



# The Role of the Home Learning Environment on Early Cognitive and Non-Cognitive Outcomes in Math and Reading

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The home learning environment (HLE) has been considered to contribute to children's early math and reading development. Previous studies examined the HLE by examining the influence of parent-child math and reading activities on math and reading outcomes, however also parents' own perceptions of math and reading and their math anxiety (MA) and reading anxiety (RA) contribute to the HLE but the latter factors have been scarcely explored. The aim of this study was to provide a more holistic view of the HLE and its relations with children's cognitive and non-cognitive outcomes in math and reading at the start of primary school. This paper examined the relations within the HLE, and the relations between the HLE and children's early math and reading outcomes. Participants were 301 first-grade children and their parents. The HLE was measured by the parent questionnaire. Children's digit comparison, number line estimation, letter knowledge and phonological awareness skills were measured as well as their math and reading anxiety levels. The results demonstrated a significant association between parents' perceptions and their anxiety towards math and reading. No significant associations were found between parents' perceptions towards math and the frequency of home numeracy activities, whereas significant relations were found in the domain of reading. Socioeconomic status was found to provide a unique contribution in children's digit comparison and math anxiety, while no significant relations were observed between other HLE factors and children's outcomes. The current study suggests the importance of including parents' perceptions and feelings to explore the dynamics of the HLE and its impact on children's math and reading outcomes.

**Keywords:** home learning environment, home numeracy environment, home literacy environment, early numeracy, early literacy

## INTRODUCTION

Math and reading abilities are essential in people's life. They are not only the foundation of basic education and later academic performance, but also contribute to future economic and social life such as employability and political participation (Hulme & Snowling, 2013; Schneider et al., 2017; OECD, 2019). Previous studies observed that math and reading abilities begin to develop long before entering primary school, and individual differences in their development already exist at the start of formal instruction (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Duncan et al., 2007). Moreover,

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such differences at the start of formal instruction seem to persist in later learning, even after interventions (Aunola et al., 2004; Hulme & Snowling, 2013). Therefore, it is important to explore what contributes to these individual differences in initial math and reading outcomes before formal instruction.

Children's math and reading developments are multi-dimensional processes influenced by not only their individual factors, such as cognitive and non-cognitive factors (Ramirez et al., 2018, 2019), but also environmental factors such as the home learning environment (HLE) (Anders et al., 2012; Skwarchuk, Sowinski, & LeFevre, 2014; Susperreguy, Douglas, Xu, Molina-Rojas, & LeFevre, 2018). The HLE has been generally understood as the way in which families engage and provide children interactive activities and resources (e.g., puzzles and books) related to math and reading (Manolitsis et al., 2013; Niklas & Schneider, 2017a). However, previous studies often operationalised the HLE only by measuring the frequency of home learning activities (e.g. Manolitsis et al., 2013) whereas also parents' own perceptions and feelings towards math and reading may be an important part of the HLE as well (Kluczniok et al., 2013). In addition, little is known about the HLE's impact on children's non-cognitive outcomes in math and reading, such as math anxiety (MA) and reading anxiety (RA).

This study aims to provide a comprehensive view of the HLE by examining multiple measures. In addition to measuring the activities parents do with their children, this study includes also measures of parents' own perceptions of math and reading as well as parents' own MA and RA. Furthermore, we explore the role of the HLE on children's early cognitive and non-cognitive outcomes in math and reading. First, cognitive and non-cognitive factors in the domain of math and reading are described which are predictive for later academic performance. Second, several components of the HLE, the relationships between these components and how these might influence children's cognitive and non-cognitive outcomes are discussed.

## Individual Factors in Children's Math and Reading Development

### Domain-Specific Cognitive Factors of Math

Previous research has established that early math abilities, basic intuitive skills such as symbolic and non-symbolic number knowledge, are crucial in children's math development (Sasanguie et al., 2012; Schneider et al., 2017). Symbolic number knowledge refers to an understanding and ability to use numerosity representation by digits, and non-symbolic number knowledge refers to that by non-digits (Sasanguie et al., 2012; Schneider et al., 2017). Some studies demonstrated that symbolic number knowledge is more crucial to math development than non-symbolic number knowledge (Schneider et al., 2017).

To examine early math abilities, digit comparison and number line estimation tasks are frequently adopted in multiple studies, using digits for symbolic and dots for non-symbolic number knowledge assessments (Schneider et al., 2017, 2018). Cross-sectional and longitudinal associations have been shown between early math precursors with broader mathematical

competence such as counting, arithmetic, and algebra (Aunola et al., 2004; De Smedt et al., 2013; Sasanguie et al., 2013). Furthermore, early numerical skills are foundational to acquire higher-level mathematical competence. In sum, to enhance math development, stimulation of these early math abilities is crucial.

### Domain-Specific Cognitive Factors of Reading

The literature on reading development states the importance of early reading precursors for future reading achievement (Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004). Gunn et al. (1995) use the term "emergent literacy" to refer to such early reading precursors, which begins to develop before formal reading instruction by acquiring through home environment, preschool or other informal environments. Emergent literacy consists of literacy knowledge (e.g., letter knowledge, phonological awareness, text structure comprehension) and literacy experiences such as story reading (Gunn et al., 1995).

Among these early reading precursors, letter knowledge and phonological awareness have been proved to be the best predictors for reading achievement across several studies (Sénéchal & LeFevre, 2002; Niklas & Schneider, 2017b). Letter knowledge encompasses of awareness of print, knowledge of letter sounds and letter names, which lead to acquisition of new vocabulary (Schatschneider et al., 2004). Phonological awareness is broadly defined as an ability to understand the sound structure of oral language (Niklas & Schneider, 2017b). Many developmental studies have shown that individual differences in phonological awareness and letter knowledge influenced beginning word-reading skills as well as later reading skills at least through fourth grade (Wagner et al., 1997; Lyytinen et al., 2006). A meta-analysis by Melby-Lervåg et al., 2012 revealed that phonemic awareness was the strongest correlate of individual differences in word reading ability.

### Domain-Specific Non-Cognitive Factors of Math

Recently, researchers have shown an increased interest in domain-specific non-cognitive factors in children's math development, namely MA. MA is broadly understood as a feeling of anxiety and tension in math-related situations (Dowker et al., 2016; Ramirez et al., 2018). Various studies observed a negative correlation between MA and math performance, which could be partially explained by MA's influence on working memory (see review by Dowker et al., 2016). For example, Cargnelutti et al. (2017) conducted a study on Grade 4 students to explore the relation between cognitive factors (working memory and magnitude processing speed) and non-cognitive factors (general anxiety and MA). In this study, they observed that students with higher MA were likely to perform weaker in math than their peers with lower MA.

Interestingly, MA seems to have a different impact on children with different gender. A study by Van Mier, Schleepen, and Van den Berg (2019) showed that girls were more likely to have higher MA than boys, and a correlation between MA and performance was significant only for girls. Additionally, it is known that MA increases as children grow, maybe due to the increase in general anxiety in adolescence, or as a result of facing parents' and

teachers' negative attitudes toward math (Dowker et al., 2016). However, with a limited number of studies, the parents' role on children's MA remains unclear (Dowker et al., 2016).

### Domain-Specific Non-Cognitive Factors of Reading

Regarding reading development, domain-specific non-cognitive factors such as reading motivation, self-concept, and anxiety have been examined by multiple studies (Katzir et al., 2018; Ramirez et al., 2019). Recently, there has been a renewed interest especially in the role of RA in children's reading development. RA, a negative reaction or fear against acts and situations of reading (Ramirez et al., 2019), is suggested as a factor which undermines reading performance. Ramirez et al. (2019) demonstrated that RA of the first and second grade students were negatively associated to their reading performance, and this relation was stronger than the association between their positive reading affect (interest and positive attitude) and reading performance. In the study by Katzir et al. (2018), the relation between early reading skills and non-cognitive factors such as RA and reading self-concept of second graders were explored, and it was found that there was a moderate but negative correlation between RA and reading self-concept. Taken together, RA may be a critical component which impacts not only concurrent reading performance, but also later reading achievement.

### The Relation Between Early Numeracy and Literacy

Research has emphasized the importance of cross-domain relations between early numeracy and literacy. A recent review on the similarities and differences between the development of reading, writing and number acquisition by Moura et al., 2021 emphasized how precursors of math are related to reading development and vice versa. For example, Krajewski and Schneider (2009) showed that individual differences in phonological awareness assessed at an early stage in kindergarten influence math performance in school assessed a few months later. Also, studies investigating children and adults with reading difficulties showed that people with a reading disorder show poorer performance on particular mathematical tasks like fact retrieval (De Smedt et al., 2010; Göbel, 2015).

## Home Learning Environment

The impact of the HLE on math and reading has been examined separately by most of the studies; the home environment concerning math is called the *home numeracy environment*, and that of reading is named the *home literacy environment* (LeFevre et al., 2009; Niklas & Schneider, 2017b).

### Home Numeracy Environment

#### *Frequency of Home Numeracy Activities*

Extensive research has examined *home numeracy activities*, math activities parents do with their children (del Río et al., 2017; LeFevre et al., 2009; Susperreguy et al., 2018). Typically, researchers examined the home numeracy environment by requesting parents to report frequency of home numeracy activities. These practices include not only parents' teaching of math, but also math-related activities in various contexts at home (LeFevre et al., 2009; Skwarchuk et al., 2014).

To illustrate the complexity of home numeracy activities and its effects on children's math development, Skwarchuk et al. (2014) developed a home numeracy model, which categorises two types of home numeracy activities: *formal numeracy activities* which aims to teach math concepts (e.g., counting, arithmetic), and *informal numeracy activities* without such aim but related to math (e.g., playing number related games at home, assisting while parents cook). Drawing from this model, multiple studies found the link between home numeracy activities and children's math performance. Positive relations were shown between formal numeracy activities and children's math performance (Sasanguie et al., 2012; Skwarchuk et al., 2014; Huntsinger et al., 2016; Mutaf Yıldız et al., 2018). Skwarchuk et al. (2014) demonstrated that formal numeracy activities predicted symbolic number knowledge. Mutaf Yıldız et al., 2018 found a significant association between children's enumeration and the home numeracy activities. Moreover, advanced formal numeracy activities have been presented as a strong predictor of children's math performance (Skwarchuk et al., 2014; Huntsinger et al., 2016). In contrast, the relation between informal numeracy activities and children's math performance has been debated. Some studies found a link between informal numeracy activities and non-symbolic arithmetic knowledge of children (Skwarchuk et al., 2014; Susperreguy et al., 2018), whereas Huntsinger et al. (2016) found a negative correlation between informal home numeracy activities and children's math performance.

#### *Parents' Perceptions of Math*

Multiple studies examined the relationship between parents' perceptions of math and the frequency of math activities they provide to their children at home. Perceptions of math are generally understood as their beliefs, interests, and attitude toward math (Skwarchuk, 2009; Skwarchuk et al., 2014). Susperreguy et al. (2018) found that parents with more positive math attitudes and higher academic expectations toward their children reported a higher frequency of advanced math activities provided to their children at home. Additionally, parents' own positive math experiences were found as a predictor of children's math performance (Skwarchuk, 2009). Together, these studies indicate that parents' perceptions of math may be a critical component of the home numeracy environment which fosters children's math development.

#### *Parents' MA*

With limited number of studies, the role of parents' MA on children's math development remains unclear. del Río et al. (2017) showed that parents with lower MA were more likely to frequently do advanced math-related activities with their kindergartener children than parents with higher MA. Maloney et al. (2015) examined the intergenerational impact of MA from parents to their first and second grade children, and found a negative significant relation between parents' MA and children's math achievement when parents reported to give frequent help in their children's math homework. Moreover, this negative correlation was statistically significant even after controlling for parents' math knowledge and children's school

factors such as teachers' factors (MA and math knowledge) and their schools' SES levels (Maloney et al., 2015). These findings may imply that parents' support in children's math development do not always result in a positive impact on children's math performance, considering the role of parents' MA. Overall, previous studies underscore the importance of more examinations on the role of parents' MA in children's math development.

## Home Literacy Environment

### *Frequency of Home Literacy Activities*

Multiple studies examined the link between home literacy activities and children's early reading performance. Similar to home numeracy activities, home literacy activities are broadly separated into *formal literacy activities*, which involves formal literacy instruction and *informal literacy activities*, which do not aim but touch literacy concepts (Sénéchal and LeFevre, 2002). Sénéchal and LeFevre (2002) observed that formal literacy activities were related to the children's emergent literacy skills such as decoding skills and letter knowledge, whereas informal literacy activities (e.g., storybook reading) accounted for vocabulary and listening comprehension skills. Moreover, they found that vocabulary and listening comprehension were not significant reading predictors in Grade 1, while emergent literacy skills and phonological awareness were significant predictors.

The findings of Sénéchal and LeFevre (2002) were replicated by some studies (Niklas & Schneider, 2013; Skwarchuk et al. (2014). In contrast, some scholars confirmed only a part of those findings (Liu et al., 2018), indicating that mixed findings exist in the relation between home literacy activities and children's reading performance (cf. Sénéchal & LeFevre, 2002; Skwarchuk et al., 2014). Generally, home literacy activities are found to be an important predictor for not only early literacy skills but also for reading achievement (Huntsinger et al., 2016; Manolitsis et al., 2013; Niklas & Schneider, 2013, 2017a). Yeo et al. (2014) found that parents who provide frequent reading activities generally had children who performed higher in reading than their peers. Huntsinger et al. (2016) found that reading activities provided by parents significantly predicted children's concurrent reading scores. Thus, home literacy activities, especially formal literacy activities, seem to be a key aspect of the home literacy environment. Furthermore, the recent studies suggest the need of more examinations of the home literacy model across different cultural contexts.

### *Parents' Perceptions of Reading*

While many studies focused on parents' perceptions of their children's reading performance (e.g., Martini & Sénéchal, 2012), few studies focused on parents' own perceptions of reading in the field of HLE. Baker and Scher (2002) observed that parents' own pleasure in reading was a strong predictor of children's motivation in reading for enjoyment, accounting for 16% of variance. Moreover, children whose parents enjoy reading as a pleasure are found to have more positive attitudes than their peers whose parents perceive reading as a skilled activity (Baker & Scher, 2002). Since motivated readers are likely to engage in more reading activities and have higher reading achievement (Tunmer

& Greaney, 2008), the impact of parents' perceptions of reading should not be underestimated.

### *Parents' RA*

In comparison to MA, research on parents' RA is scarce. A study by Dobbs-Oates, Pentimonti, Justice, and Kaderavek (2015) demonstrated that parents' negative beliefs in shared reading was a robust predictor of children's letter knowledge; the fewer negative beliefs the parents had towards shared reading, the higher the children tended to perform on the letter knowledge task. Although Dobbs-Oates et al. (2015) did not focus on parents' RA, their study indicates that parents' own negative attitudes towards reading may impact their children's reading performance. Furthermore, as argued above, parents' positive attitude towards reading (e.g., reading motivation) has been known to have positive impacts on children's reading attitude. This suggests that children's non-cognitive outcomes in reading may be also influenced by parents' negative attitude towards reading (i.e., RA). Therefore, like MA, intergenerational effects of RA would be interesting to explore.

## Cross-Domain Relations Between the HLE and Children's Development

Recent studies examined the cross-domain relations between the HLE and children's math and reading development (Anders et al., 2012; Segers, Kleemans, & Verhoeven, 2015; Napoli & Purpura, 2018). Findings about relations between children's math outcomes and the HLE seem to be incompatible. Anders et al. (2012) and Manolitsis et al. (2013) demonstrated that both home numeracy environment and home literacy environment were significant predictors of children's early math skills. On the contrary, Segers et al. (2015) and Susperreguy et al. (2018) showed that parents' reports of literacy activities did not predict children's early numeracy skills.

A few studies examined the impact of the HLE on children's math and reading outcomes simultaneously. A longitudinal study by Huntsinger et al. (2016) showed that home numeracy activities predicted concurrent math and reading outcomes of children, however such math activities did not continue predicting children's reading outcomes a year later. Napoli and Purpura (2018) examined the cross-domain relations between the home numeracy environment and the home literacy environment. The home numeracy environment was found to be a predictor of children's numeracy and vocabulary, while the home literacy environment did not predict children's numeracy (Napoli & Purpura, 2018). Overall, the cross-domain relations between the HLE and children's outcomes are still unclear.

### **Impact of SES**

SES, indicated by parents' educational levels and income, is frequently examined as a factor that impacts the HLE (Chung, 2015; del Río et al., 2017; Niklas & Schneider, 2013). SES is known as a predictor of children's early math and reading skills (Hartas, 2011; Anders et al., 2012), and the HLE is considered to play a mediating role between SES and children's cognitive skills in math and reading (del Río et al., 2017; Niklas & Schneider, 2013; Mutaf Yildız et al., 2018). A recent review of 37 articles on the

relationship between home numeracy and mathematical skills concluded that there are positive associations between home numeracy activities and SES (Mutaf Yıldız et al., 2018). However, the moderating effects of SES on the relation between home numeracy and children's mathematical skills still has to be disentangled.

Elliott and Bachman (2018) suggest a relation between parents' math cognitions and SES; they claim that communication between parents and children or cultural capitals may be different across parents' educational levels, as their beliefs of education could be influenced by their educational backgrounds. For the association between SES and frequency of home learning activities, mixed findings exist. Susperreguy et al. (2018) observed that parents with higher education level were likely to provide advanced numeracy activities to their children more frequently than parents with lower education level. On the other hand, del Río et al. (2017) found that low-SES mothers engaged in advanced numeracy activities more than high-SES mothers. All in all, more examination is needed to explore the relations between SES and other HLE factors.

## Gaps in Research

Although extensive research has been conducted on the HLE, multiple gaps remain. Firstly, few studies examined the impact of parents' own perceptions toward math/reading and parents MA/RA (i.e., indirect factors of the HLE), and how they relate to the frequency of home learning activities (e.g., Skwarchuk et al., 2014; Susperreguy et al., 2018). Particularly, parents' MA/RA seem to be neglected in numerous studies.

Secondly, only a few studies examined the impact of these indirect measures (e.g. parents' perceptions towards math/reading) of the HLE on cognitive outcomes of children (e.g., del Río et al., 2017). From the Vygotskian view which highlights importance of social interactions with more knowledgeable people such as parents in children's learning (Niklas & Schneider, 2017a; Elliott & Bachman, 2018), the indirect measures of the HLE on children's cognitive outcomes is understudied, although they may impact interactions between parents and children.

Thirdly, the relations between the HLE and children's non-cognitive outcomes such as MA and RA are not sufficiently explored (Cargnelutti et al., 2017). Notably, far too little attention has been paid to the impact of the indirect factors of the HLE on children's non-cognitive outcomes. Since the importance of non-cognitive factors in children's math and reading development has been acknowledged, more studies should address how the HLE is related to these aspects in addition to cognitive factors.

## Present Study

This study aims to provide a more holistic view of the HLE and its relations with children's cognitive and non-cognitive performance in math and reading. To fill the research gap, this paper addresses three research questions. Firstly, this paper explored how the HLE factors are related. Specifically, it examined how parents' indirect factors (i.e. parents' perceptions of math/reading and MA/RA), direct factors (frequency of the

home learning activities in math and reading), and SES were related. Additionally, the cross-domain relationships between the home numeracy environment and the home literacy environment were examined. A positive relation between parents' perceptions of math and frequency of the home numeracy activities, and a positive relation between parents' perceptions of reading and frequency of the home learning activities were expected.

Secondly, this study investigated the relations between the HLE factors and the children's cognitive outcomes in math and reading. Positive relations between the frequency of home learning activities and children's cognitive outcomes in each domain were hypothesized. Also, positive associations between parents' perceptions of math and children's cognitive outcomes in math, and the same associations in the reading domain were predicted. Moreover, positive relations between SES and children's cognitive outcomes were expected.

Thirdly, the relations between the HLE factors and the children's non-cognitive outcomes in math and reading were explored. This research question which explores the impact of the HLE's on children's non-cognitive outcomes is exploratory.

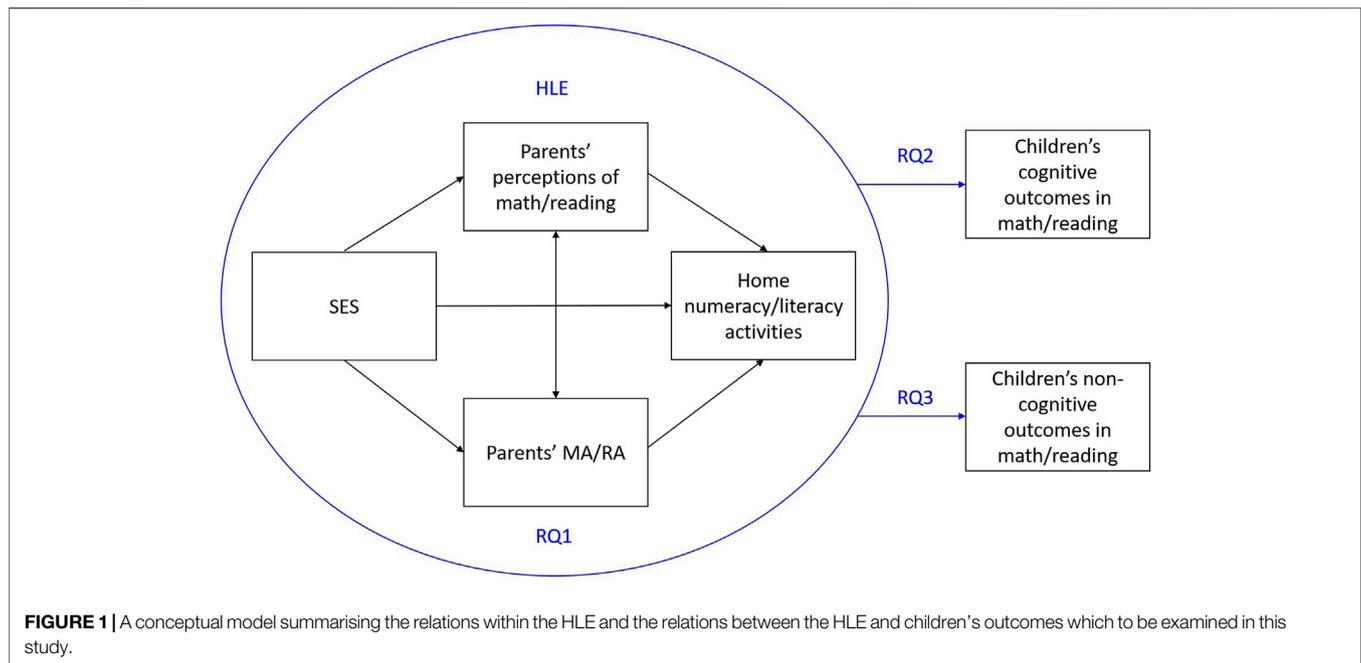
The relations to be examined in this study are summarised in **Figure 1**. For children's cognitive factors, digit comparison and number line estimation tasks were examined for math ability, while letter knowledge and phonological awareness were chosen as predictors for their reading ability. Participants were at the start of primary school at the time of the data collection, so it was too early to assess arithmetic skills or reading fluency. The predictors were selected for their robustness as precursors for early development in math and reading. At the start of first grade, most children were able to perform early math and reading tasks due to formal (e.g. preschool) and informal (e.g. home) learning experiences. For children's non-cognitive factors, MA and RA were examined. This choice was motivated by the relative scarcity of research on MA and RA of young children, especially in relation to the HLE.

To the best of our knowledge, this is the first study to include parents' own perceptions of math and reading together with their MA and RA. This study aimed to provide a more comprehensive view of the HLE in comparison to previous studies. Moreover, this study included both math and reading domains of the HLE as well as children's outcomes, which enabled us to give a broader view of the HLE and its relations with children's performance.

## METHODS

### Participants

Participants were 336 children in Grade 1 and their parents from 10 primary schools in Flanders, Belgium. This sample was chosen because at the start of grade 1, children have received little formal math and reading instruction yet and therefore instruction has limited impact on children's performance. Moreover, children of this age are able to perform tests and questionnaires measuring their cognitive and noncognitive factors in a reliable way (which is more difficult to achieve with kindergartners due to difficulties with understanding and expressing feelings). Parental consent forms were obtained from the participating children. The return



rate of the parents' questionnaire was 89.6%. Children whose parents did not submit the questionnaire were excluded ( $n = 35$ ). The final participants consisted of 301 first graders (137 boys,  $M_{\text{age}} = 6.35$  years) and their parents. The majority (88%) of the participants' home language was Dutch; 30 families (10%) spoke other languages than Dutch as their home language, and this data was missing for six families (2%).

The independent sample  $t$ -test revealed significant differences between the children included in the analyses and those excluded. On average, the excluded children were older by 0.22 years ( $t(331) = -2.92$ ;  $p = 0.00$ ), and 28.6% of the excluded children spoke other languages than Dutch at home ( $t(326) = 3.4$ ,  $p = 0.00$ ).

## Data Collection

The data was collected from the participants in the context of the larger-scaled LEAPS research project (<https://www.imec-int.com/nl/imec-icon/research-portfolio/leaps>) to develop a self-learning system based on adaptive learning (see also Vanbecelaere et al., 2019, 2020). For children's data, the pretest results of the study by Vanbecelaere et al. (2020) were used in this analysis. The data was collected at their schools in the beginning of the academic year during the school hours. Although various measures were taken in this study, several efforts were made to avoid over-testing children (for details, see Vanbecelaere et al., 2020).

For parents, a paper questionnaire was distributed in the parents' meetings in October 2017 where explanation about the research project was provided. During these meetings, the researchers provided translation of the questionnaire for parents who needed assistance in Dutch. The parents who did not attend these meetings received the paper questionnaire from their children's teachers. Parents were requested to submit the

completed questionnaire to the schools via their children by the specified date, and they received a reminder 1 week before the deadline if they had not submitted yet. The researchers collected the paper questionnaires from the schools.

## Materials

### Children's Measurement

#### Cognitive Outcomes

To assess cognitive outcomes in math, digit comparison and number line estimation tasks were used. For reading, letter knowledge and phonological awareness were measured.

For digit comparison, a paper-and-pencil one-digit subtest of the Symbolic Magnitude Processing Test (SYMP Test; Brankaer, Ghesquière, & De Smedt, 2017) was used. The subtest consists of 60 pairs of single digits (1–9) shown in four columns with 15 pairs. The distance between two digits of the pair was one for the half of the pairs, and three or four for the other half. The task included all the possible combinations of these distances, and the digit pairs were presented randomly. Children were asked to indicate the larger digit of each pair and solve as many items as possible in 30 s. The SYMP Test was selected for its reported satisfactory reliability ( $r = 0.70$  for Grade 1) and satisfying construct and criterion-related validities, indicated by significant and stable correlations with math achievement (Brankaer et al., 2017). Considering the possible influence by children's general motor speed, a paper-and-pencil test for motor speed was also given (Brankaer et al., 2017). The number of correctly answered items was used for the outcome index.

For the number line estimation task, children were asked to mark a target number on an empty number line. The number line was 25 cm length with 0 on the left and 10 on the right endpoints, and the to-be-positioned number was presented at the centre, 6 cm above this line. Children performed nine trials in total, for

all the digits (1–9) at random. Percent absolute error (PAE) for each trial was calculated with the formula by Siegler and Booth, 2004, (p. 432):

$$PAE = \frac{Estimate - Target\ Number}{Scale\ of\ Estimates} \times 100$$

The mean of all the nine trials' PAE was used as the outcome index.

The letter knowledge task (Aarnoutse, Beernink, & Verhagen, 2016) measured the extent of children's ability to match letter sounds to graphemes. The task included 21 items, where each item had a picture of a caterpillar with 22 graphemes placed respectively in its segments. Children were asked to listen to the letter uttered by the instructor, and then shade the matching grapheme of the caterpillar. The Cronbach's alpha of the test was 0.90 (Verhagen, Aarnoutse, & Van Leeuwe, 2009).

For the phonological awareness task (Aarnoutse et al., 2016), children listened to isolated letter sounds of a word (e.g., b-u-s), and indicated the corresponding image out of four different images. 24 items were given to the children in this task, including four practice items. This test has satisfactory reliability (Cronbach's alpha = 0.89; Verhagen et al., 2009) and consistent validity (Aarnoutse, et al., 2016; Verhagen et al., 2009).

### Non-Cognitive Outcomes

Children's MA was measured by the adapted version of Child Math Anxiety Questionnaire by Ramirez, Chang, Maloney, Levine, and Beilock (2016). Specifically, the questionnaire was translated into Dutch, the number of items were reduced from 16 to 8, and some of the math problems were adapted into Flemish contexts (cf. Vanbecelaere et al., 2020). In parallel, the RA scale composed of 8 items was developed by Vanbecelaere et al. (2020) based on the Flemish reading curriculum. The adapted MA and RA scales (see supplementary materials) had a Cronbach's alpha of 0.77 respectively (Vanbecelaere et al., 2020). The levels of MA and RA was measured by a 4-point Likert scale from *very scared* (1) to *not scared at all* (4). To encourage children's interpretation, a picture of a face was paired with each anxiety level. The corresponding mean scores were used for the outcome indices of MA and RA.

### Measurement of HLE

The HLE was measured by the questionnaire about the following three variables each for math and reading: parents' perceptions, parents' domain-specific anxiety, and the frequency of home learning activities. If 75% of the items were answered for each variable, the means were calculated. If not, they were eliminated from the analyses. The questionnaire was conducted in Dutch (English translations are included in supplementary materials).

### Parents' Perceptions of Math and Reading

We developed four items each to measure parents' perceptions of math and reading. Parents answered their preference and opinions of math and reading on a 5-point Likert scale respectively, ranging from *strongly disagree* (1) to *strongly agree* (5). The coding for item B was reversed as it inquires

negative attitude towards math or reading. The questionnaire had satisfactory reliability; both parents' perceptions of math and reading had the Cronbach's alpha of 0.84. The mean scores of each scale were used as indices.

### Parents' MA and RA

Parents' MA was assessed with *The Abbreviated Math Anxiety Scale (AMAS)* by Hopko et al. (2003). The scale consisted of nine items, and parents were asked to answer their degree of anxiety in math-related situations with a 5-point Likert scale, ranging from *not nervous at all* (0) to *very nervous* (4). The internal consistency of the AMAS was satisfactory (Cronbach's alpha = 0.90). In parallel with the AMAS, we developed a parents' RA scale with nine items (Cronbach's alpha = 0.89). Each mean score was used as indices of MA and RA.

### Frequency of Home Numeracy Activities and Home Literacy Activities

For frequency of the home learning activities, the questionnaire developed by Skwarchuk et al. (2014) was used. Parents reported the frequency of 13 numeracy activities and 11 literacy activities they do with their children based on the following 5-point Likert scale: *never* (0), *monthly* (1), *weekly* (2), *several times per week* (3), and *daily* (4). The sums of the items were used as indices of home numeracy and literacy activities. The Cronbach alpha's of the home numeracy and literacy activities scale can be found in the results section.

### SES

The maternal degree was asked in the parents' questionnaire as a proxy of children's SES. Our sample was slightly oriented to higher SES, however considered as representative of the Flemish population (Statbel, 2019); 19.6% reported to have a degree from lower secondary education or below, labelled as *low* SES; 36.5% had a degree from higher secondary education, labelled as *middle* SES; and 42.2% had a tertiary education degree, labelled as *high* SES. This information was missing for 1.7% of the participants.

### Data Analysis

The data analysis was conducted with IBM SPSS Statistics for Windows, Version 26.0. Supplementary materials and data are freely available at: [https://osf.io/39xrv/?view\\_only=d51baa573daa4eaf978e9ad7dd79bdba](https://osf.io/39xrv/?view_only=d51baa573daa4eaf978e9ad7dd79bdba). Firstly, following Skwarchuk et al. (2014), principal component analyses (PCA) were conducted for home numeracy and literacy activities for data reduction. For the first research question, correlation analysis was conducted to examine the relations among the HLE factors, namely parents' perceptions of math/reading, MA/RA, frequency of home numeracy/literacy activities, and SES. To address the second and the third research questions, the relations between the HLE factors and children's cognitive and non-cognitive outcomes were examined by correlational analyses and one-way ANOVA. In this analysis, children's gender and age were treated as control variables. If meaningful correlations were observed, regression analyses were conducted to examine the unique contributions of the variables. All the statistical tests were conducted at  $\alpha = 0.05$  level. More detailed

**TABLE 1** | Bivariate correlations among the HLE factors.

	1	2	3	4	5	6
1. Parents' perceptions of math						
2. Parents' MA	-0.451**					
3. Frequency of home numeracy activities	0.055	0.05				
4. Parents' perception of reading	0.057	-0.07	0.153**			
5. Parents' RA	0.007	0.379**	-0.09	-0.492**		
6. Frequency of home literacy activities	-0.015	0.016	0.716**	0.206**	-0.130*	

Note. N = 289. \* $p < 0.05$ , \*\* $p < 0.01$ .

explanation about the conducted analyses can be found in the results section.

## RESULTS

### Data Reduction of Home Learning Activities

Following Skwarchuk et al. (2014), the home learning activities whose frequencies close to the theoretical minimum (0) and maximum (4) with less than one standard deviation were eliminated (see supplementary data). Specifically, item A and K of the home literacy activities were excluded (see **Supplementary Table S5 in Supplementary Material**). Next, PCAs were conducted for the frequencies of the home numeracy activities and the home literacy activities respectively to explore the components, and consequently group the related activities. Since missing data in each activity was less than 10, they were replaced with mean (Field, 2018, p. 804–805). The results of PCAs were non-satisfactory, as more than 50% of non-redundant residuals had absolute values greater than 0.05 in both numeracy and literacy activities. Concerning this unsatisfactory fit (Cf. Field, 2018, p. 812), the results of PCA were not used for further analyses. Instead, mean scores were calculated for home numeracy activities (Cronbach's alpha = 0.87) and literacy activities (Cronbach's alpha = 0.83) for further analyses.

### Relations Among HLE Factors

To examine the relationship within the HLE factors, bivariate correlations were computed (**Table 1**, descriptive statistics are in **Supplementary Material**). In the math domain, a significant negative correlation between parents' math perceptions and parents' MA was observed, indicating that parents with more positive perceptions towards math were more likely to have less MA. No statistically significant correlations were found between frequency of home numeracy activities and parents' perceptions of math or MA. Hence, the hypothesised positive correlation between parents' perceptions of math and frequency of home numeracy activities was not confirmed. In the reading domain, all three factors were observed to be significantly correlated with each other. Parents' perceptions of reading were negatively correlated with parents' RA. As hypothesised, a positive correlation between parents' perceptions of reading and frequency of home literacy activities were observed. Thus, parents with more positive perceptions towards reading were

likely to have less RA and do reading-related activities with their children more frequently. Parents' RA was.

Negatively correlated with frequency of home literacy activities, meaning that parents with higher RA were likely to do reading-related activities with their children less frequently.

For cross-domain relations, a significant correlation between parents' MA and RA was found, meaning that parents who experience higher MA were more likely to also have RA. Moreover, frequency of home numeracy activities was highly correlated with frequency of home literacy activities. Therefore, parents who do math-related activities with their children more frequently were likely to do reading-related activities more frequently. Lastly, a small but positive correlation was observed between frequency of home numeracy activities and parents' perceptions of reading.

One-way ANOVA was conducted to compare means of the HLE factors on SES levels. Welch  $F$  tests and Games-Howell's post-hoc tests were used for parents' perceptions of math, MA and RA, as heterogeneity of variance was identified. For the other variables, Gabriel post-hoc tests were adopted, as sample size differed across SES levels (Field, 2018).

In the math domain, a significant mean difference among SES on parents' perceptions of math was found,  $F(2, 166.45) = 12.883$ ,  $p < 0.001$ ,  $\eta^2 = 0.08$ . A Games-Howell's post-hoc test demonstrated that high SES parents had a significantly higher mean score of the perceptions of math than low SES ( $p < 0.001$ ) and middle SES parents ( $p = 0.001$ ). No significant mean difference was found between low SES and middle SES parents ( $p = 0.27$ ). Concerning MA, a significant mean difference in parents' MA on SES levels was found,  $F(2, 141.94) = 4.80$ ,  $p = 0.01$ ,  $\eta^2 = 0.03$ . A Games-Howell's post-hoc test showed that the mean score of high SES parents was significantly lower than that of low SES parents ( $p = 0.03$ ). No significant mean difference was found between high and middle SES parents ( $p = 0.06$ ) and low and middle SES parents ( $p = 0.69$ ). There was no significant mean difference of frequency of home numeracy activities on SES levels,  $F(2, 289) = 0.41$ ,  $p = 0.67$ ,  $\eta^2 = 0.003$ . Overall, high SES parents were likely to have more positive perceptions of math and less MA compared to low and middle SES parents. Frequency of home numeracy activities did not significantly differ across parents' SES levels.

In the reading domain, a significant mean difference of parents' perceptions of reading on SES levels was found,  $F(2, 293) = 7.57$ ,  $p = 0.001$ ,  $\eta^2 = 0.05$ . A Gabriel post-hoc test indicated that the mean score of high SES parents was significantly higher than middle SES ( $p = 0.01$ ) and low SES parents ( $p = 0.001$ ). However, no significant mean difference was observed between

**TABLE 2** | Correlations among control variables, HLE factors and children's cognitive outcomes.

	1	2	3	4	5	6	7	8	9	10	11	12
1. Age												
2. Gender	-0.113											
3. Motor speed	0.178**	0.074										
4. Digit comparison	0.177**	-0.059	0.527**									
5. NLE (PAE)	-0.002	0.044	-0.08	-0.160**								
6. Letter knowledge	0.231**	0.107	0.230**	0.385**	-0.08							
7. Parents' perceptions of math	-0.118	0.053	0.066	0.105	-0.088	0.069						
8. Parents' MA	0.08	-0.017	-0.07	-0.116	0.069	-0.105	-0.462**					
9. Home numeracy activities	0.006	0.07	0.101	0.106	-0.062	0.047	0.05	0.079				
10. Parents' perceptions of reading	-0.104	-0.057	.162**	.177**	0.01	0.109	0.053	-0.083	0.113			
11. Parents' RA	0.06	0.03	-0.104	-0.093	-0.042	-0.017	0.014	0.366**	-0.049	-0.493**		
12. Home literacy activities	-0.023	0.117	0.112	0.107	-0.004	0.066	-0.014	0.052	0.713**	0.201**	-0.091	

Note. NLE (PAE) = number line estimation (percentage absolute error). N = 270. \*\* $p < 0.01$ .

low and middle SES parents ( $p = 0.61$ ). No significant mean difference was found for parents' RA and frequency of home literacy activities across SES levels,  $F(2, 153.60) = 0.60$ ,  $p = 0.55$ ,  $\eta^2 = 0.004$  for RA and  $F(2, 288) = 0.64$ ,  $p = 0.53$ ,  $\eta^2 = 0.004$  for frequency of home literacy activities. Taken together, the high SES parents had a significantly more positive perceptions of reading than the low and middle SES parents. However, parents' RA and the frequency of the home literacy activities were not significantly different among SES levels on average.

## Relations Between HLE Factors and Children's Cognitive Outcomes

The ceiling effect was observed in phonological awareness, as 42.2% of children had all the trials correct. Hence, phonological awareness was omitted for further analyses. No outliers, a score below or above three standard deviations, were detected in children's cognitive outcomes (see **Supplementary Material** for descriptive statistics).

Bivariate correlations were computed to examine the relation between children's cognitive outcomes and the HLE factors with control variables (**Table 2**). For control variables, no significant correlations between gender and children's cognitive outcomes were found, whereas age had significant correlations with digit comparison and letter knowledge. The motor speed was a control variable for digit comparison. The analysis revealed no significant correlation between children's early math skills and the home numeracy environment, or between children's early reading skills and the home literacy environment. A significant correlation was found between children's digit comparison and parents' perceptions of reading.

One-way ANOVA was conducted to examine the associations between SES and children's cognitive outcomes. A significant mean difference among SES in children's digit comparison was observed,  $F(2, 288) = 14.515$ ,  $p < 0.001$ ,  $\eta^2 = 0.1$ . A Gabriel post hoc test showed that the mean score of high SES children was significantly higher than middle SES ( $p = 0.002$ ) and low SES children ( $p < 0.001$ ). The mean difference between middle SES and low SES children was not significant ( $p = 0.06$ ). No significant mean difference in number line estimation was found on levels of SES,  $F(2, 279) = 0.810$ ,  $p = 0.45$ ,  $\eta^2 = 0.01$ . For letter knowledge,

no significant mean difference was observed on levels of SES,  $F(2, 287) = 1.157$ ,  $p = 0.32$ ,  $\eta^2 = 0.01$ . In sum, high SES children performed in digit comparison significantly higher than low and middle SES peers, however no significant difference was observed in other cognitive outcomes across SES levels. A hierarchical regression analysis was conducted to examine the unique contribution of SES on digit comparison, after controlling age, gender and motor speed in the first model (see **Supplementary Material**). SES accounted for 4.8% of the variance in digit comparison,  $F_{\text{change}}(2, 282) = 10.396$ ,  $p < 0.001$ .

## Relations Between HLE Factors and Children's Non-Cognitive Outcomes

Three outliers (a score above or below three standard deviations from the mean) were found in children's MA and children's RA. However, skewness was smaller than  $|1|$ , and the boxplots did not detect any outliers. Hence, no child was removed from this analysis.

Bivariate correlations were calculated to examine the relations among children's non-cognitive outcomes, the HLE factors and control variables (**Table 3**). We observed significant correlations between gender and children's MA as well as RA. It should be reminded that children's MA and RA were ranged from *very scared* (1) to *not scared at all* (4). Hence, this indicates that girls were more likely to have higher MA and RA. Age was not significantly correlated with neither children's MA or RA. Regarding the HLE, no statistically significant correlation was observed between children's non-cognitive outcomes and the HLE factors.

One-way ANOVA was conducted to compare means of children's non-cognitive outcomes based on SES. A significant mean difference among SES on children's MA was found,  $F(2, 287) = 4.046$ ,  $p = 0.02$ ,  $\eta^2 = 0.03$ . The Gabriel post hoc test showed that the mean score of high SES children was significantly higher than that of middle SES children ( $p = 0.014$ ), however the difference was not significant from low SES children's mean score ( $p = 0.57$ ). No significant mean difference in MA was observed between middle and low SES children ( $p = 0.56$ ). For children's RA, no significant mean difference was found across SES levels,  $F(2, 287) = 0.838$ ,  $p = 0.43$ ,  $\eta^2 = 0.001$ .

**TABLE 3** | Correlations among control variables, HLE factors and children's non-cognitive outcomes.

	1	2	3	4	5	6	7	8	9	10
1. Age										
2. Gender	-0.097									
3. Children's MA	0.007	-0.230**								
4. Children's RA	-0.055	-0.118*	0.639**							
5. Perceptions of math	-.120*	0.03	0.061	0.017						
6. Parents' MA	0.082	0.008	-0.021	-0.03	-0.463**					
7. Home numeracy activities	0.005	0.063	0.09	0.071	0.05	0.062				
8. Perceptions of reading	-0.085	-0.057	0.089	-0.011	0.056	-0.071	0.152*			
9. Parents' RA	0.051	0.035	-0.021	0.037	0.003	0.368**	-0.083	-0.498**		
10. Home literacy activities	-0.033	0.092	0.068	0.07	-0.005	0.03	0.726**	0.213**	-0.116	

Note. N = 283. \* $p < 0.05$ , \*\* $p < 0.01$ .

To examine the unique contribution of SES on children's MA, a hierarchical regression analysis was conducted. This was examined in the second model, after entering the control variables in the first model (see **Supplementary Material**). SES accounted for 2.2% of the variance in children's MA,  $F_{\text{change}}(2,283) = 3.306$ ,  $p = 0.04$ .

## DISCUSSION

This study proposed a more holistic conceptualisation of the HLE compared to previous literature. We scrutinised the HLE by investigating parents' perceptions of math/reading and MA/RA, frequency of home numeracy and literacy activities and SES. Particularly, we explored (1) the relations among the HLE factors, (2) the relations between the HLE factors and children's cognitive outcomes in math and reading, and (3) the relations between the HLE factors and children's non-cognitive outcomes in math and reading. With a multifaceted view of the HLE, this study disentangled the complexity in relations between the HLE and children's early math and reading abilities.

### Relations Within the HLE Factors

Regarding the relations within the HLE factors, the hypotheses pointed to a positive relation between parents' perceptions of math and the frequency of home numeracy activities, and likewise for the reading domain. The correlational analysis demonstrated that this hypothesis was confirmed only in reading; a statistically significant correlation was found between parents' perceptions of reading and frequency of home literacy activities, however not for math. A similar result was observed in Skwarchuk et al. (2014), who also found a significant relation between parents' attitude and home activities only in reading. On the contrary, Susperreguy et al. (2018) observed that parents with more positive math attitudes and higher academic expectations reported a higher frequency of home numeracy (mapping and operational) activities. These incompatible results may be due to the differences in age of children. Thompson, Napoli, and Purpura (2017) showed that frequency and levels of home numeracy activities depend on children's ages. Our participants were approximately 2 years older than the participants in Susperreguy et al. (2018), and

1 year older than those in Skwarchuk et al. (2014). The set of home numeracy activities by Skwarchuk et al. (2014) may not have been the best measure to reflect the actual learning activities of older children as in our study. All in all, future work is needed to examine these relations.

In both math and reading domains, moderate negative correlations were observed between parents' perceptions and anxiety in math and reading, indicating that how they perceive math or reading both concurrently and retrospectively were associated with domain-specific anxiety. This finding underscores the importance of examining MA and RA in learning, in consideration of the association between them and learning experiences. For the relations between indirect and direct measures of the HLE, no significant correlation was found between parents' MA and frequency of home numeracy activities. This outcome is contrary to that of del Río et al. (2017) who found a significant negative relation. On the other hand, RA had a small but significant negative correlation with frequency of home literacy activities. These results suggest that indirect measures of the HLE partially explain the differences in quality of the young children's HLE.

SES was found to be associated with parents' perceptions of math and reading, and parents' MA, whereas no significant relation was found with home learning activities. In line with Hartas (2011) our participating parents provide a wide range of learning activities for their children at home regardless of their SES. However, parents' capability of supporting children may be different across SES or parents' educational levels. Hence, it is critical to take into account indirect measures of the HLE as well as SES when planning interventions on parents to support their children's learning.

For the cross-domain relationships, a moderate significant relation between MA and RA, and a strong positive relation between the frequency of home numeracy activities and that of home literacy activities were identified. This means that parents who provide more home numeracy activities were likely to provide home literacy activities. Although no significant correlation between parents' perceptions of math and that of reading was found, our findings imply that parents tended to value both math and reading activities equally for their children. In sum, our study suggests that parents' perceptions and domain-

specific anxiety plays a part in building HLE to stimulate children's early math and reading abilities.

## The Relations Between the HLE and Children's Cognitive Outcomes

The second research question investigated the relations between the HLE factors and children's cognitive outcomes in math and reading. It was hypothesised that there would be a positive relation between the frequency of home learning activities and children's cognitive outcomes in math and reading domains respectively. The correlation analysis demonstrated no significant relations between the home learning environment and children's early math and reading skills. One-way ANOVA showed a significant relation between children's SES levels, indicated by their maternal education levels, and the digit comparison. Hence, the findings of the current study do not support the previous research (e.g., Skwarchuk et al., 2014). For example, Skwarchuk et al. (2014) found a positive relation between children's symbolic number knowledge (number identification, magnitude, counting and ordinal numbers) and advanced formal home numeracy activities. Mutaf Yıldız et al., 2018 observed a significant relation between symbolic number line estimation and the home numeracy, however the relation between digit comparison and the home numeracy was insignificant. This discrepancy could be attributed to the differences in kinds of home learning activities adopted in each study, which may have tapped into different early math abilities of children. For reading, another possible explanation for this inconsistency is test materials. For instance, Skwarchuk et al. (2014) and Huntsinger et al. (2016), who found a significant relation between the reading-related activities and children's reading skills, conducted a test including both letter knowledge and word knowledge. Hence, the HLE might provide significant impact on early reading ability which involves words and their meaning rather than letter knowledge.

## The Relations Between the HLE and Children's Non-Cognitive Outcomes

Regarding the third research question, there was no statistically significant relation between the HLE factors and children's non-cognitive outcomes in this study. There are two possible explanations for this finding. Firstly, the contents children learn through the home numeracy activities in their early stage of learning math (e.g., basic number knowledge) may be different from the math concepts which parents are fond of or anxious with. Secondly, children and their parents have a different amount of experiences in math, which may contribute in different levels of MA (Ramirez et al., 2018). In this study, no significant impact by the HLE on children's MA and RA was observed. However, previous studies demonstrated that such domain-specific anxiety increases over ages (Dowker et al., 2016). Also, the level of MA and RA might change as they learn more advanced math

and reading. Therefore, it might be possible that the relation between the HLE and children's non-cognitive outcomes in math and reading might change over time. Thus, future studies should conduct a longitudinal study to explore the impact of HLE on children's non-cognitive development in math and reading.

For associations between SES and children's non-cognitive outcomes, a significant mean difference on SES levels was found in MA. Moreover, this association was significant even after age and gender were controlled. In this study, children from middle SES demonstrated the highest MA and the high SES peers scored the lowest on average, and only the mean difference between middle SES and the high SES was statistically significant. This is a different pattern from parents' MA, in which low SES parents had the highest score on MA and high SES parents scored the lowest. However, both parents and children of high SES were likely to have lower MA than their peers. One possibility which may explain such similar pattern is the parents' talk. Gunderson et al. (2012) showed that parents' own feelings about math are likely to impact on what they say about math. Considering the finding of this study which showed the relations between parents' perceptions of math and SES, indexed by their educational levels, it may be that what parents convey about math and reading might have been influenced by their own learning experiences through education, which eventually impact children's MA and RA. For RA, like parents' RA, no significant mean difference on SES levels was found. However, it cannot be denied that this relation becomes significant as children gain more experiences in reading, since RA is also influenced by children's reading achievement (Ramirez et al., 2019).

## Limitations

Several limitations in this study should be discussed. Firstly, although the PCAs on the frequency of home numeracy and literacy activities conducted by Skwarchuk et al. (2014) were successfully replicated by some of the previous studies (e.g., Susperreguy et al., 2018), the PCAs in this study were not a satisfactory fit. It may be that the questionnaire on the frequency of home learning activities by Skwarchuk et al. (2014) was not the most suitable in terms of our participants' age. Second, the children whose parents did not respond the questionnaire were omitted from the data analyses. Significant differences in age and home languages were observed between the excluded and included children. Hence, the result might have not completely reflected the Flemish educational context characterised by children's multi-cultural backgrounds and grade retention system. The difficulty in reaching these parents is a lesson for future studies to consider alternative way of communication, such as giving personal reminder. Third, the present study is correlational thus causal relationships cannot be inferred. However, manipulation of indirect measures of the HLE and children's non-cognitive factors is neither practical nor ethical. Fourth, limitations in the measurements should be discussed. The activities parents do with their children are usually not a direct training of the specific skills that were assessed in this study. Previous studies have shown that transfer from what children

know and can do during daily activities being reflected in test performance is difficult to achieve (Reynvoet et al., 2021). Also, this study did not include children's general cognitive abilities such as working memory or IQ which are known to influence children's math and reading outcomes (Niklas & Schneider, 2013; Dowker et al., 2016; Ramirez et al., 2019). Additionally, children's reading ability was resultingly measured only by letter knowledge. As in previous studies, measurements of word knowledge may supplement further understanding of the relations between the HLE and children's reading ability (Skwarchuk et al., 2014; Huntsinger et al., 2016).

Furthermore, children's non-cognitive outcomes were also measured solely by the questionnaire. Although the scales adopted in this study were developed for young children, some might argue that children as young as our participants might have difficulty in self-reporting their anxiety levels (e.g., Ramirez et al., 2018). Finally, although this study aimed to grasp a holistic view of the impact of HLE, the HLE was examined only by questionnaire. Hence, it cannot rule out the possibility of social desirability effect in the questionnaire. However, considering the variety of parents' responses, our choice of questionnaire can be considered as adequate to measure the HLE.

## Future Directions

Future studies should have a longitudinal design to examine the HLE's impact on children's cognitive and non-cognitive development in math and reading over time. Moreover, adding qualitative measures of the HLE such as observations and interviews could provide more comprehensive understanding of the relations between the HLE and children's math and reading development. Including physiological measurements to existing scales could also supplement the assessment of children's MA and RA (Ramirez et al., 2018). In order to extend our findings from correlational studies, intervention studies on parents' factors can be conducted for exploring causal relationships between the indirect measures of the HLE and children's outcomes (e.g., Schaeffer et al., 2018).

To develop a full picture of children's early math and reading development, it may be important to examine the impact of preschool environment together with HLE; preschool is another influential environment for children to encounter math and reading concepts, and teachers also play a significant role in their learning (Gunderson et al., 2012). Future research could also look into how different early education systems influence the relation between the HLE and children's outcomes. As in Flanders participation rate to formal caring environments and preschool is high, the HLE might play a less significant role here compared to countries where children spend more time at home during early childhood. Additionally, future studies should include the wider view of literacy and numeracy brought by digital technology development when examining the HLE's impact on children's leaning, since many young children learn math and reading with digital texts and apps both at home and school recently (Griffith, Hagan, Heymann, Heflin, & Bagner,

2020), and their familiarity and learning with digital technology seems to be influenced by parents' factors, i.e., the HLE (Neumann, 2014).

## CONCLUSION

The present study provided a more holistic view of the HLE by examining the multiple variables of the HLE and disentangled its relations with children's cognitive and non-cognitive performance in math and reading. The significant relation between indirect measures and direct measures were observed in the home numeracy environment, whereas a significant relation was absent in the home literacy environment. SES was found to be related with parents' perceptions of math and reading, and parents' MA, however not with home learning activities. Among the relations between the HLE factors and children's outcomes in math and reading, only SES was found to be related to children's digit comparison and MA. During the COVID-19 pandemic, the HLE obtained increased significance due to lockdowns and closed schools. Against this background, the results obtained in this study become even more significant as parents' perceptions and anxiety towards reading are associated with the frequency of learning activities parents do with their children. Furthermore, although in this study we could not find a relation between children's SES background and the home learning activities, it is possible that inequalities widened during the pandemic due to financial constraints, stress, social isolation, and so forth. Overall, the current study demonstrated the importance of including indirect measures of the HLE to explore the dynamics of the HLE. Further work is required to investigate the associations between the HLE and children's cognitive and non-cognitive outcomes in math and reading, taking into account how these factors develop over time.

## DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: **Supplementary Material** and data are freely available at: [https://osf.io/39xrv/?view\\_only=d51baa573daa4eaf978e9ad7dd79bdba](https://osf.io/39xrv/?view_only=d51baa573daa4eaf978e9ad7dd79bdba).

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by SMEC (Social and Societal Ethics Committee), G-2017 09907. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## AUTHOR CONTRIBUTIONS

SV, BR, and FD contributed to conception and design of the study. SV was responsible for the data collection. KM and SV

organised the datafile. KM performed the statistical analysis and wrote the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feduc.2021.746296/full#supplementary-material>

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