Maternal Cognitive Guidance and Early Education and Care as Precursors of Mathematical Development at Preschool Age and in 9th Grade

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Abstract

Finnish students' international success in mathematics has been largely explained by the high-quality compulsory basic education system, while increasing evidence suggests that early childhood contexts can also promote development long before formal instruction begins. This study examined, in a sample of 66 mother-infant dyads, two early contextual precursors of later mathematical development at preschool age and at the end of comprehensive school. The path analyses showed that maternal autonomy support and scaffolding observed during joint play interactions in infancy, and time spent in various care contexts beyond infancy contributed more to variation in numerical skills than spatial skills tested at preschool age. Maternal autonomy supportive behaviors were related to differences in mathematics and other school grades collected in 9th grade, even after controlling for time spent in various care contexts. Moreover, joint play interactions mediated the relation between mothers' education and children's mathematical outcomes. The findings are discussed in relation to why early developmental contexts can provide an advantageous base for children's mathematical achievement in a society with a high-quality education system.

Key words: autonomy support, scaffolding, early education, mathematics

Daily activities with parents and caregivers outside the home constitute the first learning contexts for children to practice and develop their numeracy and literacy skills (for the home learning environment, see Manolitsis, Georgiou, & Tziraki, 2013; Melhuish et al., 2008; for early childhood education, see Li, Farkas, Duncan, Burchinal, & Vandell, 2013; Peisner-Feinberg et al., 2001). Although research treating the parent-child dyad as the unit of analysis has demonstrated the impact of early contextual precursors on literacy development, we know less about the influence of early contexts on numeracy development. Longitudinal research has related parents' number and spatial talk during daily activities to children's mathematical skills assessed before school entry (e.g., Gunderson & Levine, 2011; Pruden, Levine, & Huttenlocher, 2011). Also a multifaceted parenting construct which merges different ways parents support their child's activities during interactions in early childhood has been associated with mathematical outcomes at kindergarten age (Martin, Ryan, & Brooks-Gunn, 2007; NICHD ECCRN, 2003) and at school age in 3rd and 5th grade (Belsky et al., 2007; NICHD ECCRN, 2008).

Studies exploring the link between specific interactional processes in early childhood and later mathematical outcomes are rare (for a theoretical framework, see Pino-Pasternak & Whitebread, 2010). We addressed this gap in a recent study on Finnish mothers and their children followed up from infancy until early preschool age, but did not control for other crucial contextual factors (Sorariutta, Hannula-Sormunen, & Silvén, 2017). Our novel goal in this follow-up study is to explore the longer-term prediction of two early developmental contexts, quality of maternal cognitive guidance and amount of children's experiences in various care contexts, rarely acknowledged in the same study. This is an intriguing question because Finnish students are among the best performers in worldwide international comparisons. The Program for International Student Assessment (PISA) shows that Finnish

9th graders score at the top level in reading, mathematics, and science (OECD, 2012). The high-level learning outcomes have been largely explained by the education system: free-of-charge public school services which are equally available to all children, research-based teacher education and competent teachers, and the autonomy given to schools (Ministry of Education and Culture, 2016). The role of Early Childhood Education and Care (ECEC) on school achievement has received relatively little attention in Finland despite the fact that high-quality and low-cost day-care services are available for every family and child in need of it (the principle of universality).

Development of Mathematical Skills

From a very early age, infants attend to objects and their properties such as quantity, as well as motion and location in space. These early perceptual experiences form the foundation of memory representations and core concepts which influence later perception of new events in the physical environment (e.g., Goswami, 2008; Karmiloff-Smith, 1992; Mandler, 2012). Research beyond infancy provides evidence that children’s representations become gradually enriched, and their earliest receptive and productive vocabulary, including specific words for spatial and numerical concepts and relations is a reflection of their growing understanding of the concepts these words represent (Cannon, Levine, & Huttenlocher, 2007; Choi & McDonough, 2007; Sarnecka, Goldman, & Slusser, 2014; Wynn, 1990).

Children’s spatial knowledge and skills improve during the preschool period as shown by their deeper understanding of various basic spatial concepts such as properties of objects (e.g., size and shape) and spatial relations between objects (e.g., location) (Aslan & Arnas, 2007; Clark, 1980; Meints, Plunkett, Harris, & Dimmock, 2002; Smith, 1984). With regard to numerical development, children become more accurate in assigning one and only one number word to each object, and learn to use the number words always in the same order when counting a set of objects (e.g., Colomé & Noël, 2012; Sarnecka et al., 2014; for the principles of counting skills, see Gelman & Gallistel, 1978). There is increasing evidence to suggest that spatial and numerical development might be interrelated (e.g., Gunderson, Ramirez, Beilock, & Levine, 2012; Sorariutta et al., 2017; Verdine et al., 2014). We therefore assessed children's spatial and numerical skills at early preschool age and followed up these outcomes one year later.

The knowledge and skills acquired prior to school entry lay the foundation for later development in mathematics (for a review, see Duncan et al., 2007). In a study on Finnish children, Hannula and Lehtinen (2005) found high degrees of stability in mathematical skills from preschool to kindergarten age (from 1st to 3rd and 4th grade, for US studies, see Jordan, Kaplan, Ramineni, & Locuniak, 2009; Mattanah, Pratt, Cowan, & Cowan, 2005). Another Finnish study reported even higher stabilities, as well as increasing variance from kindergarten age up to 2nd grade (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; for US and Swedish studies, see Burchinal, Peisner-Feinberg, Pianta, & Howes, 2002; Broberg, Wessels, Lamb, & Hwang, 1997). Studies spanning a longer time period between assessments show lower stabilities from kindergarten competence to later mathematical outcomes across grades (Reynolds & Temple, 1998; see also Campbell, Pungello, Miller-Johnson, Burchinal, & Ramey, 2001). Given that few studies have explored longer-term influences beyond primary grades, we decided to collect data on mathematics grades in 9th grade.

Early Social Predictors of Children's Mathematical Development

According to Vygotsky's sociocultural theory (1978), all higher forms of cognition originate from joint activities with more knowledgeable partners. Parents, teachers, and more capable siblings and peers provide guidance during social interactions and support the novice learners' autonomous activities within the zone of proximal development of their cognitive skills. In the language of self-determination theory (e.g., Deci & Ryan, 1985; Vansteenkiste & Ryan, 2013), parents may enhance (or weaken) children's interest and enjoyment in play and exploratory activities and hereby satisfy (or deprive) the basic needs for autonomy and competence, which, through the process of internalization, influence the children's intrinsically motivated behavior and achievement from infancy onwards. This theoretical framework provides the basis for understanding how the social environment influences growth processes across the life span.

The research focusing on autonomy and competence support has resulted in divergent approaches to how to conceptualize and operationalize these two major dimensions of cognitive guidance. The concept of scaffolding, rooted in the Vygotskian theory, describes the educational process through which the more knowledgeable partners' appropriate verbal and non-verbal guidance boosts the children's competence and enables them to reach more advanced developmental levels (Wood, Bruner, & Ross, 1976). Much of the later research on this topic suggests that parental scaffolding predicts a wide range of child outcomes in the context of cognitive development such as language acquisition and self-regulated learning (for reviews, see Mermelshtine, 2017; Pino-Pasternak & Whitebread, 2010; Tamis-LeMonda, Kuchirko, & Song, 2014). Even though young children are initially dependent on scaffolding within the zone of proximal development, they become increasingly competent and independent. The children learn to act more autonomously when the partners gradually reduce their support, as they allow and encourage the novice learners to act independently. A recent meta-analysis mainly based on school-aged children suggests that parents' autonomy support has a positive relation with a variety of desirable academic outcomes (Vasquez, Patall, Fong, Corrigan, & Pine, 2015; see also Mattanah et al., 2005). In one of the few existing studies on parenting in infancy, the two major and interrelated constructs of autonomy support and scaffolding have been shown to differently predict mathematical performance at early preschool age (Sorariutta et al., 2017). Studies based on a somewhat different operationalization demonstrate that a multifaceted construct (or composite score) relates to variation in cognitive outcomes in toddlerhood (Bernier, Carlson, & Whipple, 2010; Mermelshtine & Barnes, 2016). Taken together, based on the way cognitive guidance has been assessed one can argue that the construct seems to represent a broad dimension which varies in structural complexity.

Parents' longer term influences on children's later academic outcomes have been explained by stability in parenting across time. While parenting behaviors were most stable with school-aged children, Holden and Miller (1999) concluded from their meta-analysis that quality of parenting assessed already in infancy can persist over time. It is typical that parents change their behaviors – rather than behave similarly in absolute terms – in response to the growing child's competence but, nevertheless, they seem to maintain their relative position compared with others. For example, Matte-Gagné, Bernier, and Gagné (2013) found that mothers' autonomy support was fairly stable from infancy to preschool age even though such behaviors decreased over time. Else-Quest, Clark, and Owen (2011) also reported evidence for homotypic stability in maternal sensitivity and scaffolding behavior, as well as for heterotypic stability from infancy and preschool age into adolescence. Hence, parenting can have ongoing, cascading, and enduring effects on children's adjustment to educational contexts that require self-regulated learning and academic engagement.

Beyond infancy children become increasingly exposed to social relationships outside the home context. In line with the basic tenets of Bronfenbrenner's theory (1986), various early ecological systems may contribute to children's later academic outcomes. Longitudinal research on out-of-home care experiences has reported positive effects of quality and type of ECEC on children's mathematical outcomes assessed before school age (e.g., Anders et al., 2012; Côté et al., 2013; Li et al., 2013; NICHD ECCRN, 2003; Peisner-Feinberg et al., 2001). Early entry into out-of-home care has also been related to better mathematical skills at kindergarten age (Loeb, Bridges, Bassok, Fuller, & Rumberger, 2007; for academic achievement at school age, see Andersson, 1992). In US samples, more time spent in out-of-home care predicts higher mathematical skills in 5th grade (Belsky et al., 2007) and in 6th grade (Field, 1991; for contrasting findings on Swedish 2nd graders, see Broberg et al., 1997). Finally, scientifically rigorous intervention studies on low-SES families reveal that children enrolled in high-quality ECEC programs from infancy to age 5 outperformed the control children in mathematical achievement from 8 to 21 years of age (Campbell et al., 2001; for extended interventions on older children, see Reynolds & Temple, 1998).

The large-scale prospective longitudinal NICHD study is among the few studies (see also Anders et al., 2012) that has included children's experiences in the family context when exploring to what extent ECEC influence later mathematical outcomes. According to a review of NICHD ECCRN (2006), the quality of the mother-child relationship makes a larger difference to children's later academic outcomes than, for example, quantity of non-maternal care in the typical US range. This evidence highlights the importance of recognizing the crucial factors that influence the link between predictor variables and child outcome variables because the observed relationships may be confounded by selection and omitted variable biases related to intra- and extra-familial characteristics (Jaffee, Van Hulle, & Rodgers 2011; see also Duncan, Magnuson, & Ludwig, 2004; Reynolds & Temple, 1998).

The Present Study

Parents' verbal activities specific for mathematics have been related to children's spatial and numerical skills (e.g., Gunderson & Levine, 2011; Pruden et al., 2011). Thus far, little is known about the earliest contextual precursors of mathematical development. Moreover, the conceptual differences between autonomy support and competence support have received relatively little attention in the literature relating parenting behaviors in infancy to later developmental outcomes. We examine how these two major constructs of mothers' cognitive guidance of infants who are on the threshold of understanding their first words, and amount of home and out-of-home care experiences beyond infancy directly and indirectly associate with children's later mathematical outcomes. We applied path analyses to explore the predicted direct and indirect relations shown in the hypothetical model (Figure 1).

First, we hypothesized that due to stability of parenting behaviors (Else-Quest et al., 2011; Matte-Gagné et al., 2013), the two major constructs, mothers' autonomy support and scaffolding observed during play interactions at age 1;0 would relate to mathematical outcomes. In line with prior evidence (Sorariutta et al., 2017), mothers' autonomy support would be a more powerful predictor of performance on tasks representing complex spatial and numerical tasks during the preschool period, whereas mothers' scaffolding would be a stronger predictor of performance on less complex object location tasks. Moreover, autonomy support would predict children's mathematics grade and academic achievement in general, i.e. grades in other school subjects in the last year of comprehensive school, which would be in concordance with self-determination theory (Deci & Ryan, 1985; Vansteenkiste & Ryan, 2013) and recent empirical evidence (Vasquez et al., 2015).

Second, on the ground of previous findings (NICHD ECCRN, 2006), more ECEC experiences with professional caregivers beyond infancy would foster children's later mathematical outcomes, in addition to their early and ongoing interactional experiences with the mother. In Finland, the first legislation on the role of early childhood education in fostering child development and learning was passed four decades ago (Day Care Act, 1973). Today, the personnel in family-based and center-based settings are supposed to implement the core content areas of the national ECEC curriculum, built on six domains including mathematics (Ministry of Education and Culture, 2016). Thirdly, we expected to find short-term homotypic continuity in spatial and numerical performance from early to late preschool age using the same tasks and procedure across age (see also Aunola et al., 2004; Levine, Huttenlocher, Taylor, & Langrock, 1999). Given the few studies on more far-reaching relationships (e.g., Reynolds & Temple, 1998), we also explored heterotypic continuity between mathematical skills at preschool age and mathematics grade in 9th grade.

In addition to the main research question, the path analyses allowed us to explore background characteristics, i.e. child gender and parent education, which have been shown to directly influence mathematical outcomes (e.g., Anders et al., 2012; Burchinal et al., 2002; Melhuish et al., 2008). We anticipated no gender differences in mathematics in a society with high gender equality, which is in line with a recent meta-analysis (Lindberg, Hyde, Linn, & Petersen, 2010; see also Verdine et al., 2014; for contradicting evidence, see Levine et al., 1999; Lonnemann, Linkersdörfer, Hasselhorn, & Lindberg, 2013). Nor did we expect any selection biases related to mothers' level of education and children's enrollment in ECEC, but we hypothesized that mothers' cognitive guidance would mediate the effect of maternal education on child mathematics in the path models. The empirical evidence for the predicted indirect effect is scarce, given that the regression models applied in previous studies can only demonstrate direct relationships between maternal cognitive guidance and child outcomes above and beyond maternal education (e.g., Mermelshtine & Barnes, 2016; Neitzel & Stright, 2003).

Method

Participants

We report longitudinal data on children and their mothers (N = 66) recruited from the files of the Population Registration Centre, Helsinki, to reduce biased sampling (for more details, see Silvén, Poskiparta, Niemi, & Voeten, 2007). According to these files, Finnish is the native language of the majority of the population (92%). Most Finnish children (84%) live in two-parent families, and about 80% of all children in young families are firstborns. In line with these demographic characteristics, only families who met the following sampling criteria were chosen for the study: first-born children of Finnish-speaking two-parent families living in a middle-to-large city in the south-western region of Finland.

The data were collected at four age levels: the mother-infant observations were collected when the child turned 1 year of age (within one week of the birthday), the mathematical skills were tested when the child turned 3 years (±1 week) and 4 years (±1 week), and the school grades were gathered at the end of 9th grade after the child's 16th birthday. At the time of the first data collection at 1;0 the mothers were 21 to 37 years old (*M* = 27.9, *SD* = 5.0), and had 9 to 23 years of education (*M* = 14.1, *SD* = 3.2). Parental socioeconomic status matched the nationwide distribution reported for the 22–44 age group living in urban areas in Finland (for more details, see Silvén et al., 2007). A unique feature for Nordic welfare states is the high level of social security (e.g., free health care and schooling from first grade through university) that reduces the socioeconomic risks for all citizens. The numbers of boys and girls were 26 (39%) and 40 (61%), respectively. The few missing values (one child at 3;0, five children at 4;0, and one child at 16 years; a total of 1.51% of all values) were imputed using the expectation maximization algorithm (Muthén & Muthén, 2010).

Assessments

Mothers' Cognitive Guidance during Play Interactions in Infancy. Mother-child dyads' play interaction was videotaped at home visits at 1;0. During the semi-structured play sessions, the examiner put a set of small plastic toys representing animals, people, furniture, and other objects on the table and instructed the partners who sat in their own chairs side by side to play just as they would normally do with the toys.

The ten-minute recordings of the mother-child dyads were assessed using the Parent's Interactional Sensitivity with the Child (see Silvén, Niemi, & Voeten, 2002). The on- and offsets of activities were observed by running the recording several times in real time from second to second. The coder marked every change in the flow of activities. The recordings were coded on 7 five-point scales ranging from 1 to 3 (1, 1.5, 2, 2.5, and 3). According to Sorariutta et al. (2017), three of the scales stand for *Autonomy Support*: (scale 1) The child mainly sets the goals for the activities even during moments of joint play between the child and the parent (e.g., the child puts the boy to sleep inside the animal pen with the cow instead of the bed); (scale 2) The parent allows the child's independent activities (e.g., when the child makes the girl drive the car, the parent verbally supports the child's activities); (scale 3) The parent controls and restricts the child's cognitive processes and occasionally even interrupts the child's activities in order to achieve her own goal (e.g., the parent takes the spade from the child who feeds the boy and puts it in the wheelbarrow (scale reversed). Four of the scales represent *Scaffolding*: (scale 4) The parent provides subtle guidance which respects and promotes the child's goals during joint play (e.g., the child puts the girl in bed and the parent gives a blanket); (scale 5) If the parent seeks to influence the child's goals, she sets the new goal slightly above the child's current goal and level of performance (e.g., the child bangs the man with the car, the parent suggests putting the man in the car); (scale 6) The parent assists and guides the child when necessary by dividing the problem into smaller more manageable tasks or breaking it up step by step into smaller sub-problems (e.g., when the child tries to make the girl ride the horse, the parent suggests first putting the girl to sit on the horse-back and then ride the horse); (scale 7) The parent adjusts her guidance to the child's level of cognitive development (e.g., the parent uses simple vocabulary and suggests familiar activities, such as feeding and sleeping). A score of 3 on all scales describes a mother who consistently provides cognitive guidance in a highly sensitive and responsive manner, a score of 2 was assigned to a mother who every now and then provides cognitive guidance in such a manner, and a score of 1 to a mother who rarely provides cognitive guidance to the child (for more details, see Sorariutta et al., 2017).

One trained observer rated all play sessions. Another trained observer independently rated a sample (20 dyads) of the play sessions. The intra-class correlation coefficients for *Autonomy Support* varied between .76–.82 and for *Scaffolding* between .79–.86. In cases where the observers assigned different ratings, both reviewed the recordings together and agreed upon a final score.

Pre-Mathematical Skills at Early and Late Preschool Age. Children's spatial and numerical skills were tested during laboratory visits at 3;0 and 4;0 by two trained female examiners, one for each age level. The Early Language Test (see Silvén et al., 2002) consisted of six sets of four objects, which were used to assess children's understanding of spatial and number concepts. All items were toy replicas of real-world objects such as animals, people, furniture, and familiar to children from everyday routines. After being presented with a set, the child was allowed to play with the objects for 10-20 seconds. Thereafter, the examiner began to stimulate the child with standard questions about the objects. If the child's response was wrong, the examiner did not provide the correct answer. The child's answers and reactions were analyzed from the 15–20-minute long videotapes.

Size Tasks. In the large-small task, the examiner placed two large and two small animals side by side on the table. First, the examiner pointed at the large objects and asked how the horse is similar to the cow (about 4x7 cm in size) and then pointed at the small objects and asked how the dog is similar to the cat (about 2x4 cm in size). Next the examiner asked the child to put the large ones (the horse and the cow) inside the empty animal pen. After placing all animals in the pen, she asked the child to take out the small ones (the dog and the cat). In the tall-short task, the examiner placed two tall and two small people side by side. First, the examiner pointed at the two tall objects and asked how the woman is similar to the man (about 8 cm) and then pointed at the two short objects and asked how the girl is similar to the boy (about 5 cm). Next she asked the child to give her the tall ones (the woman and the man) and then after placing all the toy-people on the table, she asked for the short ones (the girl and the boy). One score was assigned for each correct verbal response *large, small, tall,* and *short* and for each correct requested action. The maximum score of the size tasks is 8.

Shape Tasks. In the round-square task, the examiner showed a ball to the child and asked what shape it is. Next she showed a building block and asked what shape it is. *Round* and *square* were scored as the correct answers (no child produced the word *circle* or *cube*; in Finnish *ball* and *block* are incorrect). After placing a ball, a building block, a car, and a doll side by side on the table, the examiner asked the child to give her a round object and then a square object. Giving or pointing at the ball and the building block were scored as the accurate actions. The maximum score of the shape tasks is 4.

Location Tasks. The examiner placed two toys, a table, and a boy, on the table. Then she put the boy in different locations *on, under, beside,* and *behind* the table, and asked the child each time where the boy is. The following were scored as correct verbal responses for location: "on the table" *pöydän | päällä* [Table of | on] or *pöydä|llä* [Table | on]); "under the table" *pöydän | alla* [Table of | under]; "beside the table" *pöydän | vieressä* [Table of | beside]; "behind" the table" *pöydän | takana* [Table of | behind]. Next, the examiner asked the child to put the boy in different locations *on, under, beside,* and *behind* the table. Putting the boy in the correct location was scored as an accurate response. The maximum score of the location tasks is 8.

Number Tasks. Children's numerical skills were assessed using two different procedures. In the "give me x items" task, there were four animals, four people, and four pieces of furniture on the table. The examiner gave the child three instructions: 1) *give me one* person, 2) *give me two* animals, and 3) *give me three* pieces of furniture. One score was assigned for each accurate action. The maximum score of the "give me x items" task is 3. In the "how many items" task the examiner introduced a baby doll to the child and dressed the doll in trousers, shirt, hat, and shoe. Then the examiner posed the child questions about the number of the baby doll's body parts. One score was assigned for each accurate verbal response: *one* for head, *two* for legs, *three* for head and hands, and *four* for legs and hands. The maximum score of the "how many items" task is 4.

As shown in Table 1, performance on all pre-mathematical tasks at the group level was better at age 4;0 than age 3;0. The alpha coefficients at 3;0 and 4;0 were .47 and .62 for the size and shape tasks, .64 and .58 for the location tasks, and .46 and .53 for the number tasks, respectively. The somewhat low internal consistency is due to the number of tasks, and hence not an impediment to their use (Schmitt, 1996). One trained observer rated all testing sessions, and another trained observer independently rated a sample (20 children) of the sessions. The inter-rater reliability coefficients varied at 3;0 from .82 to .96, and at 4;0 from .97 to 1.00.

Grades in Mathematics and Other School Subjects in 9th Grade. At the end of the final year of the comprehensive school the children were asked to report their latest 16 school grades including mathematics. The grades are based on individual teachers' ratings of the students' performance on examinations and activity during classes. The grades range between 4 (= fail) and 10 (= excellent). We found no differences between the students' reports of their grades (M = 8.3, SD = 0.7) and the actual grades taken from school records (M = 8.2, SD = 0.7) for a subsample of 27 students. Moreover, the association between the two variables was very high (r_p = .99, p < .001). The mathematics grade was used to answer the research question (for descriptive statistics, see Table 2), as well as composite scores based on grades averaged across three subjects areas: natural science (mathematics, physics, chemistry, biology, geography), humanistic science (history, religion), and language and literacy (Finnish, Swedish, and English).

Early Childhood Care. Most Finnish children are cared for at home during their first nine months because all parents are entitled to paid maternity or paternity leave, and then to parental leave. During laboratory visits at 2;0, 3;0, and 4;0, the mothers were asked to fill in questionnaires about child care arrangements such as type and amount of care during the previous year(s). They assessed how many months the child had attended care at home with mother, father, or relative and/or outside the home in family day-care and/or in child-care center. A higher number represents more months of out-of-home care, whereas a smaller number implies more home care during the child's first three and four years of life.

Results

Maternal Predictor and Children's Outcome Variables

Principal Component Analyses (PCA) were performed to obtain a smaller number of maternal predictor variables and reasonable unidimensionality of child outcome variables (Sorariutta et al., 2017). The PCAs on the correlations between the seven maternal scales in infancy resulted in a two-component solution with eigenvalue larger than 1. The PCA distinguished *Autonomy Support* (explaining 76% of the variance in the original scales 1–3) from *Scaffolding* (explaining 67% of the variance in the original scales 4–7).

The two PCAs performed on the correlations between the three spatial variables showed that size and shape loaded high on the first principal component (explaining 55% of the original variance at 3;0 and 59% at 4;0, respectively). We decided to keep the location variable at early and late preschool age as a separate outcome from *Size-Shape* which is in line with suggestions about object-based and environment-based spatial concepts (Hegarty & Waller, 2004). The two PCAs on the two numerical variables, indicating *Number*, explained 63% of the variance at age 3;0, and 54% at age 4;0.

For use in the path analyses, *z*-scores (with mean 0 and variance 1) for each principal component were constructed with the regression method in SPSS (2013). As shown by the descriptive statistics in Table 2, the correlations between the maternal predictor variables and the child mathematical outcome variables were moderate and mainly significant.

Maternal Cognitive Guidance and Children's Mathematical Development

We used path analyses to examine whether mothers' scaffolding and autonomy support assessed from play interactions in infancy, and amount of home and out-of-home care beyond infancy predict children's mathematical development from early to late preschool age and mathematics grade in 9th grade, while controlling for the effect of mother's education. We applied Mplus 6.1 (Muthén & Muthén, 2010) to estimate the regression equations. The Maximum Likelihood Robust (MLR) estimation was chosen because it is robust to non-normality and the distributions of the variables were not normal throughout (West, Finch, & Curran, 1995). In evaluating the goodness-of-fit of the theoretical models to the sample data, we used three indicators suggested in the literature: the Chi-square > .05, the Comparative Fit Index (CFI) > .90 and the Root Mean Square Error of Approximation (RMSEA) < .08 (Browne & Cudeck, 1993; Hoyle & Panter, 1995; Hu & Bentler, 1995).

The path analyses were performed separately for *Size-Shape*, Location, *Number*, and Mathematics Grade. In order to specify how the maternal predictors in infancy were related to differences in the outcome variables, we started with the hypothetical model (see Figure 1). All parameters relating the constructs to one another were estimated. The non-significant effects (p > .05) were removed one by one on the basis of their t-values. Only the end results of the model-fitting process are presented in Figure 2. The fit indices suggest a good fit for all four models. These models include children's home versus out-of-home care experiences during their first three years because care experiences during the first four years were not significantly related to any child outcomes. In all models, the correlation between the two maternal predictors was fairly high (see note of Figure 2).

Figure 2(a) shows the path diagram of the *Size-Shape* model. Mothers who were more supportive of their child's autonomous activities during joint play in infancy tended to have children who performed better in size-shape tasks two years later, as well as three years later, at age 4;0. Neither mothers' *Scaffolding* nor amount of home versus out-of-home care was related to children's size-shape skills. Task performance at 3;0 was not associated with task performance at 4;0. The model explained 11% of the variance in children's size-shape skills at late preschool age.

Figure 2(b) shows a path diagram of the Location model. Mothers who provided more guidance during joint play in infancy were likely to have children who performed better on location tasks. *Scaffolding* was directly associated with child outcomes at age 3;0 and indirectly at age 4;0 (.44 × .44 = .19). Neither mothers' *Autonomy Support* nor amount of home versus out-of-home care was related to children's location skills. Children who performed better on location tasks at 3;0 also performed better one year later. The model explained 19% of the variance in children's location skills at late preschool age.

As shown by the *Number* model depicted in Figure 2(c), mothers who were more autonomy-supportive of their child's activities during joint play in infancy tended to have children with more developed numerical skills at 3;0. In addition to the maternal effect, more time spent in out-of-home care beyond infancy until preschool age was associated with better performance on the numerical tasks at 3;0, whereas more home care experiences was related to poorer performance, respectively. The direct effects of *Autonomy Support* and home versus out-of-home care explained 22% of the variance in numerical skills at early preschool age, but neither could explain growth in skill development from early to late preschool age.

Growth in numerical development appeared to be associated with mothers' *Scaffolding* in infancy. Mothers who provided more cognitive support for their child's activities during play interactions had children who performed better on the number tasks three years later. The direct effect of *Scaffolding* (path coefficient = .26) was somewhat stronger than the indirect effects of mothers' *Autonomy Support* (.35 × .42 = .15) and home versus out-of-home-care (.31 × .42 = .13). Finally, those children who performed better on the numerical tasks at 3;0 also performed better one year later. The model explained 29% of the variance in children's numerical performance at 4;0.

Finally, we explored the effects of maternal predictors on children's mathematics grades in 9th grade. We started with the hypothetical model (see Figure 1). The fit statistics of all developmental models using one pre-mathematical variable at a time as a predictor of mathematics grades indicated an unacceptable model fit. We therefore ran the Mathematics Grade model without the pre-mathematical variables. Figure 2(d) shows that mothers' *Autonomy Support* in infancy was related to variation in children's mathematics grades 15 years later. *Scaffolding* and amount of home versus out-of-home care experiences had no effect on mathematics grades. The model explained 12% of the variance in mathematics at the end of comprehensive school.

To explore whether the parenting effects are unique to mathematical achievement, we then ran the models replacing, one at a time, the mathematics grade with the three composite scores of grades. In all models, mothers' *Autonomy Support*, but not *Scaffolding*, was positively related to grades in natural science, humanistic science, and language and literacy (*βs* ranged from .44 to .47). The model explained 22% of the variance in academic achievement at the end of comprehensive school.

The direct effects of maternal education on children's mathematical skills were not significant. As shown in all models (a) – (d) depicted in Figure 2, more years of maternal education was related to higher levels of *Autonomy Support* and *Scaffolding.* There were significant indirect effects of mothers' education through *Autonomy Support* on *Size-Shape* at 3;0 (a), on *Number* at 3;0 and at 4;0 (c), and mathematics grades in 9th grade (d), and through

Scaffolding on Location at 3;0 and at 4;0 (b). To explore the stability of the models, we reran the regression models without maternal education, as well as with child gender. The predictive relations between cognitive guidance and mathematical skills in Figure 2 remained essentially the same. Child gender was not related to mathematical performance at any age level.

Discussion

The present study carried out in a North European country ranking high in international comparisons on education systems provides new knowledge about the earliest precursors to success in mathematics at preschool age and at the end of comprehensive school. Our findings suggest that maternal autonomy support and scaffolding during joint play interaction in infancy and amount of ECEC beyond infancy contributed more to variation in numerical skills than spatial skills during the preschool period. To our knowledge, few studies have linked maternal autonomy support at a very early age with later school achievement. It is also interesting that maternal education was associated with child outcomes at preschool and school age through quality of mother-child interaction but not selection of child care arrangements. As it is well known that parenting and education systems differ across societies (e.g., Pianta, Barnett, Burchinal, & Thornburg, 2009), the findings of Finnish families can be generalized to other Western societies with high gender equality and relatively similar education systems.

Autonomy Support and Scaffolding as Predictors of Mathematical Development

We drew on the theoretical approach to successful learning and development advocated by Vygotsky (1978; see also Wood et al., 1976) and Deci and Ryan (1985; see also Vansteenkiste & Ryan, 2013) but, in contrast to previous studies on mathematical outcomes (Belsky et al., 2007; Martin et al., 2007; NICHD ECCRN, 2003), we kept apart conceptually distinct parenting dimensions (for reviews, see Mermelshtine, 2017; Pino-Pasternak &

Whitebread, 2010; Vasquez et al., 2015). The two-component PCA solution reported here can be regarded as support for the conceptual difference between autonomy support and scaffolding based on observations of mother-child play interactions (see also Sorariutta et al., 2017). However, when interpreting the relations between parenting and child outcomes, one should take into account the fairly high correlation between the two maternal dimensions in the path models.

The path model on children's numerical development revealed differential maternal effects as a function of child age: autonomy support predicted variation in numerical skills at early preschool age, whereas growth in development during the preschool period appeared to be somewhat more strongly associated with maternal differences in scaffolding than in autonomy support. This pattern of findings might reflect an ongoing process of successive change from autonomy support to scaffolding and back again repeatedly. It seems that mothers who allow independent exploration of toys, can become aware of the child's step-by-step progress and, by encouraging participation, provide appropriate scaffolding when needed within the zone of proximal development. This educational process probably promotes learning throughout development because, drawing on studies on stability of parenting (Else-Quest et al., 2011; Holden & Miller, 1999; Matte-Gagné et al., 2013), these key elements in mother-child interactions, autonomy support and scaffolding, tend to persist beyond infancy.

The path models on spatial development suggest differential maternal effects as a function of task complexity, findings which are in line with prior evidence from the same children (Sorariutta et al., 2017). Autonomy support was associated directly, at both early and late preschool age, with children's competence on object size and shape tasks involving complex spatial skills. Scaffolding, on the other hand, was related directly to competence on less complex object location tasks at early preschool age, as well as indirectly one year later through the child's own competence level. The path model on school grades sheds further light on the antecedents of optimal functioning by revealing patterns similar to those found in early childhood. Mothers who were more autonomy-supportive during joint play in infancy tended to have children who performed better not only in mathematics but in all school subjects as much later as at the end of comprehensive school. From the point of view of stability of parenting (Else-Quest et al., 2011; Matte-Gagné et al., 2013), a single assessment in infancy may represent one moment of an ongoing and enduring dynamic process which has a general influence upon variation in later learning and development (Holden & Miller, 1999) including academic achievement in secondary school (see also Vasquez et al., 2015).

It seems that early autonomy- and competence-oriented behaviors evident already in infancy gradually prepare the child for an educational environment that requires self-regulation and academic engagement. Taken together, mothers who foster the need for autonomy may boost the child's confidence and self-reliance in optimal functioning even when exposed to demanding tasks, whereas satisfying the need for competence may contribute to the child's joy and pleasure resulting from the activities themselves. Then again, the bidirectional influences, as shown by the fairly high correlation between the two maternal dimensions, may imply that autonomy support involves appropriate levels of maternal scaffolding adapted to the child's task-specific developmental needs for competence. This interpretation is concordant with the basic tenets of self-determination theory (Deci & Ryan, 1985, Vansteenkiste & Ryan, 2013). When parents successfully support their child's feelings of autonomy and competence, they maintain and enhance the child's intrinsically motivated behavior as indicated by the child's interest and enjoyment in optimal functioning, which enables parents, in turn, to reduce their support as the child takes increasing responsibility for later adjustment to new more demanding tasks. This process may be reflected in the finding that students' self-reliance in the classroom assessed at 1st grade is a more powerful predictor of mathematical achievement at 3rd grade than a maternal construct partly based on autonomy support at kindergarten age (NICHD ECCRN, 2008).

Our findings on mathematical development during the preschool period are in agreement with prior studies showing short-term homotypic continuity in Finnish children's performance on numerical tasks before and after transition to school (Aunola et al., 2004; Hannula & Lehtinen, 2005). With respect to spatial skills, there was developmental continuity in children's performance on location tasks, a finding which extends prior cross-sectional studies (Clark, 1980; Meints et al., 2002). The path models did not confirm continuity in more complex spatial skills even though at the group level the children on average performed better on size and shape tasks at late preschool age than one year earlier. This is consistent with earlier cross-sectional findings suggesting that four-year-olds perform better on spatial tasks than three-year-olds (Aslan & Arnas, 2007; Smith, 1984). The discontinuity reported here might result from a ceiling effect due to many children's high performance at early preschool age on the tasks requiring actions (e.g., the child puts the large animals inside the pen) and, on the other hand, from a floor effect due to many children's low performance at late preschool age on the demanding verbal response tasks (e.g., the child names the shape of the squared object).

Regarding heterotypic continuity, the few studies that have reported longer term influences up to the end of primary or secondary school have been based on achievement tests (Duncan et al., 2007; Reynolds & Temple, 1998). We found no evidence that performance on spatial and numerical tasks during the preschool period would predict differences in mathematics grade composed of highly advanced and multiple skills in algebra, geometry, and trigonometry, as well as teachers' ratings on students' activity in class at the end of comprehensive school (see Mullola et al., 2010). It is plausible that assessments of mathematics during the transition to school may have yielded acceptable fit indices for the

Mathematics Grade model reported here. Longitudinal studies spanning a shorter time period have found that mathematical performance before school entry strongly predicts later school achievement (Aunola et al., 2004), suggesting that more temporally proximal measures might be better predictors.

ECEC, Maternal Education, and Gender as Predictors of Mathematical Development

Amount of experiences in family-based and center-based settings from infancy to preschool age made a unique contribution to children's numerical outcomes, over and above the effects of mothers' autonomy support and scaffolding in infancy. More time spent in ECEC was related to higher proficiency and more growth of numerical skills, whereas more home care experiences were related to lower proficiency and less growth during the preschool period. However, the same relationship did not hold for spatial skills. One reason for this pattern of findings may be that mathematics is often understood as dealing with knowledge of number and number operations and, therefore, spatial skills have to some extent been ignored in the curriculum of ECEC (see also Clements & Sarama, 2011). Even though we did not find far-reaching effects of ECEC experiences on mathematics grade in 9th grade, our finding confirms other Nordic evidence on students from lower grades (Broberg et al., 1997; for contradictory evidence from US studies, see Belsky et al., 2007; Field, 1991; for high-quality interventions on low-SES children in US studies, see Campbell et al., 2001; Reynolds & Temple, 1998).

It is obvious that children attend day-care services because parents seek early education and care services due to their interest in promoting, in addition to their own employment, their children's development, and school readiness. It is worth noting that in our path analyses, mothers' educational background had no influence on how much time children spend outside the home context in ECEC during their first three years of life. This is in contrast to evidence from other societies suggesting that children of more highly educated mothers tend to enter out-of-home care at an early age (Andersson, 1992), tend to spend more time in out-of-home care (NICHD ECCRN, 2006), and tend to experience higher quality care (Côté et al., 2013; NICHD ECCRN, 2006) compared to children of less well educated mothers. Our path analyses also revealed that years of education per se have no direct influence on child outcomes as suggested by some studies (e.g., Anders et al., 2012). Instead, more highly educated mothers provided more cognitive guidance during joint play in infancy and were more supportive of their child's autonomous activities, which in turn were related to children's mathematical skills at preschool age and school age. This evidence indicates that the quality of early cognitive guidance mediates the relation between maternal education and child outcomes. This indirect relationship provides new insight into the mechanism of intergenerational transmission of education, when taking into account that previous studies have shown a direct effect of parents' as well as grandparents' educational level on children's school achievement (e.g., Ferguson & Ready, 2011; for cross-cultural evidence, see OECD, 2012).

As expected in a society with high gender equality, boys and girls performed equally well on spatial and numerical tasks at preschool age (see also Verdine et al., 2014) and in 9^{th} grade, which is in concordance with PISA findings of Finnish students (OECD, 2012). A recent meta-analysis by Lindberg et al. (2010) has shown that gender differences in mathematics performance are very small and, depending on the sample and outcome measure, sometimes favor boys and sometimes girls (e.g., Aunio, Aubrey, Godfrey, Pan, & Liu, 2008; Levine et al.,1999).

Methodological Considerations and Conclusions

Some major methodological strengths and limitations should be taken into account when interpreting and generalizing the results of our longitudinal study. To reduce biased sampling, the participating families representing the south-western region of Finland were chosen from the register of the total population. Furthermore, the children were enrolled in different early childhood care settings and comprehensive schools which made the sample more representative in this respect. The sample size of the present study is small but typical for laborious micro-level coding of interaction, and for estimating regression models for dyadic data (Kenny, Kashy, & Cook, 2006). The attrition rate was small, ensuring that loss of data did not bias the findings, and the few missing values were imputed using a strongly recommended technique (Baraldi & Enders, 2010). The pre-mathematical tasks have meaningful content coverage, the upper limits of validity ranged from .68 to .80, and the inter-rater reliabilities were very high (see also Schmitt, 1996; Streiner, 2003). It has been shown that self-reported grades should be used with caution because they might include some bias (Kuncel, Credé, & Thomas, 2005). The Finnish students' reports were highly accurate and reliable when compared with actual grades taken from school records.

Controlling for potential factors that might determine the expected relations is one way to ensure that the estimated effects are not biased (Duncan et al., 2004; Jaffee et al., 2011). We used path analyses, an efficient tool for testing mediation and moderation (Baron & Kenny, 1986), to explore the predictive relations between early developmental contexts and child mathematical outcomes across the 15-year follow-up and controlled for maternal education and child gender. The time span linking maternal autonomy support with later school achievement is clearly longer than in any previous study (e.g., Belsky et al., 2007). Among the major limitations of the study is the lack of assessments of children's mathematical skills on the one hand and self-regulation skills on the other hand during the transition periods from preschool age through kindergarten to first school years. In addition, observations of the quality of out-of-home care would have strengthened the findings reported here.

The present study provides further evidence that, in addition to parents' mathematical speech that emerges during early childhood (Gunderson & Levine, 2011; Pruden et al., 2011), quality of cognitive guidance, assessed as early as in infancy, relates to mathematical development at preschool and at school age irrespective of the amount of time children spend in various early childhood care contexts. This knowledge can be implemented in academic teacher education to further improve pedagogical training and collaboration between parents and professionals in ECEC. To date, longitudinal studies including both parents' interactions with their child are still scarce but such studies are needed to understand the process by which the family context affects mathematical outcomes. Given that parents vary greatly in cognitive guidance, it would be valuable to identify those who would benefit from training in autonomy-supportive and scaffolding behaviors. The challenge for future research is to design evidence-based interventions programs that focus on effective means of supporting mathematical development.

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Table 1

Children's Pre-Mathematical Skills at 3;0 and at 4;0: Descriptive Statistics and the Results of Paired Sample t-tests (N = 66)

	at 3;0		at 4;0		
	M (SD)	Range	*M (SD)*	Range	*t(65), p*
Size	1.89 (1.02)	0–4	2.89 (1.25)	1–8	5.40, .001
Shape	1.28 (0.71)	0–3	2.07 (0.95)	0–4	6.15, .001
Location	5.76 (1.65)	1–8	6.24 (1.39)	3–8	2.44, .017
"Give me x"	1.73 (0.73)	0–3	2.71 (0.47)	1–3	9.86, .001
"How many"	1.02 (0.95)	0–4	2.12 (0.87)	0–4	8.45, .001

Table 2

Maternal and Out-of-Home Care Predictors and Children's Mathematical Outcomes: Descriptive Statistics

	M (SD)	Range	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. *Autonomy Support*	-	-2.40–1.26	-											
2. *Scaffolding*	-	-1.58–1.83	.56**	-										
3. Out-of-Home Care at 3;0	11.64 (8.91)	0–26	-.05	-.11	-									
4. Out-of-Home Care at 4;0	17.81 (11.79)	0–38	-.04	-.07	.93**	-								
5. *Size-Shape* at 3;0	-	-2.46–2.09	.40**	.28*	.06	.04	-							
6. Location at 3;0	5.76 (1.65)	1–8	.41**	.44**	.01	.02	.11	-						
7. *Number* at 3;0	-	-2.16–2.21	.34**	.20	.29*	.31**	.47**	.21	-					
8. *Size-Shape* at 4;0	-	-1.72–3.31	.34**	.30*	.05	.10	.22	.23	.28*	-				
9. Location at 4;0	6.24 (1.39)	3–8	.28*	.22	-.01	-.02	.18	.46**	.28*	.23	-			
10. *Number* at 4;0	-	-2.66–1.88	.33**	.34**	.03	.01	.34**	.20	.47**	.37**	.27	-		
11. Mathematics Grade	8.06 (1.24)	5–10	.34**	.24	-.10	-.11	-.05	.41**	.15	.10	.23	.07	-	
12. Education	14.08 (3.15)	9–23	.32**	.42**	.05	.11	.15	.11	.28*	.14	-.03	.19	.05	-

Note. *p < .05, **p < .01. The italicized variables represent principal components (for the original variables, see Assessments). Scores are reported in standardized *z*-scores with mean 0 and variance 1.

Figure 1. Hypothetical Model Illustrating Relations between Mothers' Cognitive Guidance, Children's Mathematical Skills, and Background Variables.

Figure 2. Mothers' *Scaffolding* and *Autonomy Support* as Predictors of Children's *Spatial* and *Numerical Skills* at 3;0 and 4;0 and Mathematics Grade in 9th Grade. Standardized Regression Coefficients (N = 66). *Note.* The fit statistics for (a): $\chi^2(7) = 2.46$, $p = .93$, CFI = 1.00, RMSEA = .00; (b): $\chi^2(9) = 7.13$, $p = .62$, CFI = .97, RMSEA = .06; (c): $\chi^2(7) = 5.09$, $p = .65$, CFI = 1.00, RMSEA = .00; (d): $\chi^2(5) = 2.12$, $p = .83$, CFI = 1.00, RMSEA = .00. Depending on the model, the correlation between maternal predictors was .49 or .50.

Note. **$p < .01$, *** $p < .001$.

Figure 1. Hypothetical model

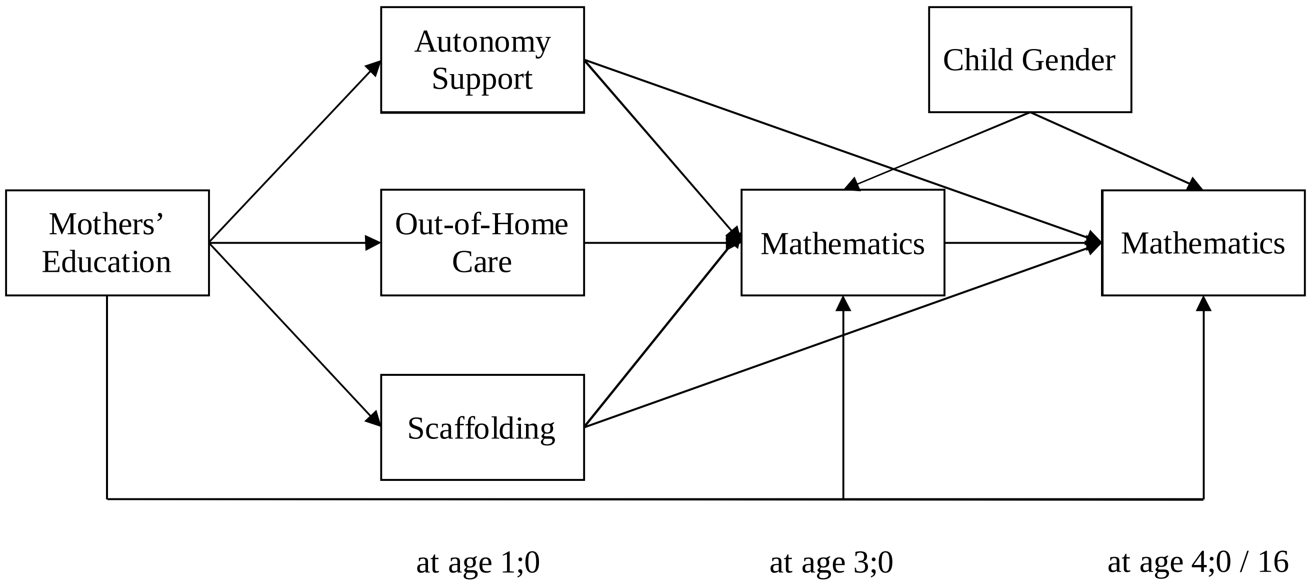

Figure 2(a). *Size-Shape* Model

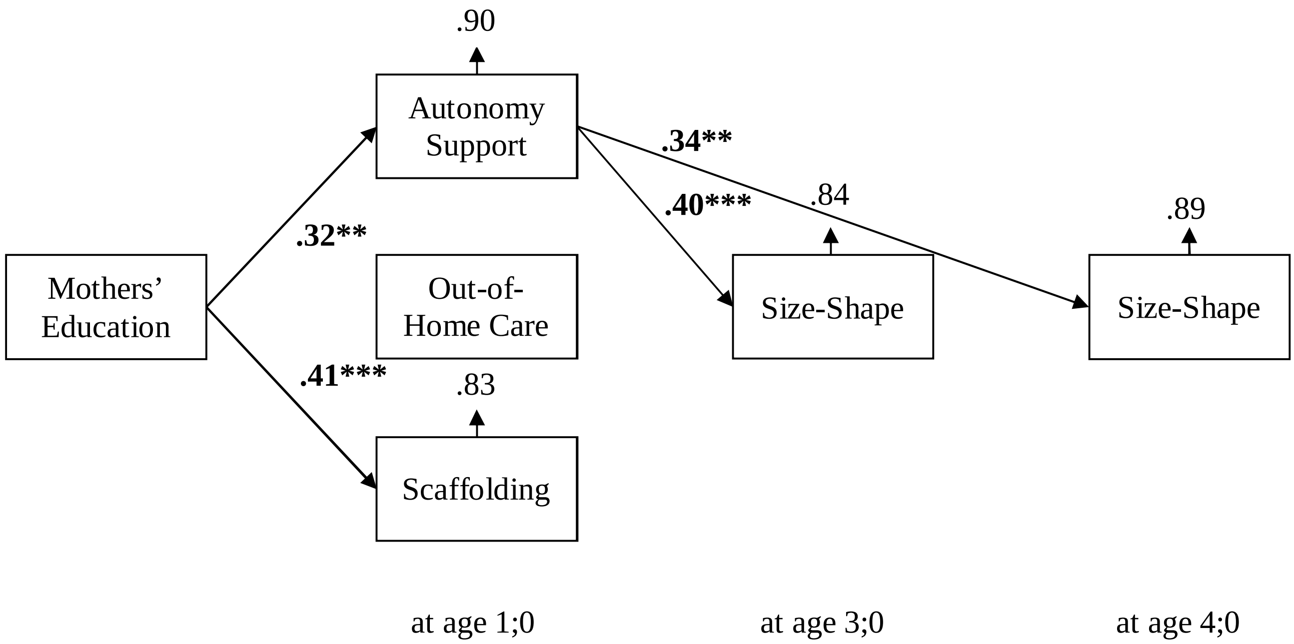

Figure 2(b). Location Model

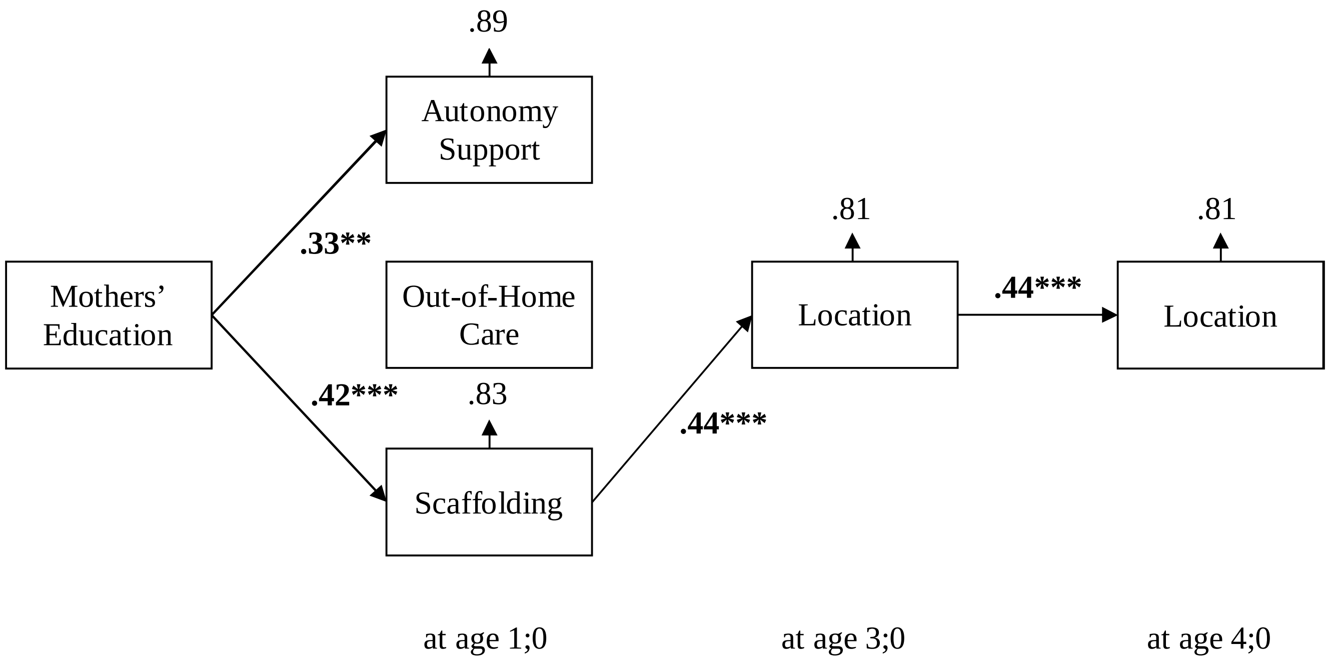

Figure 2(c). *Number* Model

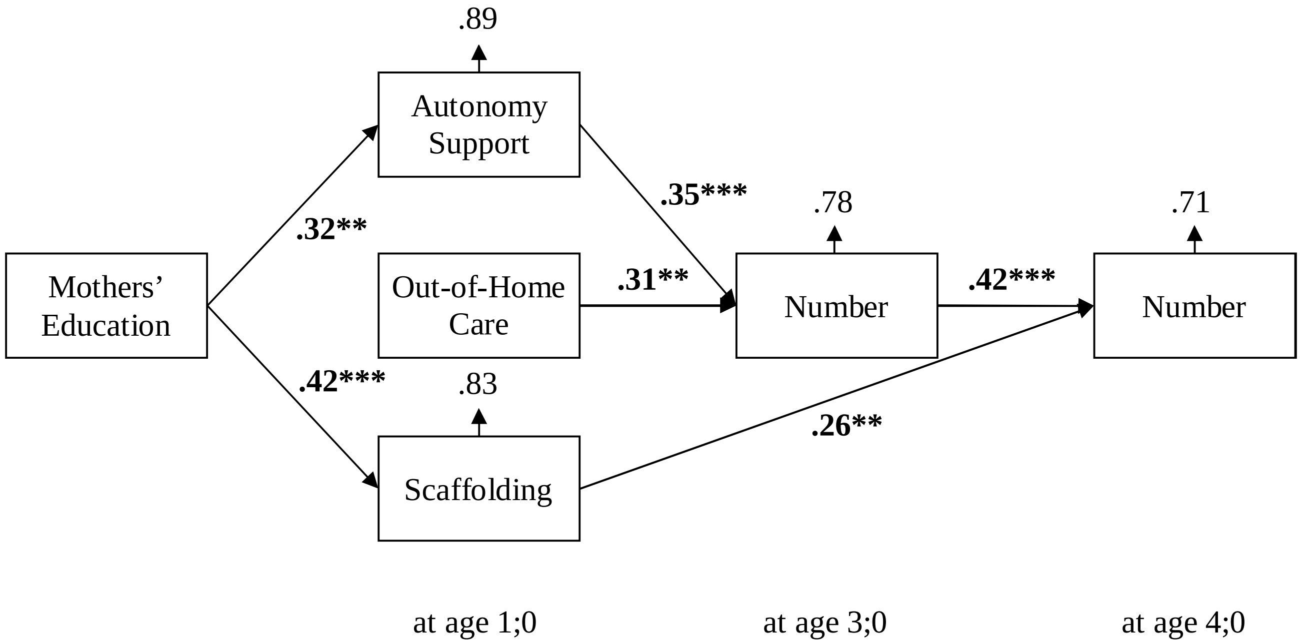

Figure 2(d). Mathematics Grade Model