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Mathematics and higher-order thinking in early childhood education and care (ECEC)

Enrico Pollarolo[1]*, Tuula H. Skarstein[2], Ingunn Størksen[1] & Natalia Kucirkova[1]
[1]Norwegian Centre for Learning Environment and Behavioural Research in Education, University of Stavanger, Norway
[2]Department of Early Childhood Education, University of Stavanger, Norway

***Contact corresponding author:** Enrico Pollarolo, e-mail: enrico.pollarolo@uis.no

Abstract
This article investigates the perspectives of Norwegian early childhood educators on mathematics and higher-order thinking. Thematic analysis of the connection between mathematics and children's higher-order thinking skills was performed based on semi-structured interviews with ten educators in three different early childhood education and care (ECEC) centres. The findings suggest that educators, recognising mathematics as vital for ECEC, associate mathematics with problem-solving, an aspect of higher-order thinking skills highlighted in the research literature. The educators identified many opportunities for working with mathematics in daily activities, in accordance with the Norwegian tradition in recent years. Our results provide insights into how mathematics can support early childhood educators' stimulation of higher-order thinking in the Norwegian ECEC context.

Keywords: *critical thinking; higher-order thinking; mathematics; problem-solving; Norwegian ECEC educators*

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Introduction

In the last few decades, mathematics in early childhood education and care (ECEC) has received increasing attention (Sarama & Clements, 2008; Ten Braak et al., 2022), and the importance of working with mathematics in the early years has become evident. Recent research indicates that children's early mathematical skills can have lasting effects on both future mathematical development and other subject areas (Lenes et al., 2020;

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Ten Braak et al., 2022). This has laid the foundation for an increased interest in stimulating children's mathematical development in early childhood (Baroody et al., 2019; Johnston & Bull, 2021; Sarama & Clements, 2008). Moreover, working with mathematics is seen as an opportunity for children to learn to think and develop higher-order thinking skills (Anderson, 1994; Hobri et al., 2018). These efforts build on the theoretical idea that educators, as supportive adults, can help children identify and elaborate upon concepts that they already know, beyond the level that the children may have achieved without the educators' help (Smith, 1998).

The importance of working with mathematics was not highly prioritised in Norwegian ECEC until the new *Framework Plan for Kindergartens* was introduced in 2006 (Ministry of Education and Research). In this plan, well-established ECEC traditions were confronted with a new learning area, 'Quantities, spaces and shapes', which focuses on exploring and discovering mathematics (Ministry of Education and Research, 2006; Østrem et al., 2009). In this context, the Norwegian *Framework Plan* has drawn attention to the crucial role of educators in teaching and supporting mathematical learning and thinking in young children (Ministry of Education and Research, 2017). This political priority in Norway builds upon a broad consensus in the research literature that educators play an essential role in developing mathematical skills in children (Benz, 2012; Bobis et al., 2005; Chen et al., 2014; Thiel, 2010).

In a previous study (Pollarolo et al., 2022), we investigated Norwegian early childhood educators' perceptions of critical thinking as a higher-order thinking skill. The findings showed the propensity of educators to identify critical thinking as being crucial for children's development and their role as essential in supporting and stimulating critical thinking in children. The educators described critical thinking more in relation to a child's disposition and attitudes than to cognitive skills and connected it mainly with social and physical aspects.

In order to develop more knowledge about the relationship between mathematics and higher-order thinking skills, the current paper investigates Norwegian educators' perspectives on their mathematics pedagogy and their views on the relationship between mathematics and higher-order thinking. Understanding educators' perspectives is important in identifying both challenges and successful approaches to developing children's higher-order thinking skills in ECEC.

Background

The early years of life play an essential role in children's cognitive, language and educational development (Melhuish et al., 2015). Three topics, including early mathematics, literacy and aspects of self-regulation, have been the main focus of ECEC research, as they are highly predictive of children's later school success (Duncan et al., 2007). In this respect,

the importance of mathematics in ECEC has been widely discussed in the literature, and there is a consensus about the potential of working with mathematics in the early years and its association with later achievements (Duncan et al., 2007; Geary et al., 2013; Watts et al., 2014), not only in mathematics but also in other areas (Claessens & Engel, 2013; Ten Braak et al., 2022).

However, despite research efforts in specific areas in ECEC, an emphasis on skills that allows children to connect factual, conceptual and procedural knowledge (as defined by Anderson and Krathwohl (2001)) to metacognitive knowledge appears to be missing. This would involve developing the skills that enable children to use and connect information in a meaningful manner and assisting them in approaching new learning areas. In other words, we need to focus on developing children's higher-order thinking skills, which are essential considering our rapidly changing and challenging world and the efforts towards a more sustainable future. Therefore, higher-order thinking skills are considered as important *21st century skills* (Collins, 2014), and are included in the key competencies in 'Education for Sustainable Development' (Rieckmann, 2018).

Research shows an association between the development of higher-order thinking skills and mathematics (Apriani & Rianasari, 2020; Richland & Begolli, 2016; Tanujaya et al., 2017), and the relationship between the two seems to be reciprocal. Mathematics as content may improve higher-order thinking skills (Hobri et al., 2018), and mathematical skills may also be enhanced through the promotion of higher-order thinking skills (Pratama & Retnawati, 2018; Tajudin & Chinnappan, 2016). However, there is scant evidence of this connection in ECEC.

Previous research has drawn attention to the crucial role of educators in teaching and supporting mathematical learning and thinking in young children. The mediation role provided by educators enhances children's propensity for learning (Howie, 2019). Educators' roles as supporting adults require teaching beyond formal mathematics, which means moving from traditional teaching approaches—in which the teacher is in charge of showing and explaining—to a function of open guidance in helping children develop their own thinking (Anghileri, 2006). Thiel (2010) demonstrated a correlation between educators' beliefs and knowledge of mathematics and their attitudes towards it, and suggested that it is essential to foster mathematics learning in ECEC teacher education to support educators' positive perspectives towards it. Various studies have described constructive attitudes and openness among ECEC educators towards mathematics and confidence in mathematics teaching in the early years (Benz, 2012; Chen et al., 2014; Thiel, 2010).

In the context of our study, we define 'perspectives' as educators' evaluations and reflections related to young children's mathematical and higher-order thinking skills. In this general definition, 'perspectives' is similar to the term 'conception' used by Philipp (2007), which includes 'beliefs, meanings, concepts, propositions, rules, mental images, and preferences' (p. 259).

Higher-order thinking

Higher-order thinking can be framed or described in different ways. Conklin (2011) argued that higher-order thinking skills incorporate critical thinking and creative thinking. Resnick (1987a) claimed that, depending on the approach, we can focus on different aspects. From a philosophical perspective, the emphasis is on critical thinking and logical reasoning. While developmental psychologists tend to highlight the significance of metacognition, cognitive scientists focus on cognitive strategies and heuristics. Furthermore, educators tend to promote problem-solving. From this perspective, Resnick (1987a) herself noted that although it is impossible to provide a precise definition of higher-order thinking, it is immediately recognisable when we encounter it.

The idea of higher-order thinking that can be perceived in different ways is well-represented by Miri et al. (2007). These authors used 'higher-order thinking' as an umbrella term encompassing different categories of thinking. In this context, Brookhart (2010) synthesised the definitions of higher-order thinking into three different categories: those that define higher-order thinking in terms of *transfer*, those that define it in terms of *critical thinking,* and those that define it in terms of *problem-solving*. This distinction demonstrates how higher-order thinking can manifest in different ways.

Critical thinking is often considered a domain of the humanities and problem-solving a domain of the sciences and mathematics (Lewis & Smith, 1993). However, there is no rigid demarcation line between problem-solving and critical thinking, as they are intertwined. For example, problem-solving is also defined as a particular kind of critical thinking (Willingham, 2007). More recent approaches define critical thinking as inevitably preliminary in the process of solving a problem and argue that real problems can be resolved only with the support of critical thinking, which can generate new knowledge, since it engages in deeper complex thinking (Voskoglou & Buckley, 2012). When involved in solving a problem, one has to evaluate the problem using and adapting previous knowledge and skills, and thinking at a higher level; this is considered the first step in using critical thinking (Doleck et al., 2017).

Some previous studies have investigated the connection between critical thinking and mathematics (e.g. Aizikovitsh & Amit, 2010; Sachdeva & Eggen, 2021), but few of them are at an ECEC level (Aizikovitsh-Udi & Cheng, 2015; Pollarolo et al., 2022; Schillinger, 2021).

Aims of the study

The purpose of this study is to examine educators' perspectives on mathematics and the elements of higher-order thinking skills foregrounded in the ECEC context when the focus

is on mathematics. This work is part of a larger body of research focused on higher-order thinking in Norwegian ECEC (Pollarolo et al., 2022). The research question we ask is as follows:

> *What are educators' perspectives on mathematics and the connection between mathematics and higher-order thinking skills in the ECEC context?*

Method

Participants

The data for this paper originate from interviews conducted for a larger project that involved the participation of three different ECEC centres. By the term 'ECEC centre,' we refer to the Norwegian *barnehage*, which means premises used for educational and care activities with children aged one to six years before compulsory school. The centres were selected due to their previous collaborations with the University of Stavanger. Information about the study was provided to the three ECEC centres, and ten educators, including eight pedagogical leaders and two educators working with children with special needs, agreed to participate in semi-structured interviews. Before starting, informed consent was obtained from all participants. The average participant's working experience in ECEC centres was 17 years, ranging from a minimum of 1.5 years to a maximum of 35 years. Eight educators had 15 years or more of working experience, which means that they started working at the centre before or at the time of the 2006 revision of the *Framework Plan for Kindergartens*, which introduced a requirement for increased focus on mathematics in ECEC (Ministry of Education and Research, 2006).

Ethical considerations were presented to and approved by the Norwegian Centre for Research Data (NSD).

Study procedure

Three pilot interviews with ECEC professional personnel at the University of Stavanger were conducted to test, verify and adjust the interview questions before finalising the interview guide (Appendix). All the participants received the interview questions a few days before the interview. Therefore, they had the opportunity to reflect on the topic in advance.

The interview guide was divided into two sections. The first section focused on the educators' perceptions of critical thinking as one of the higher-order thinking skills, and the second focused on mathematics. The questions were designed to align with the subjects in the *Framework Plan* (Ministry of Education and Research, 2017). Due to the volume of the data collected, this article focuses on the second half, which concerns

educators' perceptions of mathematics and the connection between mathematics and higher-order thinking. The topic of the first half is the subject of another article (Pollarolo et al., 2022).

Interviews

The participants were interviewed in person at their own ECEC centre. The interviews lasted between 20 minutes and an hour and were audio-recorded and transcribed. After the transcription, a native Norwegian speaker performed proofreading to identify any discrepancies between the audio recordings and the transcriptions. Each participant received a copy of their own interview, and they all approved the content.

Analysis

The interview transcriptions were analysed using thematic analysis, a method widely used for analysing qualitative data (Terry et al., 2017). Braun and Clarke (2006) defined thematic analysis as 'a method for identifying, analyzing, and reporting patterns (themes) within data' (p. 79); to this end, our analysis followed the six steps suggested in the guidelines provided by Braun and Clarke (2012). The transcripts were first read several times before coding to allow the authors to familiarise themselves with the data. Handwritten notes were taken during reading. Next, with the help of the software NVivo 12, a systematic coding of the transcripts was conducted in four stages: descriptive, *in vivo*, process and concept coding (as proposed by Saldaña (2021)). The codes were then condensed into themes in an effort to encapsulate the educators' opinions and practices regarding mathematics and higher-order thinking. After the initial definition of the themes by the first author, all authors discussed and reviewed the themes in several rounds until a final version was agreed upon. Eventually, three themes and nine subthemes were defined. Brief quotations from the transcriptions were selected to provide examples and better describe each theme. The quotations were translated from Norwegian to English. To ensure anonymity, the individual educators are referred to as Educators 1–10.

Findings

As depicted in Figure 1, the data analysis resulted in three main themes. Each theme has three subthemes, which capture different aspects of the main theme. The first theme captures the educators' perception of mathematics as the ability to solve problems. The second theme underlines the broad consensus among educators about the abundant opportunities to work with mathematics. The third theme encapsulates the educators' opinions related to their own experiences in learning mathematics.

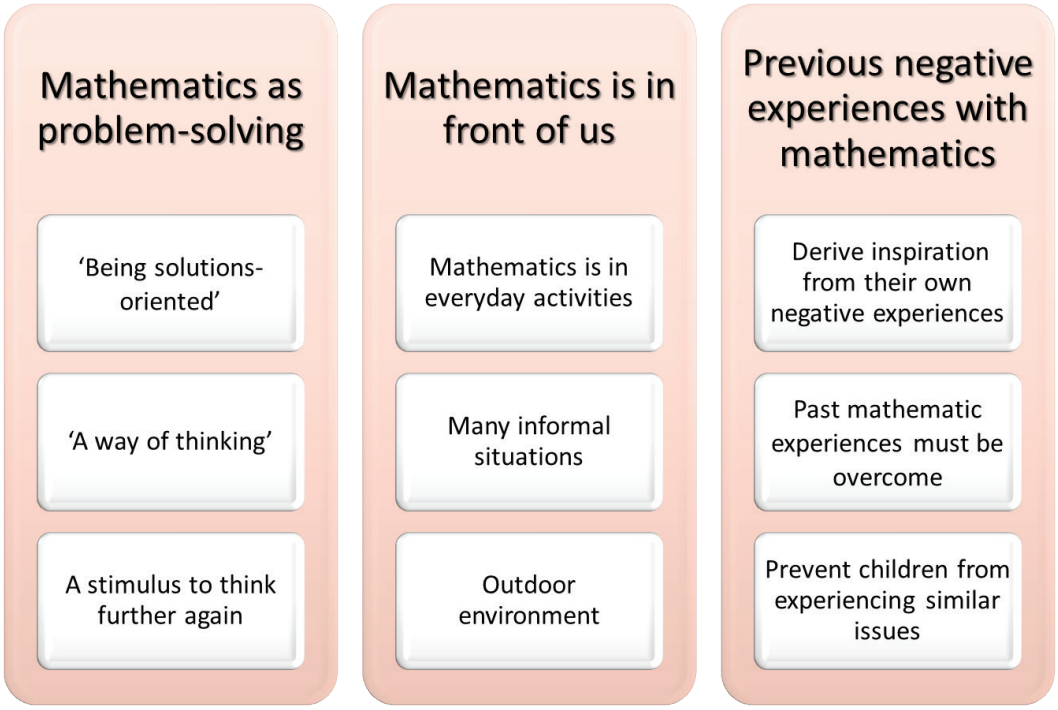

Figure 1. Themes identified through the analysis of the semi-structured interviews.

Mathematics as problem-solving

Based on the analysis, it appears that the participants perceived mathematics as a means of thinking or solving problems or as a solution-oriented approach to life. According to them, mathematics stimulates more extensive connections and helps children think further.

Half of the participants associated mathematics with the concept of being able to solve problems and being 'solutions-oriented' (Educator 1), because it is essential for educators to 'help them [children] to see solutions' (Educator 4) and, in order to find solutions, 'they need to think deeply' (Educator 9). 'I think that mathematics is about discovering and exploring to understand. It is a way of thinking, a language to solve problems according to contexts, to develop the ability to think for yourself' (Educator 1).

The same educator also found it crucial to work with mathematics in ECEC because, in this way, children could practice their abilities to solve problems and then as adults, in their working life, they would not be afraid 'to become engaged in new things'.

According to the participants' opinions, mathematics 'stimulates one to think further' (Educator 10), and it is connected with problem-solving because mathematics means 'reasoning about different paths and arriving at the goal' (Educator 1) or, as Educator 5 stated, 'It is to think about problem-solving, as it is to create different paths to develop further'. Therefore, mathematics is a language for solving problems and is essential for inspiring children to find a solution together and then enable them to find solutions by themselves.

Educator 4 highlighted the importance of transcending the intrinsic meaning of mathematics as a given form or number and recognising that there are different ways of doing things: 'to be able to see solutions, that they should also be able to see that there are many different ways of doing things, that they must not be stuck to a given form, given number.'

Mathematics is in front of us

The findings reveal a wide consensus among participants that there are many opportunities to work with mathematics in everyday life. As described by the participants: 'I think that mathematics is in everyday activities; it's right in front of us; it's in songs, in rhymes, in fairy tales' (Educator 3); 'I think everything around us actually […] I see the importance of them [children] seeing that there is really mathematics in everything we do, in a way' (Educator 6).

The notion that mathematics is everywhere is deeply rooted among the participants, all of whom mentioned it. Educator 7 highlighted this when she stated: 'It surprised me how much math there really is; you become aware of everything you did that was math that you had not thought of before, that it appeared to be just play, but there is learning.'

In this regard, educators stressed that the mathematical activities they engaged in at the ECEC centre are frequently not identified specifically as mathematics. The opinion of the participants was that, even though educators know that the activity they are doing involves mathematics, there is no need to emphasise this to the children. Some participants described informal situations or activities in which mathematics could be involved, such as reading a book or cleaning up a table. In relation to this common idea that mathematics is everywhere, six participants focused in particular on the outdoor environment as an arena for implementing mathematical activities. The participants mentioned different materials and activities, including picking up pine cones and sticks of different lengths to build shapes. They believed that the availability of these materials in nature offers many opportunities to apply mathematics differently to how they apply it indoors in the ECEC centre. Moreover, their opinion was that an outdoor setting provides more opportunities for the children's free expression and more space where they can test techniques and concepts. Most of the participants—namely, 6 out of 10—posited that the expositions we give to children influence their approach to critical thinking and mathematics. Therefore, the environment plays an important role, particularly the environment at the ECEC centre and at home, including parents' education and engagement, as pointed out by Educator 3: 'it is the environment they have at home … children often have parents at home who are very interested.'

Among other mathematical activities, approaches related to problem-solving in everyday situations were described by the participants. Educator 4 stated, 'It's also about how we will put things together so that something will come out of it.' Educator 1 also spoke about

working with '*rom og retning*' (Norwegian for 'space and direction'): 'What we do inside here, if we were going to build a cabin, how much would we need?'

Previous negative experiences with mathematics

Some of the educators admitted that they themselves did not have positive mathematics experiences during their time at school. Nevertheless, these educators believed that they had to derive inspiration from their negative experiences and work to prevent children from experiencing similar issues once they reached school. This is exemplified by the following quote: 'Maybe just because I had a bad experience with school mathematics, it made me a little interested in that: how can we avoid kids having to sit and have it the same way at school as I did?' (Educator 6).

The participants believed that their own past negative experiences must be overcome to avoid being affected by them in their approach to children's mathematical education. Most of them did not experience any challenges when working with mathematics in ECEC. The only challenges some of the educators underlined were linked to the need for educators to be aware of the importance of working with mathematics in daily life and the ability to eliminate their negative preconceptions. As Educator 9 put it, 'You carry with you a story yourself, your experiences and thoughts about mathematics. I have always struggled with mathematics at school […]. But this is on a whole different level, and you have to put it away. It still affects you. So maybe many people think it's difficult.'

Although some educators reported some negative experiences with mathematics from childhood, the results illustrate an open and positive perspective towards mathematics in ECEC. All the participants answered positively when asked about their opinions concerning the benefit of children working with mathematics in ECEC, and they underlined the importance of starting as early as possible.

Discussion

This study investigated Norwegian ECEC educators' perspectives on mathematics and higher-order thinking. Interviews with ten ECEC educators showed that they perceived mathematics as important in ECEC, identified diverse opportunities for working with mathematics in everyday activities, stressed the importance of eliminating previous negative preconceptions and perceived a clear connection between mathematics and problem-solving, which is an aspect of higher-order thinking.

The purpose of this study was twofold: to establish (i) educators' perspectives on mathematics; and (ii) the connection between mathematics and higher-order thinking skills. When it comes to the first aim, the Norwegian educators appeared confident

about the importance of mathematics in ECEC and had an open and positive perspective towards it. This is in line with previous research from Germany and the US (Benz, 2012; Chen et al., 2014; Thiel, 2010). Still, during the interviews, some of the educators reflected on their negative personal experiences with school mathematics, and they were aware of the importance of trying not to let this influence their daily work with the children in ECEC. To manage the possible challenges connected to mathematics in the ECEC context, it is important that educators think positively about their own mathematical skills and abilities (Jenssen et al., 2020). Furthermore, attitudes matter, as demonstrated by Lee (2005), who showed that educators' attitudes towards teaching mathematics were significantly associated with the practice of developmentally appropriate mathematics.

In the present study, the participants' positive approach to teaching mathematics was also reflected in their perspective that daily life is rich in opportunities to apply mathematics generally and problem-solving specifically. The idea that mathematics is everywhere can be traced back to Sumpter (2020) research on Swedish preschool teachers' conceptions about mathematics and emotional directions towards mathematics. In the present study, this idea can be seen in connection with the Norwegian ECEC tradition, in which learning opportunities are considered to arise from different pedagogical situations. Such situations can be activities initiated by the educators or more spontaneous child-initiated activities arising from everyday situations in which the educators focus on following the child's interests (Ministry of Education and Research, 2015). According to Skarstein and Ugelstad (2020), ECEC educators value the outdoors as an environment that provides many opportunities for such spontaneous activities. In the present study, the educators also viewed the outdoors as an important arena for working with mathematics and regarded it as an arena with more nature-related opportunities for children's free expression and for applying mathematics in more varied ways.

This positive result is also in line with the Norwegian ECEC policy which, from 2006 onwards, has led to great efforts to support and implement mathematics in ECEC from the point of view of both the *Framework Plan* (Ministry of Education and Research, 2017) and educators' training. Recognising that mathematics can be present in everyday circumstances and integrating mathematics learning into play helps educators to support children in acquiring confidence and positive experiences in mathematics (Björklund, 2012; Johnston & Bull, 2021).

The results particularly reflect the learning area 'Quantities, spaces and shapes' in the *Framework Plan*, which focuses on exploring and discovering mathematics in everyday life, guides educators to 'stimulate the children's sense of wonder, curiosity, and motivation for problem-solving' and highlights the importance of 'asking questions, reasoning, argumentation and seeking solutions'. Educators are also expected to 'stimulate and support the children's capacity for and perseverance in problem-solving' (Ministry of Education and

Research, 2017, p. 54). In connection to Bishop (1989), six universal mathematical activities—adjusted to Norwegian ECEC by Solem and Reikerås (2001)—problem-solving can be traced back to the 'Explanation and argumentation' category.

As for the educators' perspectives on the connection between mathematics and higher-order thinking skills, our results showed that half of the participants associated mathematics with being problem-oriented and able to find solutions. In relation to the three aspects of higher-order thinking mentioned by Brookhart (2010), educators are more problem-solving-oriented when mathematics is involved (Resnick, 1987b). The present study also supports this idea in the ECEC context: the educators' answers appear to suggest that supporting higher-order thinking through mathematics in ECEC means acting on the ability to solve problems. The association between the ability to think critically and the ability to solve problems has been pointed out earlier by, for example, Snyder and Snyder (2008), who highlighted critical thinking as a condition for being able to resolve problems in a successful and effective manner.

In the context of learning mathematics, previous research has shown that early learning in children is better facilitated by the problem-solving process and logical reasoning than by teaching specific mathematical knowledge (Perry & Dockett, 2008; Reikerås et al., 2012). It follows that working with mathematics means developing problem-solving skills which do not develop separately from critical-thinking skills.

In our previous study (Pollarolo et al., 2022), the same educators, when interviewed about critical thinking in general (and not related to any specific subject), focused more on the children's attitudes and dispositions than on their cognitive abilities. Yet, critical thinking can be defined as the sum of two components: cognitive skills (or abilities) and dispositions/attitudes (Lai, 2011). According to Lai (2011), while philosophers focus more on the characteristics of the ideal critical thinker, or rather on those dispositions and attitudes that define the hypothetical critical thinker, cognitive psychologists focus more on the product of the thought or the types of actions or behaviours of the critical thinkers. In other words, the focus is on the mental and cognitive skills, such as analysis and interpretation, that people employ to solve a problem. From the educators' answers to questions related to mathematics, it appears that the educators' perspectives are oriented towards problem-solving skills. This reflects the idea that, when placed in a particular context or a particular domain, such as mathematics, educators are more focused on aspects of thinking defined as abilities as opposed to disposition and attitudes. When looking at the results of our two studies together (Pollarolo et al., 2022, and the current study), it seems that when interviewed about critical thinking in general, the educators focused more on attitudes and dispositions, but when the interviews turned their focus to mathematics, the educators shifted their focus to cognitive abilities. Therefore, we can consider mathematics as a domain that can integrate the social and emotional aspects of higher-order thinking skills

with the more cognitive approach typical of mathematics. This finding contributes to a more holistic approach to fostering these essential skills in children.

Conclusion and future research

This study aimed to explore ECEC educators' perspectives on mathematics and the relationship between mathematics and children's higher-order thinking development. As a theoretical implication, the findings support the idea that, when considering the connection between higher-order thinking skills and mathematics, educators mainly focus on problem-solving abilities. Interestingly, in our previous study (Pollarolo et al., 2022), when the focus was on critical thinking in general, the educators connected higher-order thinking to dispositions and attitudes. This reflects the idea that higher-order thinking can be perceived in different ways and encompass different categories of thinking (Miri et al., 2007) and, as our study suggests, this may be dependent on the domain.

Although several educators had negative experiences with mathematics in their childhoods, they showed a positive propensity towards teaching mathematics in ECEC, which is a good precondition when using mathematics to develop thinking abilities and skills. The findings also support the idea that higher-order thinking can be developed within a specific content—in the case of this study, the content being mathematics (Davies, 2006; Dewey & Bento, 2009).

The lack of investigation into actual practice does not allow us to make any claims about the relationship between educators' perspectives and actual practice in their settings. However, while our sample size was limited, our findings provide insights into the possible means by which mathematics can be used as a domain for higher-order thinking development among children in ECEC. In terms of the *Framework Plan* (Ministry of Education and Research, 2017), ECEC teacher education and ECEC educators' professional development, the results of our study highlight a need for more focus on the importance of developing children's higher-order thinking skills. Identifying specific pedagogical practices and their relationship to children's skills remains the goal of future research.

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ORCID

Enrico Pollarolo http://orcid.org/0000-0002-0458-9559
Tuula H. Skarstein http://orcid.org/0000-0002-1673-1129
Ingunn Størksen http://orcid.org/0000-0002-2258-1788
Natalia Kucirkova http://orcid.org/0000-0002-2805-1745

Author biographies

Enrico Pollarolo is a doctoral candidate at the Centre for Learning Environment at the University of Stavanger. His research focuses on higher-order thinking skills in ECE, as well as mathematics and computational thinking.

Tuula H. Skarstein is associate professor at the Department of Early Childhood Education, University of Stavanger. Her main research interests are science education, outdoor education and sustainability education within both ECEC and teacher education. She currently leads the research group Transforming Education – Towards a Sustainable Future and is also connected to Filiorum – Centre for Research in Early Childhood Education and Care.

Ingunn Størksen is a professor at the Centre for Learning Environment at the University of Stavanger and a professor II at the Queen Maud University College of Early Childhood Education. She has been the leader of several large ECEC projects financed by the Research Council of Norway and other funders. Research topics include early childhood social, emotional, and cognitive development, impacts of the family, ECEC quality, and transition to school.

Natalia Kucirkova is Professor of Early Childhood Education and Development at the University of Stavanger, Norway and Professor of Reading and Children's Development

at The Open University, UK. Natalia's work is concerned with social justice in children's literacy and use of technologies. Her research takes place collaboratively across academia, commercial and third sectors. She advocates for greater Equality, Diversity and Inclusion across academia and society.

References

Aizikovitsh-Udi, E., & Cheng, D. (2015). Developing critical thinking skills from dispositions to abilities: Mathematics education from early childhood to high school. *Creative Education*, *6*(4), 455. https://doi.org/10.4236/ce.2015.64045

Aizikovitsh, E., & Amit, M. (2010). Evaluating an infusion approach to the teaching of critical thinking skills through mathematics. *Procedia-Social and Behavioral Sciences*, *2*(2), 3818–3822. https://doi.org/10.1016/j.sbspro.2010.03.596

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. Longman.

Anderson, R. D. (1994). *Issues of curriculum reform in science, mathematics, and higher order thinking across the disciplines*. US Department of Education, Office of Educational Research and Improvement.

Anghileri, J. (2006). Scaffolding practices that enhance mathematics learning. *Journal of Mathematics Teacher Education*, *9*(1), 33–52.

Apriani, M., & Rianasari, V. (2020). Designing hypothetical learning trajectory in supporting pre-service mathematics teachers to conduct higher-order thinking oriented learning in microteaching course. *Journal of Physics: Conference Series*, *1470*(1), 012014.

Baroody, A. J., Clements, D. H., & Sarama, J. (2019). Teaching and learning mathematics in early childhood programs. In C. P. Brown, M. B. McMullen, & N. File (Eds.), *The Wiley handbook of early childhood care and education* (pp. 329–354). Wiley Blackwell.

Benz, C. (2012). Attitudes of kindergarten educators about math. *Journal für Mathematik-Didaktik*, *33*(2), 203–232.

Bishop, A. J. (1989). Mathematical enculturation: A cultural perspective on mathematics education. *Journal for Research in Mathematics Education*, *20*(4), 367–370.

Björklund, C. (2012). What counts when working with mathematics in a toddler-group? *Early Years*, *32*(2), 215–228. https://doi.org/10.1080/09575146.2011.652940

Bobis, J., Clarke, B., Clarke, D., Thomas, G., Wright, B., Young-Loveridge, J., & Gould, P. (2005). Supporting teachers in the development of young children's mathematical thinking: Three large scale cases. *Mathematics Education Research Journal*, *16*(3), 27–57.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101.

Braun, V., & Clarke, V. (2012). Thematic analysis. In H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, & K. J. Sher (Eds.), *APA handbook of research methods in psychology, Vol. 2. Research designs: Quantitative, qualitative, neuropsychological, and biological* (pp. 57–71). American Psychological Association. https://doi.org/10.1037/13620-004

Brookhart, S. M. (2010). *How to assess higher-order thinking skills in your classroom*. ASCD.

Chen, J.-Q., McCray, J., Adams, M., & Leow, C. (2014). A survey study of early childhood teachers' beliefs and confidence about teaching early math. *Early Childhood Education Journal*, *42*(6), 367–377. https://doi.org/10.1007/s10643-013-0619-0

Claessens, A., & Engel, M. (2013). How important is where you start? Early mathematics knowledge and later school success. *Teachers College Record*, *115*(6), 1–29.

Collins, R. (2014). Skills for the 21st century: Teaching higher-order thinking. *Curriculum & Leadership Journal*, *12*(14). http://www.curriculum.edu.au/leader/teaching_higher_order_thinking,37431.html

Conklin, W. (2011). *Higher-order thinking skills to develop 21st century learners*. Teacher Created Materials.

Davies, W. M. (2006). An 'infusion' approach to critical thinking: Moore on the critical thinking debate. *Higher Education Research & Development*, *25*(2), 179–193. https://doi.org/10.1080/07294360600610420

Dewey, J., & Bento, J. (2009). Activating children`s thinking skills (ACTS): The effects of an infusion approach to teaching thinking in primary schools. *British Journal of Educational Psychology*, *79*(2), 329–351. https://doi.org/10.1348/000709908X344754

Doleck, T., Bazelais, P., Lemay, D. J., Saxena, A., & Basnet, R. B. (2017). Algorithmic thinking, cooperativity, creativity, critical thinking, and problem solving: Exploring the relationship between computational thinking skills and academic performance. *Journal of Computers in Education*, *4*(4), 355–369. https://doi.org/10.1007/s40692-017-0090-9

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani, L. S., Feinstein, L., Engel, M., & Brooks-Gunn, J. (2007). School readiness and later achievement. *Developmental Psychology*, *43*(6), 1428.

Geary, D. C., Hoard, M. K., Nugent, L., & Bailey, D. H. (2013). Adolescents' functional numeracy is predicted by their school entry number system knowledge. *PLOS ONE*, *8*(1), e54651.

Hobri, H., Septiawati, I., & Prihandoko, A. C. (2018). High-order thinking skill in contextual teaching and learning of mathematics based on lesson study for learning community. *International Journal of Instruction*, *11*(2), 483–496.

Howie, D. R. (2019). *Thinking about the teaching of thinking: The Feuerstein approach*. Routledge.

Jenssen, L., Hosoya, G., Jegodtka, A., Eilerts, K., Eid, M., & Blömeke, S. (2020). Effects of early childhood teachers' mathematics anxiety on the development of children's mathematical competencies. In *Student Learning in German Higher Education* (pp. 141–162). Springer. https://doi.org/10.1007/978-3-658-27886-1_8

Johnston, K., & Bull, R. (2021). Understanding educator attitudes towards and perceptions of mathematics in early childhood. *Journal of Early Childhood Research*, *20*(3). https://doi.org/10.1177/1476718X211052785

Lai, E. R. (2011). Critical thinking: A literature review. *Pearson's Research Reports*, *6*(1), 40–41.

Lee, J. (2005). Correlations between kindergarten teachers' attitudes toward mathematics and teaching practice. *Journal of Early Childhood Teacher Education*, *25*(2), 173–184. https://doi.org/10.1080/1090102050250210

Lenes, R., McClelland, M. M., Ten Braak, D., Idsoe, T., & Størksen, I. (2020). Direct and indirect pathways from children's early self-regulation to academic achievement in fifth grade in Norway. *Early Childhood Research Quarterly*, *53*, 612–624.

Lewis, A., & Smith, D. (1993). Defining higher order thinking. *Theory into Practice*, *32*(3), 131–137.

Melhuish, E., Ereky-Stevens, K., Petrogiannis, K., Ariescu, A., Penderi, E., Rentzou, K., Tawell, A., Slot, P., Broekhuizen, M., & Leseman, P. (2015). *A review of research on the effects of Early Childhood Education and Care (ECEC) upon child development. Care project, University of Oxford.*

Ministry of Education and Research. (2006). *Framework plan for kindergartens: Content and tasks*.

Ministry of Education and Research. (2015). *OECD – Thematic review of Early Childhood Education and Care policy in Norway, background report*.

Ministry of Education and Research. (2017). *Framework plan for the content and tasks of kindergartens*. https://www.udir.no/contentassets/7c4387bb50314f33b828789ed767329e/framework-plan-for-kindergartens--rammeplan-engelsk-pdf.pdf

Miri, B., David, B.-C., & Uri, Z. (2007). Purposely teaching for the promotion of higher-order thinking skills: A case of critical thinking. *Research in Science Education*, *37*(4), 353–369.

Perry, B., & Dockett, S. (2008). Young children's access to powerful mathematical ideas. *Handbook of International Research in Mathematics Education*, *2*, 75–108.

Philipp, R. A. (2007). Mathematics teachers' beliefs and affect. In F. K. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 257–315). Information Age.

Pollarolo, E., Størksen, I., Skarstein, T. H., & Kucirkova, N. (2022). Children's critical thinking skills. Perceptions of Norwegian early childhood educators. *European Early Childhood Education Research Journal*. https://doi.org/10.1080/135029 3X.2022.2081349

Pratama, G., & Retnawati, H. (2018). Urgency of higher order thinking skills (HOTS) content analysis in mathematics textbook. *Journal of Physics*. https://doi.org/10.1088/1742-6596/1097/1/012147

Reikerås, E., Løge, I. K., & Knivsberg, A.-M. (2012). The mathematical competencies of toddlers expressed in their play and daily life activities in Norwegian kindergartens. *International Journal of Early Childhood*, *44*(1), 91–114.

Resnick, L. B. (1987a). *Education and learning to think*. National Academy Press.

Resnick, L. B. (1987b). *Education and learning to think*. National Academy Press.

Richland, L. E., & Begolli, K. N. (2016). Analogy and higher order thinking: Learning mathematics as an example. *Policy Insights from the Behavioral and Brain Sciences*, *3*(2), 160–168.

Rieckmann, M. (2018). Learning to transform the world: Key competencies in education for sustainable development. *Issues and Trends in Education for Sustainable Development*, *39*, 39–59.

Sachdeva, S., & Eggen, P.-O. (2021). Learners' critical thinking about learning mathematics. *International Electronic Journal of Mathematics Education*, *16*(3), em0644. https://doi.org/10.29333/iejme/11003

Saldaña, J. (2021). *The coding manual for qualitative researchers*. Sage.

Sarama, J., & Clements, D. H. (2008). Mathematics in early childhood. In O. N. Saracho & B. Spodek (Eds.), *Contemporary perspectives on mathematics in early childhood education* (pp. 67–94). Information Age Publishing.

Schillinger, T. (2021). Self-efficacy of kindergarten teachers' mathematical instruction. *Early Childhood Education Journal*, *49*(4), 623–632. https://doi.org/10.1007/s10643-020-01101-0

Skarstein, T. H., & Ugelstad, I. B. (2020). Outdoors as an arena for science learning and physical education in kindergarten. *European Early Childhood Education Research Journal*, *28*(6), 923–938. https://doi.org/10.1080/1350293X.2020.1836590

Smith, S. S. (1998). *Early childhood mathematics*. National Science Foundation.

Snyder, L. G., & Snyder, M. J. (2008). Teaching critical thinking and problem solving skills. *The Journal of Research in Business Education*, *50*(2), 90.

Solem, I., & Reikerås, E. (2001). *Det matematiske barnet [The mathematical child]*. Caspar forlag.

Sumpter, L. (2020). Preschool educators' emotional directions towards mathematics. *International Journal of Science and Mathematics Education*, *18*(6), 1169–1184.

Tajudin, N. A. M., & Chinnappan, M. (2016). The link between higher order thinking skills, representation and concepts in enhancing TIMSS tasks. *International Journal of Instruction*, *9*(2), 199–214.

Tanujaya, B., Mumu, J., & Margono, G. (2017). The relationship between higher order thinking skills and academic performance of student in mathematics instruction. *International Education Studies*, *10*(11), 78–85.

Ten Braak, D., Lenes, R., Purpura, D. J., Schmitt, S. A., & Størksen, I. (2022). Why do early mathematics skills predict later mathematics and reading achievement? The role of executive function. *Journal of Experimental Child Psychology*, *214*, 105306.

Terry, G., Hayfield, N., Clarke, V., & Braun, V. (2017). Thematic analysis. In C. Willig & W. S. Rogers (Eds.), *The Sage handbook of qualitative research in psychology* (Vol. 2, pp. 17–37). Sage. https://doi.org/10.4135/9781526405555

Thiel, O. (2010). Teachers' attitudes towards mathematics in early childhood education. *European Early Childhood Education Research Journal*, *18*(1), 105–115. https://doi.org/10.1080/13502930903520090

Voskoglou, M. G., & Buckley, S. (2012). Problem solving and computational thinking in a learning environment. *ArXiv.* https://doi.org/10.48550/arXiv.1212.0750

Watts, T. W., Duncan, G. J., Siegler, R. S., & Davis-Kean, P. E. (2014). What's past is prologue: Relations between early mathematics knowledge and high school achievement. *Educational Researcher*, *43*(7), 352–360.

Willingham, D. T. (2007). Critical thinking: Why it is so hard to teach? *American Educators,* 8–19.

Østrem, S., Bjar, H., Hogsnes, H. D., Jansen, T. T., Nordtømme, S., & Tholin, K. R. (2009). *Alle teller mer. Evaluering av hvordan Rammeplanen for barnehagens innhold og oppgaver blir innført, brukt og erfart. [Evaluation of the implementaion of the Norwegian Framework Plan]*. Høgskolen i Vestfold. https://www.udir.no/globalassets/upload/barnehage/forskning_og_statistikk/rapporter/alle_teller_mer.pdf

Appendix: Interview questions

1. Now, I would like to change the subject to mathematics. If I say mathematics and kindergarten, what is the first thing that comes to mind?
2. The *Framework Plan for Kindergartens* states that 'Kindergartens shall highlight relationships and enable the children to explore and discover mathematics in everyday life'. What does this mean, in your opinion?
3. So, do you / don't you think that children can benefit from working with mathematics, already in kindergarten?
4. Do you usually have any difficulties in working with mathematics? If yes, why?
5. Are there any preferred activities you do when working with mathematics?
6. Which areas within mathematics do you intend to stimulate through your activities?
7. I am specifically interested in the learning area 'Quantities, spaces and shapes' and I wonder whether you have ever considered that area in your practice in kindergarten and how.
8. What is your opinion on using mathematics to stimulate children's ability to think critically?
9. Are there any differences in relation to specific characteristics of children, for example, gender, culture, temperament and their thinking skills and or mathematics?