Educational Studies in Mathematics
https://doi.org/10.1007/s10649-026-10502-8

“I need to follow the numbers”—developing and validating a more comprehensive measure of spontaneous focusing on numerical order

Heidi Harju[1] · Lore Van Belle[2,4] · Wim Van Dooren[2] · Jake McMullen[1,3] · Jo Van Hoof[1,2,3]

Received: 5 June 2025 / Accepted: 11 March 2026

Abstract
Spontaneous focusing on numerical order (SFONO) has been suggested as a relevant construct for the development of ordinality knowledge, as children who more often notice numerical order in everyday situations tend to exhibit better ordinality knowledge. However, earlier SFONO measures risked conflating SFONO with the skills needed in them and focused only on numerical sequences with small, consecutive numbers. This study addressed this gap by developing a revised SFONO measure. The construct validity of the measure was examined through three approaches: (1) assessing its ability to replicate individual differences in SFONO, (2) evaluating the influence of various task contexts and numerical sequences on SFONO scores, and (3) confirming its divergent validity from the requisite skills needed to perform the tasks. Fifty-one children (M_{age} = 5.75 years) completed four SFONO tasks featuring varied contexts and a wider range of numerical sequences. Results indicated that consistent individual differences in SFONO could be observed across diverse situations, providing evidence for the construct validity of its measurement. In addition, the SFONO measure showed divergent validity from the necessary skills, supporting the interpretation that SFONO reflects a distinct construct. Interestingly, SFONO responses appeared more affected by the numerical sequences used in the task than by the task context. Put together, the study highlights the need to carefully consider a wider range of task features when attempting to measure spontaneous mathematical focusing tendencies.

Keywords Spontaneous focusing on numerical order · Spontaneous mathematical focusing tendencies · Ordinality · Numerical ordering · Measurement · Children

1 Theorization

Early numerical skills significantly predict later mathematics achievement (Aunola et al., 2004; Duncan et al., 2007; Jordan et al., 2009; Nguyen et al., 2016), and academic success (Claessens et al., 2009; Davis-Kean et al., 2022). Within early numeracy, cardinality (i.e., recognizing the numerical value of the set) and ordinality (i.e., knowing which number

Extended author information available on the last page of the article comes before/after another number) are regarded as key components (for a review, see Devlin et al., 2022). Recently, an increasing number of studies highlighted the significance of ordinality knowledge as a key predictor of later arithmetical skills (e.g., Liang et al., 2023; Lyons et al., 2014; Malone et al., 2021).

Learning early numerical skills does not happen only in formal and guided situations. There are also plenty of opportunities for children to practice these skills in informal and unguided situations (Lehtinen et al., 2017). Children spontaneously (i.e., in a self-initiated way) engage with mathematics in their everyday environments already before school age (e.g., Ginsburg et al., 1977; Ramani et al., 2015; Saxe et al., 1987). For instance, they may count people at the dinner table or compare who has the most candies. Furthermore, research has shown that some children tend to recognize and use numerical information in mathematically non-explicit situations spontaneously more than others (Hannula & Lehtinen, 2005; McMullen et al., 2019). Importantly, stronger tendencies to do so have been associated with better concurrent and later mathematical skills (e.g., Li et al., 2025; Verschaffel et al., 2020).

Recently, a new spontaneous mathematical focusing tendency, known as spontaneous focusing on numerical order (SFONO), has been explored (Harju et al., 2024). SFONO is indicative of children's self-initiated recognition and use of numerical order in non-explicitly mathematical situations (Harju et al., 2024). Previous studies have associated SFONO with better mathematical achievement, especially numerical ordering skills, a sub-aspect of ordinality knowledge (Harju et al., 2024; Sharir & Mevarech, 2022). However, measures of SFONO and empirical studies on the phenomenon are limited. It is unclear if individual differences in numerical ordering skills or specific task characteristics significantly influenced the individual differences observed. Therefore, the present study aimed to develop a more comprehensive measure of SFONO addressing the previous limitations, and investigate its construct validity.

1.1 Ordinality and the effect of different numerical sequences

Ordinality is often defined as a property of numbers that denotes the relative position of an item within a sequence (e.g., Lyons et al., 2016). More generally, however, ordinality is a construct that applies to any ordered sequence (e.g., letters of the alphabet, months of the year). In the context of mathematics, numerical order denotes the number-specific instance of ordinality: natural numbers form a canonical sequence, with each subsequent number in the count-list being larger than the previous one. From this perspective, cardinality and ordinality are closely intertwined. Therefore, the present study considers ordinality knowledge as the joint understanding of magnitude and position (Cheung & Lourenco, 2019). For example, in a sequence of 1–2–3, number 2 is the second number and it comes after 1 but before 3 (positional aspect), and 2 is larger than 1 but smaller than 3 (magnitude aspect). In line with this view, several interconnected aspects of ordinality can be distinguished: *numerical ordering*, which results from the repeated use of *ordinal relations* (before/after, more/less), where *ordinal numbers* can be used to tell the relative position of an item in the sequence (Clements & Sarama, 2007; Fuson, 1988).

As ordinality includes several aspects, different measures are associated with it. Most studies in the research field of ordinality have used measures of order judgment (participants judge whether three number symbols are in numerical order or not, (e.g., Hutchison et al., 2022; Lyons et al., 2014; Malone et al., 2021) or number ordering (participants order number symbols from smallest to largest, (e.g., Liang et al., 2023; O'Connor et al., 2018;

Xu et al., 2023). Some studies ask children to indicate which number comes before and/or after given number (e.g., Bakker et al., 2019; Purpura & Lonigan, 2013), or to arrange sets of items (e.g., sets of dots) from least to most dots (e.g., Harju et al., 2024; Purpura & Lonigan, 2013; Spaepen et al., 2018). Better performance in these measures has been associated with better mathematical skills, especially arithmetical skills (e.g., Liang et al., 2023; Lyons et al., 2014; Purpura & Lonigan, 2013), and it is suggested that understanding the ordinality of numbers may form the basis for understanding numbers as a coherent system (e.g., Gattas et al., 2021; Lyons et al., 2016).

Previous measures of ordinality have investigated a variety of different numerical sequences ranging from small consecutive numbers to large non-consecutive numbers with even or non-even gaps to cover a full range of ordinality. Studies using order judgment (e.g., Lyons & Ansari, 2015) or number ordering (e.g., Xu et al., 2023) measures have observed that participants are faster and more accurate in their answers on items with small consecutive numbers compared to other types of sequences. Furthermore, Devlin et al. (2024) observed that more familiar sequences, such as sequences matching the count-list (e.g., 1,2,3; 2,3,4), were processed faster than less familiar sequences (e.g., descending non-consecutive sequences; 7,4,1). Familiar sequences may be quickly retrieved from memory, while less familiar sequences may require slower cognitive strategies, like sequential magnitude comparison (Devlin et al., 2024). In addition, Hutchison et al. (2022) suggested that young children may have a strict conception of ordinality that is tied to the count-list, as they observed that 5- to 6-year-old children struggled to understand that non-consecutive numbers can be in numerical order. Overall, these findings demonstrate that the type of numerical sequence influences the responses in various ordinality measures. Consequently, this may impact which types of numerical sequences elicit spontaneous focusing on numerical order.

1.2 Spontaneous mathematical focusing tendencies

Most research on spontaneous mathematical focusing tendencies examined children's spontaneous focusing on numerosity (SFON) (for a meta-analysis, see Li et al., 2025). SFON refers to an attentional process of spontaneously focusing on the aspect of exact number of items or incidents and using this information in situations that are not explicitly mathematical (Hannula et al., 2010). The term *spontaneous* refers to the self-initiated, unguided recognition and use of exact number within a specific situation, occurring without external guidance (Hannula & Lehtinen, 2005; McMullen et al., 2019). Studies have shown substantial individual differences in children's SFON tendency, that cannot be fully explained by their current mathematical or cognitive skills (Batchelor et al., 2015; Bojorque et al., 2017; Gloor et al., 2021; Gray & Reeve, 2016; Hannula & Lehtinen, 2005). These individual differences have been repeatedly associated with concurrent (e.g., Gray & Reeve, 2016; Hannula & Lehtinen, 2005; Poltz et al., 2022; Silver et al., 2020) and later mathematical skills (e.g., Batchelor et al., 2015; Gloor et al., 2021; Hannula et al., 2007; McMullen et al., 2015; Nanu et al., 2018).

In addition to exact number, studies have identified individual differences in spontaneous focusing on other mathematical aspects: quantitative relations (SFOR; McMullen et al., 2014), mathematical patterns (SFOP; Wijns et al., 2020), and Arabic number symbols (SFONS; Rathé et al., 2019). These have also been associated with better mathematical skills (e.g., McMullen et al., 2016; Rathé et al., 2019; Wijns et al., 2020). For example, higher SFOR scores are associated with better rational number knowledge (McMullen et al., 2014), higher SFOP scores with better patterning ability (Wijns et al., 2020), and higher SFONS scores with better numerical mapping abilities (Rathé et al., 2022). In general, these studies hypothesize that children who have a higher spontaneous mathematical focusing tendency are more likely to recognize and use mathematical aspects in explicitly non-mathematical situations (such as everyday life) and therefore may gain more self-initiated practice in their mathematical skills (Hannula & Lehtinen, 2005; McMullen et al., 2019).

The aim of the spontaneous focusing measures is to capture children's general tendency to spontaneously focus on a mathematical aspect across various task contexts. To truly capture this, tasks should be mathematically unspecified, fully engaging, and include a variety of (mathematical and non-mathematical) aspects to focus on (Hannula & Lehtinen, 2005; Hannula, 2005; Hannula-Sormunen, 2015). Moreover, the task instruction should be open for multiple interpretations without hints toward (or away from) mathematical responses, and the task contexts should not be associated with typical mathematical activities (e.g., counting money). Importantly, individual differences in the spontaneous focusing tasks should not be entirely dependent on the skills needed to solve the tasks. Therefore, tasks should be within a child's numerical, cognitive, and motorical competencies.

Within the testing context, the children should not expect to be faced with mathematical tasks. Thus, the spontaneous focusing measures should be presented before any mathematical tasks. Moreover, examiners should avoid mathematical phrases, ensure the child's full attention, and refrain from giving feedback. Concerning children's responses, not only the expected response in the task, but also additional numerical behavior, should be included as indicators of spontaneous focusing (Hannula & Lehtinen, 2005).

Although numerical knowledge and skills are needed in the spontaneous focusing tasks, previous studies have delineated previous spontaneous mathematical focusing tendencies (i.e., SFON and SFOR) from the relevant numerical skills (e.g., Hannula & Lehtinen, 2005; McMullen et al., 2014). This distinction is achieved by using guided focusing tasks, which resemble spontaneous focusing tasks but explicitly guide the child's attention towards the mathematical aspect of interest. These tasks assess the numerical skills and knowledge needed to solve the spontaneous focusing tasks. If children with these skills and knowledge still vary in spontaneous task performance, those differences reflect variations in spontaneous focusing, not skill or knowledge gaps.

1.3 Spontaneous focusing on numerical order

SFONO refers to children's spontaneous (i.e., self-initiated) focusing on numerical order in situations that are not explicitly mathematical (Harju et al., 2024). For example, noticing that one can build a tower out of blocks with different numbers of stickers on them in numerical order, instead of building the tower based on the colors of the blocks. A few studies have shown individual differences in SFONO tendency in 3- to 6-year-old children (Harju et al., 2024; Sharir & Mevarech, 2022). Similarly to the reciprocal relation between SFON tendency and cardinality skills (Hannula & Lehtinen, 2005), children with a higher SFONO tendency may acquire more experiences with numerical order in different situations, thus enhancing the development of their ordinality knowledge (Harju et al., 2024). Indeed, Harju et al. (2024) found that higher SFONO tendency in 3–4-year-olds was associated with better performance in arranging sets of items from least to most (i.e., numerical ordering), while controlling for age, cardinality skills, and number sequence production. In addition, Sharir and Mevarech (2022) found that spontaneous focusing on mathematical structures, including numerical order, was associated with better mathematical achievement in 4–6-year-olds. Furthermore, Harju et al. (2022) showed that individual differences in children's focusing on numerical order at the age of 5 predicted mathematical achievement at the age of 12. Focusing on numerical order was measured with a task that required children to notice themselves that items were arranged in numerical order in order to reproduce it later in the task. The task was close to measuring SFONO, but was not spontaneous as its instruction included some hints towards mathematical aspects in the task deviating from the guidelines of measuring spontaneous focusing (Hannula-Sormunen, 2015). Therefore, these last two studies did not specifically measure SFONO, and the results need to be treated with caution.

To measure SFONO, Harju et al. (2024) introduced three tasks with different contexts, where one potential aspect of the task that could be focused on was numerical order. The tasks included two production tasks where one possible answer was to arrange sets of items in numerical order (e.g., build a tower in numerical order). The third task was a reproduction task, where children had to notice that sets of items were arranged in numerical order, in order to reproduce it later. Children were given a SFONO score of 1 from each trial if they arranged the sets of items in numerical order, or showed other indications of noticing the numerical order aspect in the task (e.g., verbal and/or behavioral indications of recognizing numerical order). Results indicated that around 65% of the 3–4-year-old children ($N = 150$) spontaneously focused on numerical order at least once in the three tasks.

While these previous findings indicate the tasks' potential in measuring SFONO, there are still crucial limitations, which are addressed in the current study. First, it is unclear whether the individual differences in children's SFONO responses can be explained by differences in their ability to numerically order the sets of items in the tasks. Indeed, Harju et al. (2024) did not specifically investigate whether the children were able to order sets of items numerically in the SFONO tasks with explicit instruction (i.e., with guided focusing measures) but merely assumed that they could.

Second, Harju et al. (2024) included only items containing small, consecutive numbers (i.e., 1–6). Considering that these numbers are highly familiar in terms of numerical order (Devlin et al., 2024), and that the concept of numerical order is closely tied to the count-list in young children (Hutchison et al., 2022), numerical order may be more salient in items with small consecutive numbers, and more strongly trigger spontaneous recognition and use of numerical order. Thus, it remains unclear whether SFONO is also elicited in items with larger or non-consecutive numbers. Measuring SFONO with such tasks could provide a more complete picture of children's SFONO tendency.

Third, previous studies have suggested that spontaneous focusing on mathematical aspects can be influenced by task context (Batchelor et al., 2015; Mazzocco et al., 2020). Harju et al. (2024) used a set of tasks that were quite distinct in their answer formats, and found that these tasks did not produce equal outcomes. Differences might be explained by a greater saliency of numerical order in the reproduction task. Thus, a new set of tasks is required that share a consistent answer format across task contexts, in which numerical order is consistently salient. Put together, these limitations highlight the need to strengthen the validity of the measurement of SFONO tendency.

The current study presents a revised measure of SFONO tendency to address key gaps in the literature and to investigate its construct validity. Previous work has largely relied on small, consecutive numbers and few task contexts, thus limiting generalizability of the construct of SFONO (Harju et al., 2024). To address these gaps, our revised measure includes numerical sequences with non-consecutive and larger numbers, aligning with prior ordinality research (Hutchison et al., 2022; Liang et al., 2023). As well, we use four parallel task contexts with the open-play, pre-arranged structure of the previously used Tower building task (Harju et al., 2024; Wijns et al., 2020), addressing previous concerns about varying task saliency. We expect this approach to improve the reliability of measuring SFONO tendency and, consequently, extend the research on spontaneous mathematical focusing tendencies, which have typically relied on using fewer items (1–3 tasks with 1–3 items). In addition, it remains unclear whether the previous measurements of SFONO assessed a construct separable from the requisite numerical skills, leaving its divergent validity unresolved. Therefore, the current study addressed the following research question:

RQ1. Does the revised measure demonstrate construct validity as an indicator of SFONO?

Specifically, the construct validity of the revised SFONO measure was investigated from three perspectives:

RQ1a. Does the measure capture individual differences replicating prior findings?

To answer RQ1a, we test whether the new measure reproduces previously observed individual differences in SFONO (Harju et al., 2024), indicating a stable, measurable construct.

RQ1b. To what extent are the SFONO scores captured with the new measure influenced by task characteristics (i.e., task context and type of numerical sequence)?

For RQ1b, we examined the influence of task characteristics (i.e., task context and type of numerical sequence) on SFONO scores captured with the new measure. To do so, we compared the mean sum scores across trials within the same context and across trials involving the same sequence types. Finding similar SFONO scores across the four parallel contexts would indicate that the measure captures a construct that generalizes across settings rather than being driven by specific task contexts. Meanwhile, systematic differences between sequence types would demonstrate that performance on the measure reflects similar differences to those observed in prior ordinality studies (e.g., Hutchison et al., 2022), thereby supporting its construct validity.

RQ1c. Does the revised SFONO measure demonstrate divergent validity, more specifically, does it capture a construct distinct from the requisite skills needed to perform the tasks?

To assess divergent validity, we restricted our analysis to a subgroup of children who demonstrated the necessary skills to spontaneously focus on numerical order in the SFONO tasks. Concentrating on this subgroup allowed us to test whether SFONO varies beyond the requisite skills required to perform the SFONO tasks, indicating that the measure taps a distinct attentional tendency rather than merely the numerical skills and knowledge involved in task execution.

2 Methods

2.1 Participants

The participants in the study were children in their final year of kindergarten in Flanders, Belgium (5–6 years old). After obtaining consent from two schools to conduct the research, parents were informed and asked for permission for their child to participate. Ultimately, 53 parents consented to their child's participation. In line with Harju et al. (2024), only children without diagnosed learning difficulties were included in the analyses, leading to the exclusion of two children who were reported to have learning difficulties. This led to a total sample of 51 children ($N=51$; 22 girls, 29 boys; $M_{age}=5$ years and 9 months). The study received ethical permission from the Sociaal-Maatschappelijke Ethische Commissie (SMEC) of KU Leuven (G-2022–6019-R2(MIN)).

2.2 Procedure

Children were tested individually in two[1] different video-recorded sessions in a silent room. The sessions were recorded to provide the opportunity to code children's subtle (mathematical) behavior such as counting with fingers, pointing towards sets of items, whispering the number word sequence, after the testing took place (see Harju et al., 2024). Parents gave their permission for their child to be video-recorded and the footage was saved in a secure place that only the involved researchers have access to.

In the first session, which took around 30 minutes, the child was given the four SFONO tasks. After receiving two SFONO tasks, the child was shown a picture of a farm and asked to describe what they saw as a distractor from the mathematical nature of the testing situation. Then the last two SFONO tasks were provided. After the first session, the child was taken back to their classroom. Only when all children finished the first session did the second session—testing children's early numerical skills—take place. This ensured that the children were not aware of the possible mathematical nature and solution method during the SFONO tasks. In the second session, which took about 15 minutes, children's guided focusing on numerical order, cardinality skills, and number sequence production were measured.

2.3 Measures

2.3.1 SFONO

As described above, different task contexts were used to measure children's SFONO. The 'Tower building task' as used by Harju et al. (2024) formed the basis to create other SFONO tasks with similar features and structures, resulting in a total of four different SFONO task contexts (see Fig. 1). In each task, children were presented with four items per trial, each containing a unique number of elements (e.g., animal stickers, stars), displayed in two colors (two items per color). This design allowed for the children to decide to arrange the items by color (e.g., blue blue green green), pattern (e.g., blue green blue green), numerical order (from least to most), position (from the item closest to the child to the item furthest away from the child) or randomly. In all trials, dice-like patterns of numbers were avoided, lowering the salience level of the numerical aspects.

The tasks were always presented in the same manner: the order of the items did not match the correct result for numerical order, color, or pattern. In the Ladybug and Laundry tasks, the ladybugs and T-shirts were placed in a windowpane-style arrangement to avoid a direct copy of the order of the material (see Fig. 1 for the beginning situations). After each trial, independently of the strategy used by the child during the SFONO task, the experimenter

[1] Due to time constraints one child was tested in three instead of two sessions.

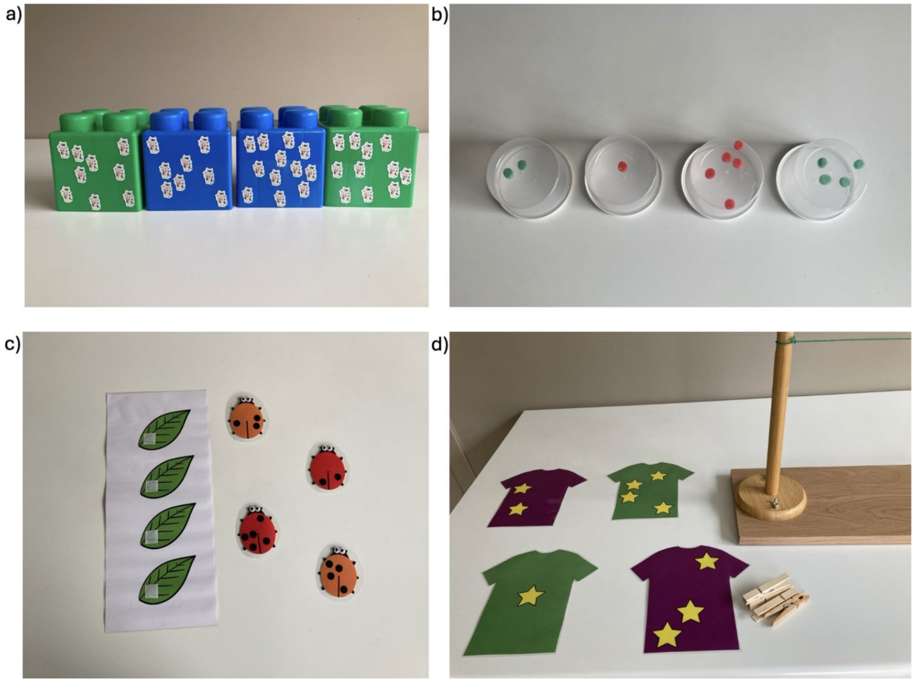

Fig. 1 The beginning situations within each SFONO task context. Note. **a**) Tower building task, **b**) Boxes task, **c**) Ladybug task, **d**) Laundry task

said to the child: “Well done!”. This was done (1) to not give away the possible mathematical nature of the task and (2) to keep the child’s motivation up during the trials.

Tower building task The first SFONO task context was the exact same task as used in the study of Harju et al. (2024) The Tower building task was adapted by Harju et al. (2024) from the Wijns et al.’s (2020) Construction task. In the Tower building task, four big blocks with different numbers of animal stickers were put on a table in front of the children one at a time (Fig. 1a). After that, the children were asked to “Build a tower going straight up, using all the blocks.”

Boxes task In the boxes task, children were given four see-through boxes with a different number of balls glued on the inside (see Fig. 1b). Similarly to the Tower building task, the children were instructed to “Build a tower going straight up, using all the blocks.”

Ladybug task In the Ladybug task, four ladybugs with a different number of dots were put in front of the children, next to a picture of leaves of a tree (Fig. 1c). The experimenter introduced the material and task instruction to the children as follows: “Oh look, these are ladybugs. All the ladybugs are very hungry, and are looking for a leaf to eat from. Can you help them? Place a ladybug on each leaf.”

Laundry task In the Laundry task, the children were presented four t-shirts with a different number of stars (Fig. 1d). The children were told the following task instruction: “Oh look, here are t-shirts. All the t-shirts need to be hung up to dry. Hang each t-shirt on the clothesline using the clothespins."

Different trial types within each task context In total, four different trial types were created within each context. The first two trial types were in line with Harju et al.'s (2024) study. More specifically, the first trial type (A) consisted of consecutive numbers, starting with one: 1,2,3,4 and the second trial type (B) also consisted of consecutive numbers, but starting with two: 2,3,4,-5. However, importantly, as described in the theoretical background of the present study, numerical order is not limited to only consecutive numbers in the count list. Therefore, two extra trial types were created. In trial type C, small non-consecutive numbers were used that were still in the subitizing range: 1,2,4,5. In trial type D, large non-consecutive numbers where subitizing was not an option to define the cardinal value of the sets were used: 8,9,11,12.

Every child received all four trial types within all four contexts, leading to a total of 16 trials. The SFONO tasks were randomized using a balanced Latin square design, which ensures that each element precedes another exactly once, and allows to better control for potential order effects (Richardson, 2018).

Scoring of the SFONO measures Outcomes of all trials, indications of numerical behavior, and indications of recognizing the numerical order in the task were recorded. These were further used to distinguish three types of SFONO manifestations described by Harju et al. (2024) from children's behavior. First, a numerical order can be created in a SFONO task by a child without any other observable mathematical behavior. This happens for example when a child puts the t-shirts in numerical order (e.g., 1,2,3,4), and does not say or do anything else. Second, a numerical order can be created with additional observable mathematical behavior. For example, while hanging the t-shirts in numerical order on the clothesline, a child can count out loud the stars on the t-shirts. Lastly, SFONO can also occur when the child does not arrange the sets of items in numerical order, but shows other signs of noticing the numerical order aspect (Table 1), for instance, by stating "*Hey, look one, two, three,*

Table 1 Examples of indications of noticing the numerical order aspect in the SFONO tasks (without arranging the items in numerical order)

Indication of noticing the numerical order aspect in the task	Examples
a) Verbal and/or behavioral indications of noticing the numerical order aspect in the task	"*I counted like this: one, two, three, four.*" (touches the ladybugs in numerical order at the beginning of the task) After building a tower in numerical order, points to the boxes from bottom to top "*Here the most, slightly less, even less, and the least.*"
b) Comments that refer to the number sequence	"*I am going to start with the first one where the number one is.*" "*I know, from one to two to three to four.*" (in a trial of 2–3–4–5) In a trial of 1,2,4,5, the child points to the blocks and says"*One, two…* (shakes shoulders). *Why the four and not the three?*"
c) Interpretation of the goal of the task as arranging the sets of items 1) in numerical order, or 2) from least to most	"*But now there are numbers, so I have to follow the numbers.*" "*And now it has to go from high to low?*"

four," while pointing towards the corresponding t-shirts, and subsequently arranging them on the clothesline by color. Additional examples from the data are presented in Table 1. Notably, our study found a novel indication for noticing the numerical order aspect in the task, namely, children describing their attempt to arrange the items from least to most (see Table 1, interpretation of the goal of the task as arranging the sets of items from least to most). While the first two types of SFONO can be seen from the outcome, the last type can only be coded by looking at the videos of the testing. A SFONO score of 1 was given if either one of these three types of SFONO occurred within a trial.

2.3.2 Guided focusing on numerical order (GFONO)

In the second session, the children were given (amongst other early numerical tasks, see below) a measure of their guided focusing on numerical order. In the task, children received again each trial type of the Tower building task. However, this time the children's focus was explicitly guided towards the numerical order aspect of the task. More specifically, they were told that the items in the task have different numbers of animals, and were asked to put the items in numerical order: "On these blocks there are different numbers of cows. Build the tower from the least to the most number of cows. So, you start with the block with the least cows, this one you put first below. On top of that one, you put the block with more cows, then the one with even more cows, and as the last one, you put the one with the most cows on top.". Therefore, the GFONO task measured children's numerical ordering skills on a restricted set of numbers, corresponding to the number range in the SFONO tasks. If the child failed to build the tower in numerical order, the trial was repeated once.

2.3.3 Early numerical skills

Cardinality skills Following Harju et al. (2024), children's cardinality skills were measured with the "Give-a-Number" task (Wynn, 1990). In this task, a child was asked to put a specific number of objects (e.g., spoons, plastic little ducks) on the table. The numbers in the trials were 2, 3, 4, 5, 9, 12, corresponding to the range of numbers used in the SFONO tasks. If the child failed, the trial was repeated once. The task was discontinued after two failed attempts in one number.

Number sequence production In line with Harju et al. (2024), children were asked to count as far as they could. The highest number up to which the children correctly counted out loud in one of two attempts was their score. If the children reached 50, their counting was stopped.

3 Results

All the statistical analyses were run in SPSS (IBM SPSS Version 28) and the figures were created using R (version 4.4.1, R Core Team, 2024). Descriptive statistics on the variables are presented in Table 2. The new measure indicated good internal consistency (Table 2). In addition, all the items seemed to contribute to SFONO as there were no items that would have substantially improved the internal consistency when removed. Descriptive statistics

Table 2 Descriptive statistics of the variables ($N = 51$)

	M (SD)	Range	Theoretical maximum	Skewness	Kurtosis	Cronbach's α
Age in months	69.75 (3.81)	63–82	-	0.44	0.87	-
SFONO tendency	3.80 (3.33)	0–14	16	0.83	0.42	.81
Trial types A & B	2.35 (2.02)	0–7	8	0.57	−0.43	.69
Trial types C & D	1.45 (1.55)	0–8	8	1.76	4.99	.62
GFONO[a]	3.54 (0.79)	0–4	4	−2.35	7.37	.53
Cardinality skills[a]	5.78 (0.55)	4–6	6	−2.47	5.16	.47
Number sequence production[a]	38.16 (12.24)	10–50	50	−0.70	−0.64	-

[a] Missing data ($n = 1$)

Table 3 Spearman correlations between the variables ($N = 51$)

Variable	1	2	3	4	5
1. Age	-				
2. SFONO tendency	.26	-			
3. GFONO[a]	-.04	.16	-		
4. Cardinality skills [a]	-.16	.09	.18	-	
5. Number sequence production[a]	.13	.05	.06	.21	-

[a] Missing data ($n = 1$)

of GFONO, cardinality skills, and number sequence production (Table 2) suggested that many children demonstrated adequate skills to spontaneously focus on numerical order in the SFONO tasks. GFONO and cardinality scores appeared to have a ceiling effect, with mean scores of 3.54 out of 4, and 5.78 out of 6 (which may explain the relatively low alpha values). In addition, Table 3 the Spearman correlations showed only low, statistically non-significant correlations between the variables, which may be partly explained by the ceiling effect and limited variance in GFONO and cardinality skill measures.

3.1 Replication and extension of prior findings on individual differences in SFONO using the revised measure

To shed light on the construct validity of the revised SFONO measure, we investigated individual differences in SFONO (RQ1a). In a first step, we examined the frequencies of children's SFONO responses in the same trial types used in the study by Harju et al. (2024) (i.e., A: 1,2,3,4; B: 2,3,4,5), within the four SFONO tasks in this study (Fig. 2a), seeing whether their findings hold true using another set of tasks with a more consistent salience. A similar distribution of SFONO scores across the new set of tasks was found, with a SFONO sum score ranging from 0 to 7, indicating a continuous tendency. In a second step, the frequencies of SFONO scores were examined in trial types with non-consecutive (i.e., C: 1,2,4,5) and larger numbers (i.e., D: 8,9,11,12), also indicating individual differences (Fig. 2b).

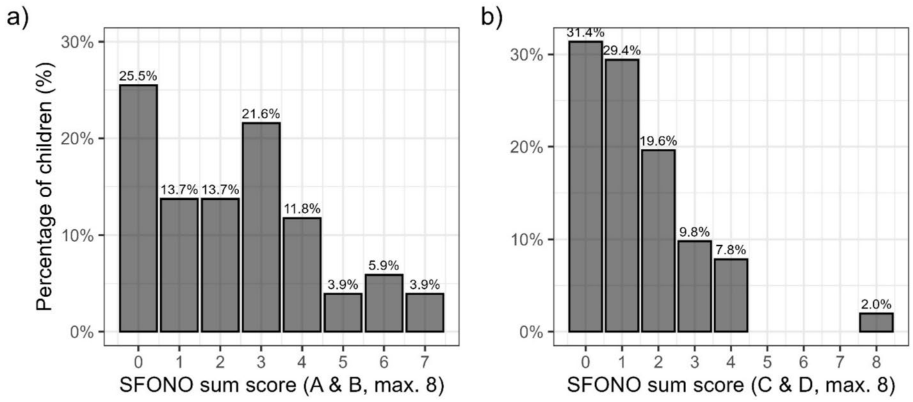

Fig. 2 Frequencies (as percentages) of children's SFONO sum scores in **a**) trial types A (1,2,3,4) and B (2,3,4,5), and **b**) in trial types C (1,2,4,5) and D (8,9,11,12) ($N=51$)

In a third step, we examined the frequencies of the different types of SFONO indications (Fig. 3). This was done to investigate whether children's behavior in the SFONO tasks was in line with their given response. The results showed, that for 66% of the observed SFONO responses, children arranged the items in numerical order, but did not show any additional numerical behavior. 31% of the children did show other indications of numerical behavior,

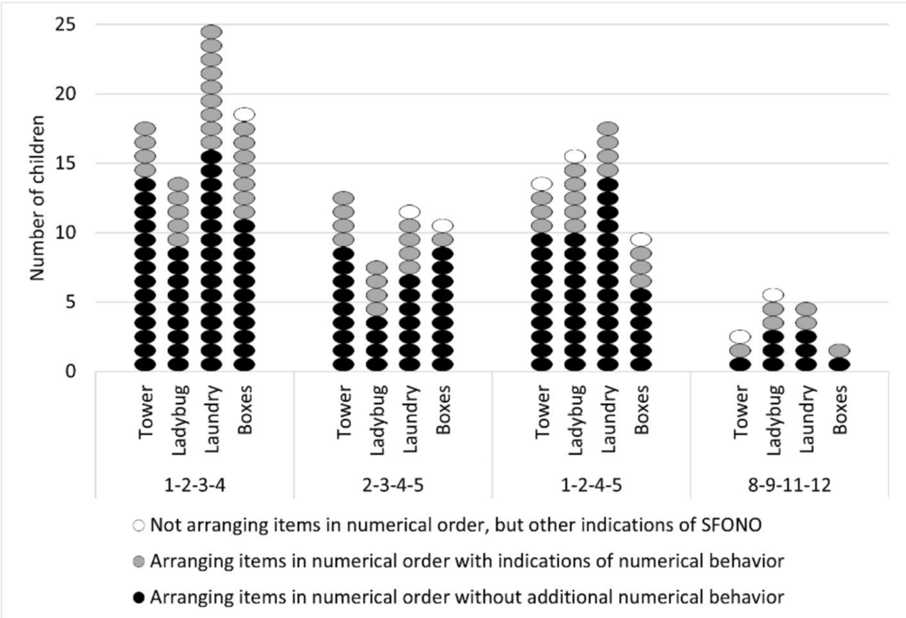

Fig. 3 Dot plot of the observed indications of SFONO per task and trial type ($N=51$)

such as saying cardinal number words or counting out loud. In around 4%, the children did not arrange the sets of items in numerical order, but showed other indications of noticing the numerical order aspect in the task. For example, the children may have noticed that from the sequence of 8,9,11,12, the number 10 is missing, and pointed it out to the researcher, thus referring to the number sequence. These results are in line with previous behavioral patterns of spontaneous mathematical focusing tendency research (e.g., Gray & Reeve, 2016).

3.2 Influence of task context and numerical sequence on SFONO scores

The effect of task characteristics (i.e., task context, trial type) on SFONO was examined to further investigate the measure's construct validity (RQ1b). The descriptive statistics and internal consistencies per tasks and trial types are presented in Table 4. The results indicated better internal consistencies (i.e., Cronbach's *α's,* inter-item correlations) for the trials within the same task context when compared to trials within the same trial type.

Following this, means of children's SFONO scores were compared between the tasks (i.e., different contexts), and between the trial types (i.e., different numerical sequences). A repeated measures ANOVA with Greenhouse–Geisser correction indicated that there were no significant differences in the mean scores between the four SFONO tasks ($F(2.52, 125.90) = 1.20$, $p = 0.31$, $\eta^2 = 0.02$) (Fig. 4).

For the four trial types (i.e., A, B, C, D), results of a repeated measures ANOVA showed that there were significant differences between children's SFONO scores in the different trial types ($F(3, 150) = 24.39$, $p < 0.001$, $\eta^2 = 0.33$). Post hoc analysis indicated that children spontaneously focused on numerical order more on trial type A compared to trial type B ($M_{diff} = 0.63$, 95% CI [0.24–1.01], $d = 0.55$), trial type C ($M_{diff} = 0.35$, 95% CI [0.01–0.70], $d = 0.30$), and trial type D ($M_{diff} = 1.18$, 95% CI [0.71–1.64], $d = 1.17$). In addition, more SFONO was observed in trial type B compared to trial type D ($M_{diff} = 0.55$, 95% CI [0.15–0.94], $d = 0.60$), and in trial type C compared to trial type D ($M_{diff} = 0.82$, 95% CI [0.41–1.24], $d = 0.88$) (Fig. 5).

Table 4 Descriptive statistics of SFONO sum scores, and internal consistencies (i.e., Cronbach's alphas, inter-item correlations) by task and trial type ($N = 51$)

		M (SD)	Range	Cronbach's α	Inter-item correlations
Task	Tower	0.94 (1.24)	0–4	.74	.16–.60
	Ladybug	0.86 (1.20)	0–4	.72	.05–.72
	Laundry	1.18 (1.23)	0–4	.66	.20–.56
	Boxes	0.82 (1.21)	0–4	.78	.26–.64
Trial type	1–2–3–4	1.49 (1.23)	0–4	.46	.01–.38
	2–3–4–5	0.86 (1.06)	0–4	.52	-.01–.50
	1–2–4–5	1.14 (1.11)	0–4	.46	-.06–.36
	8–9–11–12	0.31 (0.73)	0–4	.62	.17–.48

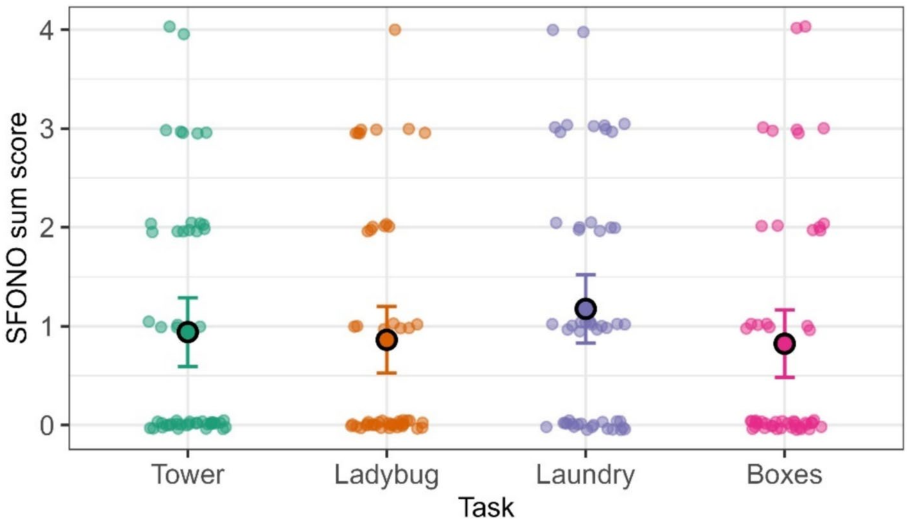

Fig. 4 Mean SFONO scores and distributions across the four SFONO tasks ($N = 51$). Large dots indicate mean SFONO sum scores, with error bars representing 95% confidence intervals

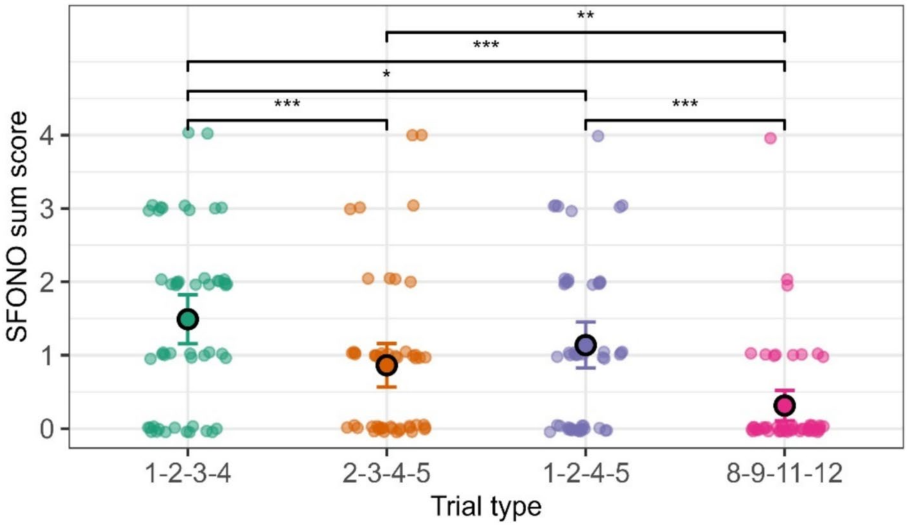

Fig. 5 Mean SFONO scores and distributions across the SFONO trial types ($N = 51$). Large dots indicate mean SFONO sum scores, with error bars representing 95% confidence intervals. *Note.* *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

3.3 Divergent validity of the SFONO measure: Distinguishing SFONO from task-specific skills

To investigate the divergent validity of the SFONO measure (RQ1c), we investigated the SFONO scores within the subset of children who demonstrated the necessary skills to spontaneously focus on numerical order (i.e., in those children who could complete all

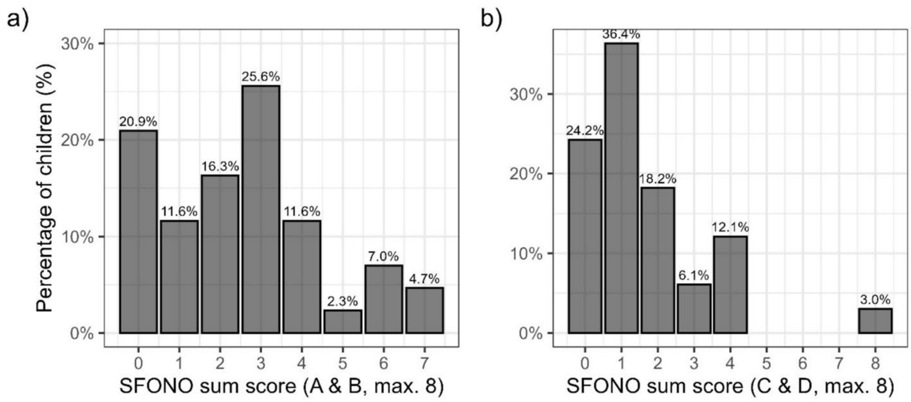

Fig. 6 Frequencies (as percentages) of children's SFONO sum scores in those children who had the necessary skills to spontaneously focus on numerical order in a) trial types A (1,2,3,4) and B (2,4,5) ($n=43$), and b) in trial types C (1,2,4,5) and D (8,9,11,12) ($n=33$)

the guided focusing tasks correctly, recognize the cardinal values of the sets correctly, and recite the number sequence until the highest number in the tasks). In trial types A and B, 43 children could correctly order the sets when guided to do so, recognize cardinal values up to 5, and recite the number sequence above five. In trial types C and D, 33 children correctly completed the guided task of these trial types, recognized cardinal values up to 12, and recited the number sequence above 12. Results showed individual differences in children's SFONO in all four trial types among these subgroups of children who had the necessary skills (Fig. 6). This indicates that the individual differences captured with the new SFONO measure are not solely due to differences in children's skills needed to spontaneously focus on numerical order.

4 Discussion

This study aimed to address gaps in the previous measurements of SFONO and investigate its construct validity. Our findings show individual differences in SFONO tendency with the broader measure, both with similar numerical sequences that were used in the previous measures, but also with other types of numerical sequences. In addition, our results indicated that SFONO responses appeared more affected by the numerical sequences used in the task than by the task context. Furthermore, this study is the first to show that the individual differences found in the SFONO measure were not solely due to differences in the numerical skills needed to use numerical order in the tasks, but due to differences in SFONO tendency. This result supports the view that SFONO tendency is a separate attentional process distinct from the requisite skills (Harju et al., 2024). Taken together, the present study suggests that the revised measure is valid for assessing SFONO tendency.

More specifically, consistent with Harju et al. (2024), our measure recovered individual differences in children's SFONO, providing evidence for the construct validity of the measure. This pattern in turn, suggests that SFONO itself reflects a stable and measurable construct. Additionally, the presence of individual differences in SFONO across trials with new types of sequences, coupled with a high Cronbach's alpha indicating good internal consistency, suggests that SFONO should be measured using a comprehensive range of numerical sequences. This approach will better capture the full spectrum of SFONO and enhance the content validity in terms of ordinality.

Next, as discussed in the theoretical background, SFONO may be influenced by task context, such as features, demands, and the salience of numerical information (Batchelor et al., 2015; Mazzocco et al., 2020). Therefore, the present study examined children's SFONO across different tasks (task context) and different types of numerical sequences (task feature). Our results indicated that the SFONO scores were broadly comparable across the four matched contexts, indicating that task demands did not meaningfully affect performance in the revised measure, and that the measure generalizes beyond surface features.

Moreover, the results showed that the patterned differences by sequence type aligned with theoretical expectations, which is further confirming the construct validity of the measure. More specifically, we observed the most SFONO in trials featuring small numbers and the least in those with larger numbers. This aligns with prior suggestion of the familiarity effect observed in ordinality studies, that have shown the start of the number sequence (e.g., 1,2,3) to be the most familiar sequence leading to faster response times in judging whether numbers are in correct order or not (e.g., Devlin et al., 2024). In addition, small numbers can be subitized rapidly while recognizing order in larger numbers requires active counting. Combined with the small numbers of items having larger differences in their numerical ratio than the larger numbers of items, the differences in set sizes and the numerical order aspect may be easier to notice among small numbers. Likewise, the numerical sequences beginning with the first two numbers in typical count sequences (i.e., 1 and 2) appear to also have somewhat higher salience.

Although children's SFONO scores differed significantly between sequence types, but not between tasks, the internal consistency was stronger within tasks than across items of the same numerical sequence. This suggests that task context affected the way children responded, leading to more consistent performance within a given task—even if the specific sequence type varied. At the same time, the sequence type still influenced the level of SFONO, as shown by the significant score differences. This indicates that while task structure may drive consistency in responses, certain numerical sequences may inherently elicit stronger or weaker spontaneous focusing. This dual influence highlights the importance of considering the salience effect of both, task context, and numerical sequence when assessing SFONO.

Interestingly, in 66% of the observed SFONO instances, the children arranged the sets of items in numerical order without showing any additional overt numerical behavior, contradictory to Harju et al. (2024) in which 44% of the observed SFONO instances excluded any additional overt numerical behavior. However, it is possible that the children in our study, given that they are older, may not have needed to show overt signs of counting, as in most of the trials the numbers were easy for them to enumerate. The study by Harju et al. (2024) investigated Finnish children, whereas the current study focused on Flemish preschoolers. These two populations differed not only in age but also in educational practice and instructional context. The participants in the current study were in the third (final) year of preschool (aged 5–6) in Flanders. At this stage, the Flemish curriculum places explicit emphasis on the development of early numerical skills such as counting up to 20, understanding the cardinal and ordinal aspects of numbers, and mastery of the one-to-one correspondence between number words and objects (Vlaamse overheid, n.d.). In the Finnish education system, mathematics is promoted through playful activities. Special emphasis is given to the development number concept (i.e., learning to join quantities with number words and Arabic numerals), and to practicing the recitation of the number sequence (Finnish national core curriculum for ECEC, National Agency of Education, 2022). However, no specific minimum targets are defined, as the practice should happen at each child's individual skill level.

Next, as it was still an open question if the individual differences in SFONO found in the previous studies were caused by individual differences in the needed numerical skills and knowledge, we investigated SFONO in a group of children who had the necessary skills to spontaneously focus on numerical order in these tasks. We still found individual differences in SFONO tendency within this group, indicating that these differences cannot be fully explained by skills and knowledge alone. This supports the divergent validity of the SFONO measure and is in line with previous findings that distinguish between spontaneous mathematical focusing tendencies (like SFON and SFOR) and guided mathematical abilities (Hannula & Lehtinen, 2005; McMullen et al., 2014). Importantly, while SFONO is conceptually distinct from the prerequisite skills and knowledge, the foundational numerical skills can still affect how challenging SFONO items are for children at earlier developmental stages. Indeed, it is plausible that, among children who have not yet acquired the necessary skills to successfully perform tasks requiring SFONO, the item difficulty on the SFONO measure is influenced by their underlying knowledge. This suggests that, especially for less experienced individuals, factors such as background knowledge may influence performance on SFONO tasks over and above familiarity and salience.

4.1 Educational implications

The present results have educational implications worth considering. Translating between different forms of mathematics between everyday life and formal learning is a central goal of mathematics instruction (Nunes & Bryant, 2015). This translation may be aided by spontaneous mathematical focusing tendencies (Hannula et al., 2005). Our results indicate that during instruction on supporting spontaneous mathematical focusing tendencies varying mathematic forms (i.e., the number sequences) may be just, if not more important, than varying the contexts (e.g., laundry versus ladybugs). Moreover, previous studies have shown that spontaneous focusing on different mathematical aspects can be supported through targeted interventions (e.g., Braham et al., 2018; Hannula-Sormunen et al., 2020; Määttä et al., 2024), leading to greater improvements in the mathematical skills of the children in the intervention group in comparison to the control group (e.g., Hannula-Sormunen et al., 2020). As our results indicated SFONO to be partially distinct from the requisite skills, and Harju et al. (2024) observed a positive association between SFONO and numerical skills, numerical order might be another important numerical aspect to focus on in everyday situations with young children.

4.2 Limitations

There are certain limitations to our SFONO measure and the present study that need to be addressed. Even though our aim was to address the limitation of varying salience in the previous measurements of SFONO, having similar structures and features, and including larger numbers in our SFONO tasks may be a limitation according to the methodological considerations of spontaneous focusing measures. Spontaneous focusing measures are designed to capture a child's self-initiated attention to mathematical aspects, reflecting the amount of informal practice in *everyday environments* (e.g., Hannula-Sormunen, 2015). From this perspective, using many tasks with highly similar features and structures may not be ideal, as the salience of numerical aspects in real-world contexts can vary significantly. Future studies could also include a wider range of task structures to more systematically examine the effects of the task demands (e.g., imitation tasks or picture description tasks) (Li et al., 2025). In addition, not all the children in our study were able to enumerate sets of 8, 9, 11, or 12, thus leading to question whether the lack of spontaneous focusing in the trials with larger numbers was due to task difficulty or lack of SFONO among these children. However, as there was also a lack of SFONO among the sub-group of children who were able to enumerate the larger sets, we hypothesize that larger numbers did not elicit SFONO as well as smaller numbers. Future studies could further investigate how the different task features affect the measurement of spontaneous focusing, and create guidelines helping to design more coherent, but sufficiently varied sets of tasks.

Next, it should be noted that the sample size of the present study was modest ($N=51$), possibly limiting the representativity of the sample. The limited sample size also restricted our analytic choices, especially while investigating the effects of task characteristics on SFONO responses. Therefore, future studies should evaluate the measure in larger samples. In addition, the effect of task characteristics could be investigated in a more detailed way by using more robust analytic approaches (e.g., generalized linear mixed-effects models).

Examining the task effects on spontaneous mathematical focusing tendencies in a more comprehensive format may be challenging. At early stages of the development of SFONO tendency, performance across contexts may appear inconsistent and fragmented, that is, it may be more dependent on context and other task features. Thus, individual differences may not be consistent and fairly low internal consistency in SFONO tendency may appear. For example, from a knowledge integration theory perspective we would expect children to have different prior experiences in situations, which may differently affect focusing across contexts. For example, some children may have prior experiences on building a tower in numerical order, while they have not hung laundry based on numerical information found on clothes. Thus, having diverse tasks can be beneficial for capturing the whole of the construct, even if reliability is potentially harmed (if not enough items are possible) (Edelsbrunner et al., 2025). In the present study, we presented children with a similar task type (i.e., the Tower building task), with a limited set of numerical sequences, but varied the context of the task (e.g., clothesline, etc.). Thus, we were able to achieve strong internal consistency across the 16 items. However, this consistency may have come to the detriment of the overall construct validity of the measure when considering SFONO as an indicator of the spontaneous use of numerical order in everyday situations. Still, having this many SFONO items did not appear to lead to children discovering the goal of the task was to spontaneously focus on numerical order. Thus, we suggest that for more reliable and valid measures, studies on spontaneous mathematical focusing tendencies could include more tasks (and items) covering a broader range of contexts, to achieve both stronger validity and sufficient reliability.

It should be considered, that next to task context and type of numerical sequence there might be other possible factors that could shape children's performance in the SFONO tasks. These factors include children's prior experiences (e.g., tower building vs. laundry), orientation (e.g., vertical vs. horizontal), and reading direction. For example, a vertical orientation may elicit more SFONO answers, as numbers are usually presented in a vertical direction (e.g., on a number line), where numbers increase in reading direction. Future studies could systematically manipulate these factors and examine their effect to SFONO beyond task context and sequence type. Furthermore, in the present study we only assessed whether children spontaneously focused on numerical order, while the tasks included also other features (e.g., color, shape, pattern) to focus on.

Furthermore, as no prior study (including ours) included numerical sequences with gaps larger than one (e.g., 1,4,6), we do not yet know whether children also show SFONO with these sequences. Future studies should include these types on numerical sequences too, to grasp the full picture of SFONO. As sometimes the children show SFONO by pointing out to the researcher that one number from the sequence is missing (e.g., 3 is missing from the sequence of 1,2,4,5), possibly even preventing them from arranging the sets of items in numerical order, it may be that SFONO limits to spontaneous focusing on the number sequence. Another line for future studies would be to investigate the developmental relations between SFONO tendency and numerical skills, especially those associated with ordinality.

Despite these limitations, the present study provides a more comprehensive measure of SFONO tendency, which addresses the previous limitations regarding its validity. The measurement of spontaneous mathematical focusing tendencies is wrought with potential threats to the validity of the measure. Hints towards or away from numerical features can lead to poor capturing of the underlying tendency of interest. Different contexts can potentially direct children's attention towards or away from numerical features. For instance, in a SFON task where the child is expected to imitate the researcher posting a certain number of letters from a pile to a postbox, one could think: why *wouldn't* you put all the letters in a postbox?

5 Conclusion

The results of the present study support the construct validity of the revised SFONO measure, thereby implying that SFONO is a stable, measurable construct. Our revised SFONO measure was able to capture individual differences in SFONO tendency, not only indicating its construct validity, but also suggesting that a comprehensive range of sequences and task contexts may better capture the full spectrum of SFONO. In addition, the individual differences found with the SFONO measure were not due to individual differences in the necessary skills needed in the tasks, highlighting the measure's divergent validity, and indicating a dissociation of SFONO tendency as a distinct construct from the necessary skills. The study further concludes that there is a need to carefully consider a wider range of task features when attempting to measure spontaneous mathematical focusing tendencies.

Acknowledgements The authors would like to warmly thank the participating schools, parents, and children who took part in the study.

Author contributions All authors contributed to the study conception and design. Material preparation was done by Wim Van Dooren, Jo Van Hoof, and Lore Van Belle. Data collection was conducted by Lore Van Belle. Analyses were performed by Heidi Harju. The first draft of the manuscript was written by Heidi Harju and Jo Van Hoof, and all authors commented on both the initial and subsequent versions of the manuscript. All authors read and approved the final manuscript.

Funding Open Access funding provided by University of Turku (including Turku University Central Hospital). The work of Heidi Harju and Jo Van Hoof was supported by funding from Research Council of Finland #331772. Jo Van Hoof and Jake McMullen are part of the EDUCA Flagship project funded by the Research Council of Finland (#358924, #358947). Jake McMullen is supported by a Jacobs Foundation Research Fellowship.

Data availability In line with the guidelines in the ethical approval, data are not shared openly but are available upon reasonable request from the authors.

Declarations

Ethics approval and consent We confirm that this work, which obtained ethical approval from the Sociaal-Maatschappelijke Ethische Commissie (SMEC) of KU Leuven (G-2022–6019-R2(MIN)), has been carried out in accordance with their ethical principles and standards. Parental consents were collected before data collection.

Competing interests The authors declare no competing interests. Wim Van Dooren is serving as co-Editor-in-Chief for Educational Studies in Mathematics. The article was assigned to another Editor to assume responsibility for overseeing peer review. This submission was subject to the exact same review process as any other manuscript submitted to the journal.

References

Aunola, K., Leskinen, E., Lerkkanen, M.-K., & Nurmi, J.-E. (2004). Developmental dynamics of math performance from preschool to grade 2. *Journal of Educational Psychology, 96*(4), 699–713. https://doi.org/10.1037/0022-0663.96.4.699

Bakker, M., Torbeyns, J., Wijns, N., Verschaffel, L., & De Smedt, B. (2019). Gender equality in 4- to 5-year-old preschoolers' early numerical competencies. *Developmental Science, 22*(1), Article e12718. https://doi.org/10.1111/desc.12718

Batchelor, S., Inglis, M., & Gilmore, C. (2015). Spontaneous focusing on numerosity and the arithmetic advantage. *Learning and Instruction, 40*, 79–88. https://doi.org/10.1016/j.learninstruc.2015.09.005

Bojorque, G., Torbeyns, J., Hannula-Sormunen, M., Van Nijlen, D., & Verschaffel, L. (2017). Development of SFON in Ecuadorian Kindergartners. *European Journal of Psychology of Education, 32*(3), 449–462. https://doi.org/10.1007/s10212-016-0306-9

Braham, E. J., Libertus, M. E., & McCrink, K. (2018). Children's spontaneous focus on number before and after guided parent–child interactions in a children's museum. *Developmental Psychology, 54*(8), 1492–1498. https://doi.org/10.1037/dev0000534

Cheung, C.-N., & Lourenco, S. F. (2019). Does $1 + 1 = 2^{nd}$? The relations between children's understanding of ordinal position and their arithmetic performance. *Journal of Experimental Child Psychology, 187*, Article 104651. https://doi.org/10.1016/j.jecp.2019.06.004

Claessens, A., Duncan, G., & Engel, M. (2009). Kindergarten skills and fifth-grade achievement: Evidence from the ECLS-K. *Economics of Education Review, 28*(4), 415–427. https://doi.org/10.1016/j.econedurev.2008.09.003

Clements, D. H., & Sarama, J. (2007). Early Childhood Mathematics Learning. In *Second handbook of research on mathematics teaching and learning: A project of the National Council Teachers of Mathematics* (Vol. 1, pp. 461–555). Information Age Publishing.

Davis-Kean, P. E., Domina, T., Kuhfeld, M., Ellis, A., & Gershoff, E. T. (2022). It matters how you start: Early numeracy mastery predicts high school math course-taking and college attendance. *Infant and Child Development, 31*(2), Article e2281. https://doi.org/10.1002/icd.2281

Devlin, D., Moeller, K., & Sella, F. (2022). The structure of early numeracy: Evidence from multi-factorial models. *Trends in Neuroscience and Education, 26*, Article 100171. https://doi.org/10.1016/j.tine.2022.100171

Devlin, D., Moeller, K., Xenidou-Dervou, I., Reynvoet, B., & Sella, F. (2024). Familiar sequences are processed faster than unfamiliar sequences, even when they do not match the count-list. *Cognitive Science, 48*(7), Article e13481. https://doi.org/10.1111/cogs.13481

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani, L. S., Feinstein, L., Engel, M., Brooks-Gunn, J., Sexton, H., Duckworth, K., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology, 43*(6), 1428–1446. https://doi.org/10.1037/0012-1649.43.6.1428

Edelsbrunner, P. A., Simonsmeier, B. A., & Schneider, M. (2025). The Cronbach's alpha of domain-specific knowledge tests before and after learning: A meta-analysis of published studies. *Educational Psychology Review, 37*(1), 1–43. https://doi.org/10.1007/s10648-024-09982-y

Fuson, K. C. (1988). *Children's counting and concepts of number*. Springer. https://doi.org/10.1007/978-1-4612-3754-9

Gattas, S. U., Bugden, S., & Lyons, I. M. (2021). Rules of order: Evidence for a novel influence on ordinal processing of numbers. *Journal of Experimental Psychology: General, 150*(10), 2100–2116. https://doi.org/10.1037/xge0001022

Ginsburg, H. (1977). *Children's arithmetic: The learning process*. D. van Nostrand. https://psycnet.apa.org/record/1979-21963-000

Gloor, N., Leuenberger, D., & Moser Opitz, E. (2021). Disentangling the effects of SFON (Spontaneous Focusing on Numerosity) and symbolic number skills on the mathematical achievement of first graders. A longitudinal study. *Frontiers in Education, 6*(629201), 1–13. https://doi.org/10.3389/feduc.2021.629201

Gray, S. A., & Reeve, R. A. (2016). Number-specific and general cognitive markers of preschoolers' math ability profiles. *Journal of Experimental Child Psychology, 147*, 1–21. https://doi.org/10.1016/j.jecp.2016.02.004

Hannula, M. M., & Lehtinen, E. (2005). Spontaneous focusing on numerosity and mathematical skills of young children. *Learning and Instruction, 15*(3), 237–256. https://doi.org/10.1016/j.learninstruc.2005.04.005

Hannula, M. M., Räsänen, P., & Lehtinen, E. (2007). Development of counting skills: Role of spontaneous focusing on numerosity and subitizing-based enumeration. *Mathematical Thinking and Learning, 9*(1), 51–57. https://doi.org/10.1080/10986060709336605

Hannula, M. M., Lepola, J., & Lehtinen, E. (2010). Spontaneous focusing on numerosity as a domain-specific predictor of arithmetical skills. *Journal of Experimental Child Psychology, 107*(4), 394–406. https://doi.org/10.1016/j.jecp.2010.06.004

Hannula, M.M., Mattinen, A. & Lehtinen, E. (2005). Does social interaction influence 3-year-old children's tendency to focus on numerosity? A quasi-experimental study in day care. In L. Verschaffel, E. De Corte, G.Kanselaar, & Valcke, M. (Eds). *Powerful environments for promoting deep conceptual and strategic learning* (pp. 63–80). Leuven: Leuven University Press.

Hannula, M. M. (2005). *Spontaneous focusing on numerosity in the development of early mathematical skills* [Doctoral dissertation, University of Turku]. https://www.utupub.fi/handle/10024/102190

Hannula-Sormunen, M., Nanu, C., Luomaniemi, K., Heinonen, M., Sorariutta, A., Södervik, I., & Mattinen, A. (2020). Promoting spontaneous focusing on numerosity and cardinality-related skills at day care with one, two, how many and count, how many programs. *Mathematical Thinking and Learning, 22*(4), 312–331. https://doi.org/10.1080/10986065.2020.1818470

Hannula-Sormunen, M. M. (2015). Spontaneous focusing on numerosity and its relation to counting and arithmetic. In R. Cohen Kadosh & A. Dowker (Eds.), *The Oxford handbook of numerical cognition* (pp. 275–290). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199642342.013.018

Harju, H., Van Hoof, J., Nanu, C. E., McMullen, J., & Hannula-Sormunen, M. (2024). Spontaneous focusing on numerical order and numerical skills of 3- to 4-year-old children. *Educational Studies in Mathematics, 117*(1), 43–65. https://doi.org/10.1007/s10649-024-10327-3

Harju, H., Lehtinen, E., & Hannula-Sormunen, M. (2022). Focusing on numerical order in preschool predicts mathematical achievement six years later. In C. Fernández, S. Llinares, A. Gutiérrez, & N. Planas (Eds.), *Proceedings of the 45th Conference of the International Group for the Psychology of Mathematics Education* (Vol. 2, pp. 347–354). https://web.ua.es/en/pme45/documents/proceedings-pme-45-vol2.pdf

Hutchison, J. E., Ansari, D., Zheng, S., Jesus, S. D., & Lyons, I. M. (2022). Extending ideas of numerical order beyond the count-list from kindergarten to first grade. *Cognition, 223*, Article 105019. https://doi.org/10.1016/j.cognition.2022.105019

Jordan, N. C., Kaplan, D., Ramineni, C., & Locuniak, M. N. (2009). Early math matters: Kindergarten number competence and later mathematics outcomes. *Developmental Psychology, 45*(3), 850–867. https://doi.org/10.1037/a0014939

Lehtinen, E., Hannula-Sormunen, M., McMullen, J., & Gruber, H. (2017). Cultivating mathematical skills: From drill-and-practice to deliberate practice. *ZDM – Mathematics Education, 49*(4), 625–636. https://doi.org/10.1007/s11858-017-0856-6

Li, X., Ching, B.H.-H., Tan, L., Li, X., Li, J., & Chen, T. T. (2025). The relation between spontaneous focusing on numerosity and mathematics performance: A meta-analysis. *Educational Psychology Review, 37*(2), Article 27. https://doi.org/10.1007/s10648-025-10007-5

Liang, Y., Zhang, L., Duan, X., Wu, G., & Yan, H. (2023). Longitudinal association between non-symbolic numerical representation and emerging math competence: The dynamic mediation effect from cardinal

knowledge to ordinal skills. *Cognitive Development, 66*, Article 101339. https://doi.org/10.1016/j.cogdev.2023.101339
Lyons, I. M., & Ansari, D. (2015). Numerical order processing in children: From reversing the distance-effect to predicting arithmetic. *Mind, Brain & Education, 9*(4), 207–221. https://doi.org/10.1111/mbe.12094
Lyons, I. M., Price, G. R., Vaessen, A., Blomert, L., & Ansari, D. (2014). Numerical predictors of arithmetic success in grades 1–6. *Developmental Science, 17*(5), 714–726. https://doi.org/10.1111/desc.12152
Lyons, I. M., Vogel, S. E., & Ansari, D. (2016). On the ordinality of numbers: A review of neural and behavioral studies. In M. Cappelletti & W. Fias (Eds.), Progress in Brain Research, 227 (pp. 187–221). Elsevier. https://doi.org/10.1016/bs.pbr.2016.04.010
Määttä, S., Hannula-Sormunen, M. M., Kiili, K., Halme, H., Koskinen, A., & McMullen, J. (2024). Promoting 5th grade students' spontaneous focusing on quantitative relations. *The Journal of Experimental Education, 93*(3), 451–477. https://doi.org/10.1080/00220973.2024.2348795
Malone, S. A., Pritchard, V. E., & Hulme, C. (2021). Separable effects of the approximate number system, symbolic number knowledge, and number ordering ability on early arithmetic development. *Journal of Experimental Child Psychology, 208*, Article 105120. https://doi.org/10.1016/j.jecp.2021.105120
Mazzocco, M. M. M., Chan, J.Y.-C., Bye, J. K., Padrutt, E. R., Praus-Singh, T., Lukowski, S., Brown, E., & Olson, R. E. (2020). Attention to numerosity varies across individuals and task contexts. *Mathematical Thinking and Learning, 22*(4), 258–280. https://doi.org/10.1080/10986065.2020.1818467
McMullen, J., Hannula-Sormunen, M. M., & Lehtinen, E. (2014). Spontaneous focusing on quantitative relations in the development of children's fraction knowledge. *Cognition and Instruction, 32*(2), 198–218. https://doi.org/10.1080/07370008.2014.887085
McMullen, J., Hannula-Sormunen, M. M., & Lehtinen, E. (2015). Preschool spontaneous focusing on numerosity predicts rational number conceptual knowledge 6 years later. *ZDM – Mathematics Education, 47*(5), 813–824. https://doi.org/10.1007/s11858-015-0669-4
McMullen, J., Hannula-Sormunen, M. M., Laakkonen, E., & Lehtinen, E. (2016). Spontaneous focusing on quantitative relations as a predictor of the development of rational number conceptual knowledge. *Journal of Educational Psychology, 108*(6), 857–868. https://doi.org/10.1037/edu0000094
McMullen, J., Verschaffel, L., & Hannula-Sormunen, M. M. (2019). Spontaneous mathematical focusing tendencies in mathematical development. *Mathematical Thinking and Learning, 22*(4), 249–257. https://doi.org/10.1007/978-3-030-00491-0_4
Nanu, C. E., McMullen, J., Munck, P., & Hannula-Sormunen, M. M. (2018). Spontaneous focusing on numerosity in preschool as a predictor of mathematical skills and knowledge in the fifth grade. *Journal of Experimental Child Psychology, 169*, 42–58. https://doi.org/10.1016/j.jecp.2017.12.011
National Agency of Education. (2022). *Varhaiskasvatussuunnitelman perusteet 2022 (Määräykset ja ohjeet 2022:2a)*. [National core curriculum for early childhood education and care]. Opetushallitus. https://www.oph.fi/fi/tilastot-ja-julkaisut/julkaisut/varhaiskasvatussuunnitelmanperusteet-2022. Accessed 12.11.2025.
Nguyen, T., Watts, T. W., Duncan, G. J., Clements, D. H., Sarama, J. S., Wolfe, C., & Spitler, M. E. (2016). Which preschool mathematics competencies are most predictive of fifth grade achievement? *Early Childhood Research Quarterly, 36*, 550–560. https://doi.org/10.1016/j.ecresq.2016.02.003
Nunes, T., & Bryant, P. (2015). The development of mathematical reasoning. In R. M. Lerner (Ed.), *Handbook of child psychology and developmental science* (pp. 1–48). Wiley. https://doi.org/10.1002/9781118963418.childpsy217
O'Connor, P. A., Morsanyi, K., & McCormack, T. (2018). Young children's non-numerical ordering ability at the start of formal education longitudinally predicts their symbolic number skills and academic achievement in maths. *Developmental Science, 21*(5), 1–17. https://doi.org/10.1111/desc.12645
Poltz, N., Quandte, S., Kohn, J., Kucian, K., Wyschkon, A., Aster, M., & Esser, G. (2022). Does it count? Preschool children's spontaneous focusing on numerosity and their development of arithmetical skills at school. *Brain Sciences, 12*(3), Article 313. https://doi.org/10.3390/brainsci12030313
Purpura, D. J., & Lonigan, C. J. (2013). Informal numeracy skills: The structure and relations among numbering, relations, and arithmetic operations in preschool. *American Educational Research Journal, 50*(1), 178–209. https://doi.org/10.3102/0002831212465332
R Core Team. (2024). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org
Ramani, G. B., Rowe, M. L., Eason, S. H., & Leech, K. A. (2015). Math talk during informal learning activities in Head Start families. *Cognitive Development, 35*, 15–33. https://doi.org/10.1016/j.cogdev.2014.11.002
Rathé, S., Torbeyns, J., De Smedt, B., & Verschaffel, L. (2019). Spontaneous focusing on Arabic number symbols and its association with early mathematical competencies. *Early Childhood Research Quarterly, 48*, 111–121. https://doi.org/10.1016/j.ecresq.2019.01.011

Rathé, S., Torbeyns, J., Smedt, B. D., & Verschaffel, L. (2022). Spontaneous focusing on Arabic number symbols: A unique component of children’s early mathematical development? *Mathematical Thinking and Learning, 24*(1), 38–51. https://doi.org/10.1080/10986065.2020.1818468

Richardson, J. T. E. (2018). The use of Latin-square designs in educational and psychological research. *Educational Research Review, 24*, 84–97. https://doi.org/10.1016/j.edurev.2018.03.003

Saxe, G. B., Guberman, S. R., Gearhart, M., Gelman, R., Massey, C. M., & Rogoff, B. (1987). Social processes in early number development. *Monographs of the Society for Research in Child Development, 52*(2), i. https://doi.org/10.2307/1166071

Sharir, T., & Mevarech, Z. (2022). Young children’s recognition of mathematical structures and its relations to mathematical skills. In A. Sharif-Rasslan & D. Hassidov (Eds.), *Special issues in early childhood mathematics education research: Learning, teaching and thinking* (pp. 171–186). BRILL. https://doi.org/10.1163/9789004510685

Silver, A. M., Elliott, L., Imbeah, A., & Libertus, M. E. (2020). Understanding the unique contributions of home numeracy, inhibitory control, the approximate number system, and spontaneous focusing on number for children’s math abilities. *Mathematical Thinking and Learning, 22*(4), 296–311. https://doi.org/10.1080/10986065.2020.1818469

Spaepen, E., Gunderson, E. A., Gibson, D., Goldin-Meadow, S., & Levine, S. C. (2018). Meaning before order: Cardinal principle knowledge predicts improvement in understanding the successor principle and exact ordering. *Cognition, 180*, 59–81. https://doi.org/10.1016/j.cognition.2018.06.012

Verschaffel, L., Rathé, S., Wijns, N., Degrande, T., van Dooren, W., De Smedt, B., & Torbeyns, J. (2020). Young children’s early mathematical competencies: The role of mathematical focusing tendencies. In M. Carlsen, I. Erfjord, & P. S. Hundeland (Eds.), *Mathematics education in the early years: Results from the POEM4 Conference, 2018* (pp. 23–42). Springer International Publishing. https://doi.org/10.1007/978-3-030-34776-5_2

Vlaamse overheid. (n.d.). *Kleuteronderwijs* [Preschool education]. Onderwijsdoelen. Retrieved October 14, 2025, from https://onderwijsdoelen.be/resultaten?onderwijsstructuur=KO

Wijns, N., De Smedt, B., Verschaffel, L., & Torbeyns, J. (2020). Are preschoolers who spontaneously create patterns better in mathematics? *British Journal of Educational Psychology, 90*(3), 753–769. https://doi.org/10.1111/bjep.12329

Wynn, K. (1990). Children’s understanding of counting. *Cognition, 36*(2), 155–193. https://doi.org/10.1016/0010-0277(90)90003-3

Xu, C., LeFevre, J.-A., Di Lonardo Burr, S., Maloney, E. A., Wylie, J., Simms, V., Skwarchuk, S.-L., & Osana, H. P. (2023). A direct comparison of two measures of ordinal knowledge among 8-year-olds. *Journal of Numerical Cognition, 9*(2), 253–267. https://doi.org/10.5964/jnc.10201

Authors and Affiliations

Heidi Harju[1] · **Lore Van Belle**[2,4] · **Wim Van Dooren**[2] · **Jake McMullen**[1,3] · **Jo Van Hoof**[1,2,3]

✉ Heidi Harju
heidi.harju@utu.fi

Lore Van Belle
lore.vanbelle@kuleuven.be

Wim Van Dooren
wim.vandooren@kuleuven.be

Jake McMullen
jake.mcmullen@utu.fi

Jo Van Hoof
jo.vanhoof@utu.fi

1 Department of Teacher Education, University of Turku, Turku, Finland

2 Centre for Instructional Psychology and Technology, University of Leuven, Leuven, Belgium

3 Faculty of Science, Turku Research Institute for Learning Analytics, University of Turku, Turku, Finland

4 Parenting and Special Education Research Unit, KU Leuven, Belgium