., 2014). Therefore, to address this publication bias, a thorough review of both

published and unpublished literature was conducted, with a transparent reporting of the search procedure in both studies. Both studies followed the preferred reporting items for systematic review and meta-analysis protocols (PRISMA) guidelines (Page et al., 2021).

The included studies underwent an appraisal process conducted independently by two researchers to assess their quality. The appraisal process is done in order to evaluate the methodological quality of each study, identify potential biases in the study design and analyses, and assess how the study was conducted (Shaheen et al., 2023). The results of this appraisal process assist the reader to evaluate and interpret the findings of the synthesis. In study II the appraisal instrument was Joanna Briggs Institute's Checklist for textual evidence: expert opinion (Joanna Briggs Institute 2019; McArthur et al., 2020). In Study III, the quality of the individual studies was assessed using the Effective Public Health Practice Project (EPHPP) assessment tool for quantitative studies. (Thomas et al., 2004).

7 Overview of studies

7.1 Study I

Luomaniemi, K., Mattinen, A., McMullen, J., Sorariutta, A., & Hannula-Sormunen, M. (2021). The Effects of a SFON-Based Early Numeracy Program on Multilingual Children's Early Numeracy and Oral Language Skills. ***Journal of Cognitive Education and Psychology, 20*****(2), 138–160. https://doi.org/10.1891 /JCEP-D-20-00006.**

The study I aimed at assessing the effectiveness of Count How Many (CHM) intervention on the early numeracy and oral language skills of multilingual children. The program is designed to enhance SFON, counting and cardinality understanding in children aged 3 to 5 in ECEC. The effectiveness of the intervention has been demonstrated in previous research with monolingual children (Hannula-Sormunen, Nanu, et al., 2020). Using previously unanalyzed data from Hannula-Sormunen et al. (2020), Study I represents the first empirical attempt to examine the effectiveness of the intervention with multilingual children.

CHM intervention's effectiveness on multilingual children's (n = 16) early numeracy and oral language skills was evaluated in comparison to two monolingual control groups. The participants in the control groups were pairwise-matched to the experimental group's children based on age and pretest scores in numeracy. All participants in the control groups were monolingual. One control group (n = 16 participated in the CHM intervention, while other group (n = 16) took part in the early literacy intervention Let's Read and Talk. Both intervention programs consisted of an intensive training period lasting 5 to 6 weeks, followed by a rehearsal phase of 5 months. The structured small-group activities in both interventions were led by ECEC professionals who had received professional development training conducted by the researchers. The numeracy program's training focused on enhancing SFON, cardinality understanding, and counting skills, whereas the training in literacy program emphasized strategies for improving vocabulary acquisition and story comprehension. The activities progressed from adult-led demonstrations to encouraging active involvement and participation from children.

The pretest was conducted before the intervention period, the posttest seven weeks after the pretest, and the delayed posttest took place five months after the posttest. A repeated measures ANOVA was employed to analyze the differences in the development of SFON, cardinality-related skills, and oral language skills between multilingual children and the control groups. The findings indicated no statistically significant interaction between time and group for any assessed skills, suggesting that the numeracy and oral language skills developed similarly across all groups. Significant main effect of time was measured within all groups in all of the skills except for vocabulary. Following the promising results of both multi- and monolingual children improving their skills during the intervention, the multilingual group was investigated more closely. The focus was particularly on eight children who did not speak Finnish at home. An analysis of these individual children's test scores indicated that the CHM intervention had a particularly positive effect on children's number sequence production, even among those who scored very low on the vocabulary pretest.

The results indicate the potential for improving SFON tendency and cardinality-related in ECEC-aged multilingual children. Furthermore, children who did not speak Finnish at home showed an ability to actively engage in activities and make progress in numeracy measures, especially in the number sequence production. In addition, it was encouraging to note that the efforts invested in developing early numeracy skills did not hinder language learning. While the CHM intervention shows potential benefits for the numeracy skills of multilingual children, there are opportunities to improve it further. The CHM intervention was not specifically designed for multilingual children. Consequently, professional development in particular could be further enhanced by integrating research-based methods specifically designed to support the learning of multilingual children. In order to identify these research-based methods for improving the intervention, Study II was implemented.

7.2 Study II

Luomaniemi, K., Kankaanpää, S. & Hannula-Sormunen, M. (2023). Suosituksia monikielisten lasten varhaisten matemaattisten taitojen tukemiseen – Temaattinen synteesi. [Recommendations for supporting multilingual children's early mathematical skills – Thematic synthesis]. ***Journal of Early Childhood Education Research 12*****(3), 23–63. https://doi.org/10.58955/jecer.126173.**

The aim of the Study II was to explore and synthesize the recommendations from previous research for enhancing the early mathematical skills of multilingual children. A search of major databases identified five relevant articles published

between 2011 and 2020. Thematic synthesis (Thomas et al., 2017; Thomas & Harden, 2008) was chosen as the analysis method as it allows qualitative material to be organized and analyzed in detail. Through the analysis method, it was possible to first outline the different recommendations and then evaluate and analyze what should be considered in pedagogical planning in order to ensure that the activity supports the development of multilingual children's mathematical skills.

Using a three-stage process of thematic synthesis, the recommendations were first coded. Next, 12 descriptive themes were created and grouped into four categories: (1) strengthening mathematical agency with culturally responsible methods, (2) enabling math talk, (3) making the mathematical learning environment visible in everyday life, and (4) strengthening mathematical and academic language skills. The third phase involved constructing an analytical model based on the descriptive themes.

The analytic model suggests that in order to support the development of multilingual children's early mathematical skills, ECEC professionals should consider the following in their pedagogical planning: (1) Making mathematical activities culturally relevant. (2) Becoming aware of their own preconceptions about learning mathematics and language, and shifting the perspective from weaknesses to strengths. (3) Enabling versatile ways to participate in math talk on a regular basis.

The recommendations synthesized in this study contribute to the limited body of literature on the enhancement of early mathematical skills among multilingual children. This research was published in Finnish to address the notable scarcity of studies available in the Finnish language on this important topic. Furthermore, the recommendations are reflected with Finnish national core curriculum for ECEC. Therefore, the findings of this study can be used to inform the planning of pedagogical activities in ECEC. The findings may also support the creation of future interventions aimed at improving early mathematical skills in multilingual children.

7.3 Study III

Luomaniemi, K., Gegenfurtner, A., Kankaanpää, S., Lehtinen, E., McMullen, J. & Hannula-Sormunen, M. (2025). The effects of early mathematical interventions for 3–5-year-old multilingual children: A systematic review and a meta-analysis. PsyArXiv. https://doi.org/10.31234/osf.io/78zme_v2.

Study III presents the current state of early mathematical intervention research with multilingual participants. By conducting a systematic review and meta-analysis, this study aimed to clarify the effectiveness of early math interventions and provide useful insights for researchers and educators in this area. Previous systematic reviews and meta-analyses have primarily examined early mathematical interventions targeting monolingual participants (e.g., Nelson & McMaster, 2019;

Wang et al., 2016). Although some studies have included multilingual participants, the interventions addressed in these reviews have largely been non-mathematical in nature (e.g., Buysse et al., 2014; Richards-Tutor et al., 2016). This gap in the research highlighted the need for a systematic review and meta-analysis that would focus specifically on the efficacy of early mathematical interventions with multilingual participants

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021) were followed in the search process. In order to capture all relevant studies, the search was conducted without date restrictions and included both peer-reviewed journals and gray literature, encompassing conference proposals and unpublished manuscripts. The study was included in the systematic review if it involved 3- to 5-year-old multilingual children, either as the main focus or as a subgroup. Additionally, the intervention needed to be designed to enhance mathematical skills and conducted within ECEC context. For a study to be included in the meta-analysis, it had to meet all of the above criteria and provide data sufficient for calculating the effect size.

The systematic review included 24 studies. The quality of the individual studies was assessed using the EPHPP evaluation tool (Thomas et al., 2004). To develop a comprehensive understanding of the studies included, the study's purpose, a brief description of the intervention, and the key findings were outlined. The information retrieval was then proceeded by coding the basic information of the studies, participant characteristics, general intervention characteristics, mathematical content, instructional features, outcome measures, and specific instructional features related to multilingual participants. The specific instructional features selected for investigation included: using mathematical language, using children's home language, and adopting a culturally responsive approach. These features were selected because they consistently emerged as significant in previous reviews and expert insights on supporting multilingual children's math skills. Additionally, they represent actions that practitioners could integrate into ECEC's daily routines.

The studies included in the systematic review ($N = 24$) were published between 2006 and 2021. Fifteen studies were conducted in the United States, four in Australia, and one each in Paraguay, Finland, Turkey, Peru, and Luxembourg. All interventions, except one, included a numeracy component, making numeracy the most widely studied mathematical domain. This was followed by geometry, measurement, and patterns. When examining specific instructional features related to multilingual participants, the most frequently used method was the use of mathematical language.

After the systematic review, a meta-analysis was conducted. Seven studies were excluded from the meta-analysis as they did not yield sufficient data for calculating effect sizes. Therefore, the meta-analysis was conducted with a subset of 17 studies.

A random-effects model was used, as it allows for the consideration of a distribution of true effect sizes rather than presuming that a single true effect size encompasses all the interventions (Borenstein et al., 2009). To assess publication bias in the results of the meta-analysis, the 'remove one study' method, a funnel plot, and the classic fail-safe N analysis were employed.

The average weighted effect size was found to be small (g = 0.46, 95% *CI* 0.32, 0.59) according to Cohen's (1988) criteria. The variation in effect sizes suggested that there were systematic differences between the studies. In further analysis the following factors were considered as potential moderators: intervention design (for multi- or monolingual children), control group, sample size, group size, duration, instructional approach (traditional or computer-based), and mathematical content. However, no significant associations with effect size were found for any of these moderators, except for intervention duration. The results indicated that the most effective interventions were those lasting the entire school year. Furthermore, one of the aims of the study was to examine whether the specific instructional features related to multilingual participants were linked to greater effects. However, none of these resulted in significant differences in subcategory comparisons.

The average weighted effect size in the current meta-analysis was smaller compared to the effect sizes found in previous meta-analyses including studies focused on early mathematical interventions with monolingual children (Nelson & McMaster, 2019; Wang et al., 2016). These findings suggest that current interventions with multilingual participants may require enhancements to achieve greater effectiveness. The current systematic review and meta-analysis revealed that interventions employing mathematical language, home language, or culturally responsive instructional approaches were marginally more effective than those that did not utilize these features. However, no statistically significant differences were identified. One potential explanation for this finding is the limited number of studies included, which may have impacted the moderator analyses. Previous research suggests that incorporating mathematical language, children's home language, and culturally responsive instructional approach support multilingual children's mathematical skills. However, further interventions in ECEC settings are necessary to better understand the effectiveness of these practices for young multilingual learners.

8 Main findings and discussion

The primary aim of this dissertation was to enhance our understanding of how to support multilingual children's early mathematical skills in ECEC. This was achieved by first testing whether an early numeracy intervention, originally designed for monolingual children, would also be effective in multilingual participants (Study I). The results were promising, but conducting the study raised the question of how future interventions could be modified to better acknowledge the needs of multilingual learners. Therefore, in Study II, the aim was to find instructional practices that have been recommended in the previous literature for supporting early mathematical skills in multilingual children. The limited and scattered nature of research on the early mathematical skills of multilingual children became apparent during Studies I and II. This observation aligns with previous research that also struggled to identify studies focusing specifically on the mathematical learning of young multilingual children (Bonifacci et al., 2016; Cross et al., 2009; Richards-Tutor et al., 2016). Thus, there seemed to be a clear need for a systematic review and meta-analysis to gather research on mathematical interventions involving ECEC-aged multilingual children (Study III). A systematic review was conducted to examine and describe the mathematical content and instructional practices currently used in early mathematical interventions for multilingual participants. Additionally, a meta-analysis was conducted to examine the efficacy of these interventions in enhancing children's early mathematical skills.

The overall results across these three studies suggest a need to refine existing early mathematical interventions to better support the learning of multilingual children. By refining these programs, more inclusive and effective educational experiences for all learners could be created. The reviewed intervention research does not seem to rely on the principles recommended in the previous literature for supporting multilingual children's early mathematical skills development. As a result, the effectiveness of these recommended approaches cannot be reliably demonstrated based on existing interventions. Furthermore, given that the existing recommended practices are forced to rely on studies conducted on school-aged multilingual students or the expertise gained by working with ECEC-aged

multilingual children, it is clear that more research is needed to test these recommendations in practice.

Study I tested how the Count How Many (CHM) intervention, originally planned to support monolingual children's early numeracy skills, would work with multilingual participants. Importantly, in the CHM intervention, supporting the development of SFON tendency and cardinality understanding is systematically integrated into everyday situations. By contextualizing mathematical concepts within familiar environments and activities, the intervention enhances children's mathematical skills while reducing potential language barriers. The activities in CHM intervention, such as noticing numerosities from the ECEC environment, provide excellent opportunity for children to actively participate even with a limited vocabulary in instructional language. In the activities, it is possible for children to engage also by using gestures or their home language. Therefore, it was hypothesized that the intervention might be effective also to multilingual children.

The main finding in Study I was that there was similar development in mathematical and oral language skills between the multilingual group and the matched monolingual groups of children. The positive outcome was that even children who did not speak the instructional language at home and scored low on the vocabulary pretest were able to develop their numeracy skills during the intervention period. The number sequence production especially showed positive development, which suggests that focusing on learning number words could be an effective starting point for children with low language proficiency in the instructional language when they enter ECEC. This could provide them with opportunities to actively participate in mathematical activities, leading to positive learning experiences, which could be less common in other, more language-demanding activities (see, e.g., Moschkovich, 2015). However, if the CHM intervention had been optimal for multilingual children, it is likely that greater improvements in numeracy skills would have been observed in multilingual children participating in the CHM intervention, compared to the skills of matched monolingual children in the early literacy program. The lack of significant differences between the groups suggests that some activities require refinement to better accommodate language diversity. Although the CHM intervention demonstrated potential for improving the numeracy skills of multilingual children, the findings suggest that there remains potential for program enhancement.

This was the starting point for Study II. The results of the CHM intervention study, along with insights from prior research (Abdulrahim & Orosco, 2020; Alisaari et al., 2019; Castro & Prishker, 2019; Kirsch et al., 2020), imply that monolingual pedagogical approaches often fall short in effectively supporting the learning of multilingual children. Therefore, Study II aimed to identify the instructional

practices recommended in the existing literature to enhance early mathematical skills in multilingual learners.

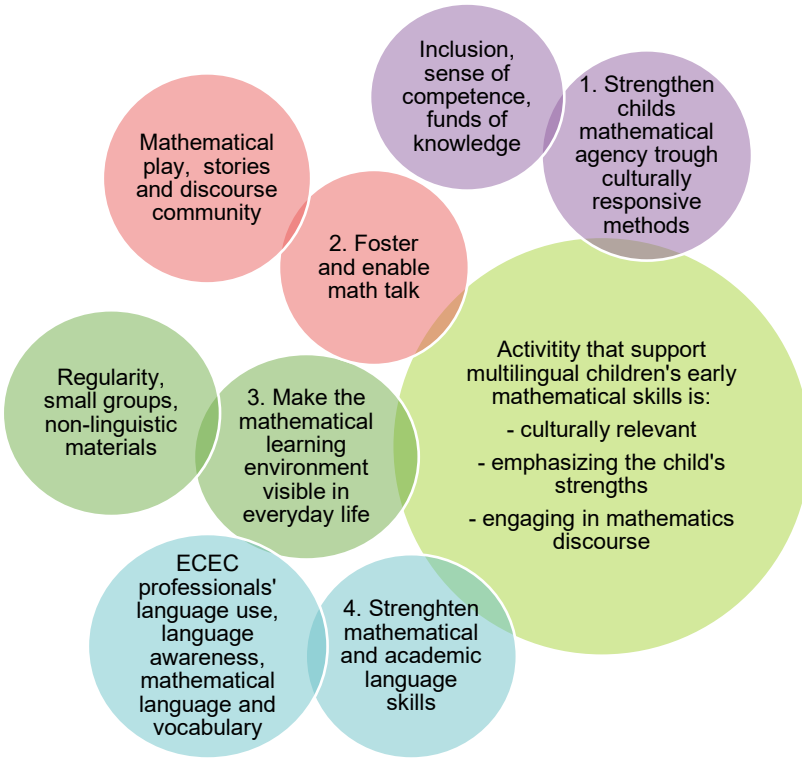


Figure 6. Synthesis of the recommendations for supporting multilingual children's mathematical skills in ECEC (Luomaniemi et al., 2023).

The main findings of Study II are presented in Figure 6, which summarizes the results of the thematic synthesis of current recommendations for supporting early math skills in multilingual children. The largest circle presents the three principles that should be considered in pedagogical planning in ECEC when the aim is to support multilingual children's early mathematical skills. The pedagogical practices recommended to support multilingual children's early mathematical skills in ECEC 1) are culturally relevant, 2) emphasize multilingual children's strengths, and 3) lead to engagement in mathematical discussions. Mathematical activities can be made culturally relevant by identifying children's interests and integrating the children's culture into the mathematical activities, for example, by working with the children's families. It is also important to be aware of any misconceptions about multilingual children as learners of mathematical and linguistic skills. Confidence in the children's skills and emphasizing their strengths can foster positive math self-

efficacy, which not only enhances their mathematical abilities but also benefits other areas of learning (see, e.g., Korpipää et al., 2021). In addition to culturally relevant activities and an asset-based view of multilingual children's abilities, the third issue to consider in pedagogical planning is the importance of math talk. Children should be given regular opportunities to engage in mathematical reasoning using their entire communicative repertoire. It is particularly important to focus on mathematics in children's responses rather than on the correct language and to reinforce the image of themselves as skilled and active members of the group.

The circles numbered 1–4 in Figure 6 describe the themes that should be seen in versatile practices during the whole ECEC day. These practices could be evident in ECEC's everyday activities when ECEC professionals (1) strengthen children's mathematical agency through culturally responsive methods, (2) foster and enable math talk, (3) make the mathematical environment visible in everyday life, and (4) strengthen children's mathematical and academic language skills.

The outermost circles in Figure 6 represent the practical implications for ECEC professionals, detailing how recommendations can be implemented in ECEC. This occurs by utilizing children's and their families' funds of knowledge – that is, the knowledge and information that linguistically and culturally diverse families possess (Lewis, et al., 2020), implementing mathematical play and mathematical stories to build a mathematical discourse community, putting effort on the regularity of the mathematical activities, using small groups and non-linguistic materials, paying attention to language use by supporting the development of everyday language, mathematical language, and academic language, and making the children's different home languages visible in ECEC. These pedagogical practices are described in more detail in the original Study II (Luomaniemi et al., 2023). The results of Study II complement the Finnish national core curriculum's (National Agency of Education, 2022) methods for supporting early mathematical skills in ECEC (see Figure 4, pp. 35) by combining multilingual pedagogies, including language-aware and culturally responsive methods, to support early mathematical skills.

Study III was conducted to assess the current state of intervention research related to early math learning for multilingual children. Previous reviews and meta-analyses were found to concentrate mainly on two areas: early mathematical interventions with monolingual participants (e.g., Nelson & McMaster, 2019; Wang et al., 2016) or interventions with multilingual participants unrelated to mathematics (e.g., Buysse et al., 2014; Richards-Tutor et al., 2016). Moreover, when reviews addressed the mathematical skills of multilingual children, they typically involved participants of school age (e.g., Sharma & Sharma, 2023). Thus, the purpose of Study III was to fill this research gap by compiling the current research on mathematical interventions specifically for ECEC-aged multilingual children.

The findings indicated a growing interest in supporting multilingual children's early math learning over the last decade, as 19 out of 24 intervention studies were published after 2014. The findings regarding the mathematical content of the interventions were in accordance with the comprehensive literature review conducted by Parviainen (2019). The review by Parviainen showed that numerical skills were the most frequently studied category of mathematical skills, while spatial thinking skills, along with mathematical thinking and reasoning skills, received less attention. This pattern remained true when early mathematical intervention research involving multilingual children was examined. The emphasis on numerical skills is understandable, as early numeracy skills have been shown to be the best predictor of later mathematics achievement (Nguyen et al., 2016). However, as Parviainen (2019) argued, spatial thinking skills, along with mathematical thinking and reasoning skills, should receive more attention because these abilities develop simultaneously and are interrelated (see, Parviainen, 2024).

When examining the instructional features suggested to be effective by previous reviews (Arizmendi et al., 2021; Banse, 2021; De Araujo et al., 2018) and experts in the research field (Cummins, 1979; Moschkovich, 2013) in supporting multilingual children's learning, we found that using mathematical language was most frequently integrated into the interventions, whereas using children's home language and using a culturally responsive instructional approach received much less attention. This indicates that, even though there are some findings from previous research on how to support multilingual children's mathematical skills, these practices are not yet widely used and tested in current intervention studies. Testing these approaches in the ECEC context would be crucial, as previous reviews and experts in the field have primarily drawn on research involving school-aged multilingual students.

The meta-analysis conducted with a subset of 17 studies revealed a small overall effect, based on Cohen's (1988) criteria, of the interventions on multilingual children's mathematical skills. Notably, these interventions involving multilingual participants demonstrated a smaller general effect size compared to the results of previous meta-analyses, including interventions involving mostly monolingual participants (Nelson & McMaster, 2019; Wang et al., 2016). This comparison of effect sizes adds to the evidence that current intervention research has found effective methods to support monolingual children's early mathematical skills, but there may be room for improvement when the participants are multilingual. Thus, there is an opportunity for further investigation to improve the effectiveness of interventions in multilingual contexts. Unfortunately, a limited number of studies posed a challenge in conducting the moderator analyses in the meta-analysis. Whether the interventions using mathematical language (n = 10), home language (n = 5), or culturally responsive instructional approaches (n = 2) would be more effective than those that did not use these features was investigated. However, no

statistically significant differences were found in any of these three features. This could have been due to these analyses using a small subset of included studies, which could have contributed to the potentially non-significant differences between the subgroups.

8.1 Theoretical and practical implications: Shifting from monolingual practices to a multilingual perspective

Social interactions and collaborative practices (Vygotsky, 1978) play a significant role in learning of mathematical skills in ECEC. A situated and socio-cultural approach by Moschkovich (2002) highlights, that multilingual children bring their own rich meanings and prior experiences to mathematical learning situations. In these everyday learning situations, the more knowledgeable individuals, often ECEC professionals, should provide support that aligns with children's mathematical skill development. To effectively work within the zone of proximal development (Vygotsky, 1978) especially with multilingual children, it would be essential for ECEC professionals to possess knowledge of mathematical learning trajectories (Clements & Sarama, 2020) as well as an understanding of children's cultural and linguistic, backgrounds (Moschkovich, 2002). However, the diverse cultural and linguistic backgrounds of children in ECEC present challenges for today's pedagogical practices, which often still rely on a monolingual perspective (Aerila et al., 2024; Kirsch & Seele, 2020). Notably, these challenges may also involve the risk of overlooking the potential positive effects of the child's language and cultural background. For example, there are cultures where mathematics is highly appreciated or languages where the transparency of the number naming system could be a benefit when learning base-10 framework (Hu et al., 2018; Schiltz et al., 2024). The monolingual perspective in pedagogical practices might miss these resources when supporting children's early mathematical skills.

Although the national core curricula for primary and secondary education (National Agency of Education, 2014) as well as ECEC (National Agency of Education, 2022) include principles that guide the shift to a multilingual perspective, the ECEC practices in Finland (Aerila et al., 2024; Repo et al., 2024) and internationally (Kirsch et al., 2020) seem to be guided by the norm of monolingualism. The same applies to classroom interactions in schools in Finland (Alisaari et al., 2019; Latomaa & Suni, 2011; Lehtonen, 2021) and internationally (Bartell et al., 2017; Jørgensen, 2008). This could be one reason for the achievement gap in mathematical skills between multi- and monolingual children, as shown by recent assessment studies (OECD, 2016, 2023; Ukkola & Metsämuuronen, 2019, 2021). Traditional monolingual practices do not optimally support the learning of

multilingual students (Abdulrahim & Orosco, 2020; Alisaari et al., 2019; Castro & Prishker, 2019; Kirsch et al., 2020).

This view can be validated by the findings of the current dissertation. Our findings show that there are recommendations for supporting multilingual children's mathematical skills, but the use of these recommended practices in the current intervention research seems to be limited. This study cannot yield conclusive evidence of whether the recommended practices will positively affect the early mathematical skills of multilingual children. However, the results from the assessment studies (OECD, 2016, 2023; Ukkola & Metsämuuronen, 2019, 2021) show that the current practices in ECEC and schools could need refining. Supporting the basic skills already in ECEC is particularly important for mathematical skills, as mathematics is an area of learning in which new knowledge is strongly based on what has already been learned. Thus, falling behind in the first grade can affect children's learning motivation and self-efficacy in mathematics, which could then have a negative effect on children's future academic performance (see, e.g., Koponen et al., 2020, 2024).

The findings of this dissertation provide an opportunity to bridge the gap between language policies in the national core curriculum for ECEC and the practical pedagogical approaches utilized in ECEC centers. Policy documents, such as the national core curriculum for ECEC, have acknowledged the growing number of multilingual children by providing guidelines for language awareness. However, these documents do not appear to provide ECEC professionals with sufficient practical guidance on how to incorporate multilingual pedagogy into daily activities and pedagogical situations (Aerila et al., 2024; Lehtonen, 2021; Repo et al., 2024) or in various learning areas, such as mathematical skills. In the current education context in Finland, the successful implementation of language-aware principles outlined in the curriculum seem to depend largely on the engagement, motivation, and skills of ECEC professionals to adjust their pedagogical approaches (Alisaari & Heikkola, 2020; Harju-Autti et al., 2022; Repo et al., 2024).

The insights derived from Study II are designed to facilitate ECEC professionals in their pedagogical planning to enhance the mathematical skills of multilingual children. By incorporating a multilingual perspective into early mathematical education, this dissertation aims to elevate daily practices in ECEC. The synthesized recommendations are based on the best available evidence and offer clear strategies to support the crucial development of early mathematical skills in multilingual learners. Using these findings could create a more inclusive and effective learning environment for all children.

8.1.1 Implications for teacher education and professional development

The language policies presented in the national core curriculum for ECEC have yet to be effectively integrated into the practical work of in-service ECEC professionals (Aerila et al., 2024; Repo et al., 2024). A similar disconnect between policy and practice is evident in Finnish teacher education (Alisaari et al., 2024). It would be important to offer pre-service teachers research-based instruction that enhances their understanding of conducting multilingual pedagogies in practice across all learning areas. The findings of this dissertation could be utilized in teacher education programs to complement courses focused on mathematics in early childhood and pre-primary education. It would be important to adopt meaningful approaches and methods in pre-service education that recognize the diverse linguistic and cultural backgrounds of children in their learning of content knowledge, such as mathematics.

As stated earlier, it appears that the implementation of language policies has been placed primarily on the shoulders of ECEC professionals and teachers. However, there is an urgent need for professional development, as these principles do not automatically translate into effective pedagogical practices. Alisaari and Heikkola (2020) examined the perceptions of primary and lower and upper secondary teachers (n = 627) on the effect of language on learning and their ability to use linguistically responsive teaching methods (Lucas & Villegas, 2011, 2013). In their survey, 87% of the teachers reported not receiving any training on the subject. A similar trend can be detected in the ECEC context (Chapman De Sousa, 2017; Pontier et al., 2020). Numerous ECEC professionals feel insecure due to their limited experience with multilingual children and their families (Bergeron-Morin et al., 2023). Bergeron-Morin et al. (2023) suggested that participating in continuous professional development could significantly enhance the quality of pedagogical practices directed toward children and their families.

Bergeron-Morin et al.'s (2023) recommendation for professional development in ECEC focused on integrating multilingual pedagogy into daily activities, whereas Parviainen et al. (2024) explored the effects of professional development specifically designed to enhance ECEC children's early mathematical skills. Their study demonstrated that training for ECEC professionals significantly expanded children's opportunities to engage regularly with a diverse range of mathematical concepts in ECEC settings. Looking ahead, there is a clear need for a professional development program that effectively merges these two important areas.

The insights gained from this dissertation provide a strong foundation for developing high-quality, research-driven professional development programs. By offering the latest pedagogical content knowledge related to the development of early

mathematical skills combined with a multilingual perspective, it is possible to foster a more inclusive and effective learning environment for all children.

Enhancing the understanding of mathematical skill development and the principles of multilingual pedagogy among ECEC professionals is important. This knowledge helps to identify children's zones of proximal development, enabling caregivers to provide appropriate support when needed (see Vygotsky, 1978). Familiarity with both mathematical content and multilingual pedagogy may increase ECEC professionals' sensitivity to effectively utilize the learning environment, children's initiatives, and their cultural and linguistic resources to promote mathematical thinking. By actively engaging in mathematizing children's world and solving problems that demand mathematical skills, ECEC professionals could significantly foster children's mathematical development (Björklund & Palmér, 2024; Mattinen, 2006). Research-based knowledge on the development of early mathematical skills, using playful activities, and mathematizing everyday situations have been the key methods in effective early mathematical interventions for monolingual children (Clements & Sarama, 2020; Hannula-Sormunen et al., 2020). The findings of this dissertation provide insights into how to engage multilingual children in mathematical discussions that arise from spontaneously focusing on numerosities and mathematizing everyday situations related to their own world and experiences.

8.1.2 Implications for future early math interventions

The findings of this study suggest that the interventions with multilingual participants do not work as effectively as the interventions with monolingual participants. Moreover, the practices that previous research and experts in the field have suggested to be effective in multilingual children's learning of mathematical skills are rarely used in the current intervention research. Previous research (Bergeron-Morin et al., 2023; Kirsch et al., 2020) has indicated that multilingual practices do not hinder the learning of monolingual children. In fact, these practices provide monolingual learners with opportunities to benefit from knowledge of other languages and enrich ECEC groups. As a result, the learning experiences of all the children involved are enhanced. This benefit also extends to the development of mathematical skills. Research has shown that instructional practices that respond to school-aged students' cultural and linguistic needs contribute positively to their mathematics performance (Abdulrahim & Orosco, 2020). However, this approach has not been fully tested in ECEC settings. Therefore, future early mathematical interventions should use recommended practices, such as using mathematical language, children's home language, and a culturally responsive instructional approach. This would provide more evidence of whether these practices also work

with ECEC-aged multilingual children. The findings from the meta-analysis conducted in Study III suggest that the effectiveness of existing interventions can still be improved. Thus, the recommended practices detailed in Study II can serve as a foundational framework for the development of novel interventions and enhance existing interventions to more effectively address the needs of multilingual children.

To better meet the needs of multilingual learners, a small-group activity from the CHM intervention was chosen as an example of how early mathematical interventions can be refined. The Vegetable Market (see Table 3) is a structured, adult-guided activity in which children play different roles, such as salespersons and customers. In the activity, children are rehearsing counting, cardinality understanding, re-counting as well as memorizing. The main aim of the activity is to foster SFON tendency in all children. The adult who is guiding the situation gives the customer a shopping list with a picture of one to seven similar vegetables and asks the child to find out how many vegetables they need to buy. The child memorizes the number of vegetables and goes to the market without the shopping list. Then the child asks the salesperson to give them the vegetables. As the child arrives back home, the adult asks the child to recount the vegetables and make sure they have the same number as in the shopping list. The activity can be modified to children's skill level by adding or decreasing the number of vegetables in the shopping list, asking the child to bring several different kinds of vegetables from the market or including money and prices to the activity. Additional roles for children to play could be introduced, such as drivers or warehouse workers. These roles would also involve participating in mathematical discussions and problem-solving, such as counting the passengers or determining the number of vegetables needed to restock the sales table.

These suggestions to improve the Vegetable Market activity in Table 3 are based on the recommendations synthesized from former literature (Celedón-Pattichis, 2018; Clements et al., 2018; Lee et al., 2011; Lewis et al., 2020; Murphey et al., 2017) in Study II. This example illustrates the potential for refining playful and engaging mathematical activities in interventions or within ECEC to better support the learning of multilingual children through relatively straightforward adjustments. It is hoped that this example could guide the designing of future early mathematical interventions to explore and implement these practices across a variety of intervention activities, fostering inclusive learning experiences for all children.

Table 3. CHM intervention's (Hannula-Sormunen, et al., 2020) Vegetable market activity refined according to recommendations.

<table>
<tr><td colspan="2">Vegetable market
 
Aims:
- To foster children’s SFON tendency
- To practice counting, cardinality understanding, re-counting and memorizing
Methods:
- Using “how many”-questions as directors of attentional focus
- Using exact number recognition in a meaningful and playful activity
- Practicing enumeration in the zone of proximal development</td></tr>
<tr><th>Refinement:</th><th>Purpose:</th></tr>
<tr><td>Sending the children to vegetable market in pairs.</td><td>To add math talk as the pair could discuss and help each other in counting and discussing with the salesperson.</td></tr>
<tr><td>Pairing multi- and monolingual child.</td><td>To promote translanguaging and appreciation for different languages among children. A monolingual child may serve as a language model in instructional language, while a multilingual child can teach number words to their peers and interact with a salesperson in their home language.</td></tr>
<tr><td>Encouraging to use all the communicative repertoire the child has.</td><td>To help children understand math concepts and engage in shared mathematical discussions. Children can use their fingers, gestures, or visual aids to communicate how many vegetables they need.</td></tr>
<tr><td>Using vegetables or fruits that are children’s favorites and/or typical to children’s home countries.</td><td>To add cultural responsiveness and make the activity more engaging by taking into account children's suggestions and opinions.</td></tr>
<tr><td>Asking caregivers to list the numbers from one to ten in their home language along with typical fruits or vegetables their family buys from the market.</td><td>To inform caregivers about the mathematical activities conducted in ECEC as well as show that every language and culture are appreciated.</td></tr>
<tr><td>Giving children time to communicate, encouraging for thinking aloud, making the atmosphere safe to speak up and make mistakes, correcting the possible mistakes together in a respective way.</td><td>To build a math talk community, where children feel safe to participate in the activities.</td></tr>
<tr><td>Repeating and extending children’s answers and modifying questions according to children’s mathematical and language skill level.</td><td>To support and stimulate children's thinking by using suitable open and closed questions and potentially extending the responses.</td></tr>
<tr><td>Making all the children feel like capable problem-solvers.</td><td>To encourage children to engage in learning and participating in shared activities. At the same time, children are given the opportunity to take pride in their own abilities.</td></tr>
<tr><td>Finding the math from the children’s answers, not focusing on the correct language.</td><td>To allow children to participate in the conversation in their own way. The transition from gestures, drawings, co-use of home language and language of instruction, and everyday language to academic mathematical language is gradual and requires support from the ECEC professionals.</td></tr>
</table>

Note. Image by Sirpa Lehti, in Mathematical learning environment for early education in-service online course (Hannula-Sormunen, et al., 2020).

8.2 Limitations and future studies

The findings of this dissertation may be subject to limitations that may influence the conclusions drawn from the studies conducted. Three themes emerged throughout this research project that could be seen as limitations: the small sample size, the overrepresentation of previous studies set in the US context, and the diversity of multilingual children. In addition to these themes, the strict focus on the ECEC environment could also be seen as a limitation. Despite the existence of a substantial body of research indicating the effects of the home environment on the development of children's early mathematical abilities (e.g., Mutaf-Yıldız et al., 2020; Torppa et al., 2025), a deliberate decision was made to focus exclusively on the supporting practices implemented within the ECEC context. This decision was made to maintain a coherent focal point throughout the dissertation.

8.2.1 Small sample size

The small sample size is a limitation that can be connected to all three sub-studies. Study I utilized previously unanalyzed data from a larger sample used in Hannula-Sormunen et al.'s (2020) study. As there were only 16 multilingual children in the original sample, we found it important to match the control children based on age and the numeracy measures at pretest to enable group comparisons. However, there were not enough multilingual children in the control groups; thus, matching the children's language backgrounds was not possible. Although these results in Study I should be taken with caution and replicated with larger samples, this intervention study could work as a good starting point in developing future interventions aimed at enhancing multilingual children's early numeracy skills. Regarding the participants in future studies, future data collection should be designed to include sufficient multilingual participants for both the experimental and control groups. In addition, previous research (Bialystok et al., 2018; Kirsch et al., 2020) highlights the potential benefits of practices designed for multilingual participants on monolingual children as well. Therefore, it would be beneficial to include monolingual participants in the sample and analyze their results as a distinct subgroup. This inclusion could offer valuable insights into how interventions grounded in multilingual pedagogies promote mathematical skills not only in multilingual but also in monolingual children, ultimately contributing to more inclusive educational practices.

Furthermore, in future studies, recognizing the diverse language profiles of multilingual children presents an opportunity to enhance the validity of measuring children's skills before and after the intervention. Allowing children to complete the assessment in their home language or a language they are comfortable using for mathematical communication can be instrumental in reducing possible

language barriers. This approach has the potential to provide a more comprehensive understanding of the children's mathematical abilities, ensuring that valuable skills are not overlooked due to possible language-related challenges (Schiltz et al., 2024).

The results of Study II should also be interpreted with caution, as the synthesized recommendations were based on only five studies. However, due to the limited previous research on supporting multilingual children's early mathematical skills, finding more studies meeting the inclusion criteria could have been impossible. The small amount of empirical research in the field also affected the recommendation articles included in Study II, as the authors based their recommendations not only on previous empirical research but also on the authors' own expertise, interviews with experts, and recommendations developed for older students. Therefore, the risk of bias assessment was conducted carefully, first, by using the Joanna Briggs Institute's (2019) "Checklist for textual evidence: Expert opinion" and, second, by ensuring that the recommendations of different articles were not based on just a few empirical studies by comparing the reference lists of recommended articles to avoid overemphasizing a few earlier studies, which could lead to incorrect conclusions (Polanin et al., 2017). Two researchers independently evaluated each study, following the directions of the Joanna Briggs Institute's (2019) checklist, and discussed the results of the evaluation. Based on the discussion, it was concluded that, although there was a shortage of referencing to prior evidence, the recommendation articles nevertheless represented the best current evidence in the topic area.

The strict criterion of including only recommendations aimed at early mathematical skills for young multilingual children may have led to the exclusion of articles that provided more general recommendations applicable to all age groups of multilingual children. This criterion also excluded recommendations intended for supporting the mathematical skills of school-aged multilingual students. While it is acknowledged that including all relevant articles without a specific age-related target group could have generated larger data, it might have made the recommendations harder to adjust to the ECEC environment, where learning experiences often take place outside of structured classroom teaching, especially in the Finnish context (Hannula-Sormunen et al., 2020; Hannula et al., 2005). In the future, as research expands on early mathematical interventions in multilingual children, it would be important to update recommendations so that are firmly rooted in the latest outcomes of intervention studies. In the future, as research expands on early mathematical interventions in multilingual children, it would be important to update recommendations so that they are firmly rooted in the latest outcomes of intervention studies. Another important and valuable future research idea related to supporting multilingual children's early mathematical skills would be to synthesize and analyze recommended practices for enhancing these

skills in the home environment. Having research-based knowledge of effective methods for both ECEC and home environments would ensure a more comprehensive mathematical learning environment for children, creating a stronger foundation for future mathematics learning at school.

The sample size can also be considered a limitation of the meta-analytic review (Study III). The meta-analysis was conducted based on a subsample of 17 studies, which provided adequate data for effect size calculations. As the limited number of studies could be affected by the randomness of the available research, the results should be interpreted with caution. Even if all available studies had been included, it is possible that the outcomes would still be affected by random variations in the study characteristics. This aspect is particularly significant in moderator analyses that rely on smaller subsets of studies, which could result in non-significant differences between subgroups in the meta-analysis (see, e.g., Schmidt & Hunter, 2015). The "file drawer problem," a typical limitation of meta-analyses, was also acknowledged. This problem relates to the fact that studies with non-significant or negative effects are often not published (Rosenthal, 1979). Despite efforts to address this issue by searching for unpublished manuscripts and conducting a classic fail-safe N analysis, an estimation of how many missing studies would be necessary for the mean effect size to lose its statistical significance, it remains a factor that could potentially affect the findings. It must be emphasized that in order to acquire greater evidence in this area, large-scale randomized controlled trials should be conducted in the future to assess the effectiveness of early mathematical interventions for multilingual participants.

8.2.2 US-focused research field

It should be noted that the five recommendation articles used as data in Study II were all set in the US context, in which the education system is different from that in Finland. Therefore, the generalizations of the recommendations should be done with caution, and the recommendations should be reflected against the different cultures and education systems. Although the thematic synthesis brought together recommendations from the international literature and complemented the extremely limited literature published in the Finnish language on supporting multilingual children's early mathematical skills, more research on this topic is needed, especially in the Finnish context and internationally. In Study III, the United States was found to be the leading country in this area of research. In the systematic review, 15 of the 24 intervention studies were conducted in the United States. Due to its large Latino population, the United States presents a unique context compared with other countries. In 2010, 66% of multilingual learners were Spanish speakers (Pandya et

al., 2011). This emphasizes the need for more global research on early mathematics interventions to incorporate greater cultural and linguistic diversity in the field.

8.2.3 The multilingualism issues

This dissertation has demonstrated the significance and necessity of the research topic, as language diversity has become an integral aspect of education worldwide (Barwell et al., 2019). Although research on mathematics education in relation to language diversity has garnered increased attention over the past 20 years (Barwell et al., 2019), there are still many areas that require further investigation. One of these areas is the mathematical skills of ECEC-aged multilingual children. When starting the current research project, it became apparent that a relatively new research tradition could pose some challenges. One of these challenges was choosing the optimal term for describing children learning more than one language in their childhood and whose home language is different from the country's dominant language(s). The term "multilingual children" was chosen because it appears to have gained widespread acceptance in recent studies in the field (e.g., Bergeron-Morin et al., 2023; Celedón-Pattichis et al., 2022; Repo et al., 2024). However, it is not only the variety of different terms used in the research field that can be seen as challenging.

In Study I, the experimental group consisted of 16 multilingual children. The parents reported 14 different home languages among this group, including English, Swedish, Arabic, Russian, French, and Spanish. When broadening the perspective to the United States, studies have indicated that children aged 0–8 years who have at least one parent speaking a language other than English at home belong to over 350 language groups. These children come from a diverse range of cultural backgrounds and socioeconomic levels within American society, although they are more likely to live in low-income households (Lewis et al., 2020). Consequently, when referring to multilingual children as a group, they encompass extremely heterogeneous linguistic and cultural backgrounds. Therefore, designing pedagogical practices that can equally support all of these children is challenging. However, this does not take away from the research aimed at supporting these children's early mathematical or academic skills in general. There is no "one-size-fits-all" approach in education, but there are many different approaches that can be useful in supporting the early learning of this diverse group of children. In the current research, we focused on presenting supportive practices for mathematical skills, aiming to add more tools to ECEC professionals' toolkits.

In multilingual educational contexts, such as Luxembourg and Singapore, individuals often become proficient in multiple languages, a skill that is widely regarded as an asset (Bialystok, 2018). However, the diverse nature of multilingual

children poses challenges in both education and research. Multilingualism exists on a spectrum, resulting in a wide variety of language learner profiles (Schiltz et al., 2024). Therefore, designing an early intervention that benefits all children is complex. When assessing the impact of multilingualism on foundational mathematical skills, several factors should be considered, including the quantity and type of language exposure, the grammatical structures of the languages involved, and the transparency of number systems in different languages (Dowker & Nuerk, 2016). For example, the number 11 is expressed as "ten-one" in Vietnamese, while in English it is called "eleven." In languages with transparent number systems, the names of numbers are closely aligned with the base-10 framework, making it easier for children to understand and process numerical concepts (Schiltz et al., 2024).

To enhance our understanding of how early mathematical interventions can effectively support multilingual children from diverse backgrounds, it is essential for future research to collect comprehensive information about children's prior mathematical experiences, as well as their cultural and linguistic resources (De Araujo et al., 2018; Moschkovich, 2012). Schiltz et al. (2024) have made a valuable contribution by developing a questionnaire for numerical cognition researchers operating in multilingual settings. It enables researchers to gather and share important details regarding participants' language backgrounds. They suggest exploring children's language status by collecting data on the number of languages spoken by individuals, the order and age of language acquisition, daily usage patterns, and personal language preferences, such as communication with family members or the preferred language for counting (Schiltz et al., 2024). This approach has the potential to deepen our understanding of the specific background factors that influence the development of early mathematical skills. Additionally, it can shed light on how effective mathematical activities are within interventions for children from different backgrounds, ultimately leading to more effective strategies for supporting young multilingual learners.

8.3 Conclusion – Bridging the gap

Overall, the findings indicate that there is potential to enhance the early mathematical skills of multilingual children through interventions conducted in ECEC. However, it appears that the current interventions involving multilingual participants are not as effective as those conducted with monolingual participants. Therefore, it is essential to refine these interventions to better address the needs of multilingual learners. One possible approach is to incorporate the recommended practices synthesized in Study II (e.g., using mathematical language, children's home language, and a culturally responsive instructional approach) into future interventions to establish a stronger evidence base regarding their effectiveness in multilingual learners.

This dissertation intends to begin bridging the gap in knowledge about effective strategies to promote early math learning among multilingual children in ECEC. The findings of this study are not only academic; they could also hold great significance for policymakers. By complementing current curricular language policies, we can ensure that multilingual pedagogies are integrated across different learning areas, particularly mathematics, thus fostering a more inclusive educational environment.

In addition, this study is relevant for ECEC professionals. It bridges the distinctive divide between the national core curriculum's guidance on language awareness and the enhancement of early mathematical skills. Combining these essential areas offers practical strategies that ECEC professionals can implement in their pedagogical planning, thereby enriching the learning experience of all children. This research also lays a strong foundation for future professional development and pre-service education. It provides the current best evidence on how to support multilingual children's early mathematical skills, giving practitioners tools to enhance multilingual children's educational outcomes in ECEC.

Above all, this study is dedicated to ECEC-aged multilingual children who currently lack adequate support for their early mathematical skills. By providing methods to foster their competence and confidence in mathematical skills, this study provides these children with a strong foundation for their future educational pathways, thereby bridging the achievement gap shown in several recent assessment studies (OECD, 2016, 2023; Ukkola & Metsämuuronen, 2019, 2021). In conclusion, this dissertation not only highlights the critical need for targeted interventions applying the recommended practices for supporting multilingual children's early mathematical skills but also serves as a call to action for all stakeholders involved in ECEC to ensure equitable learning opportunities for every child.

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