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Exploration of latent early literacy profiles in German kindergarten children using a newly developed app

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Introduction: This study explores the effectiveness of the tablet-based EuLeApp© assessment tool in identifying distinct latent early literacy profiles among German kindergarten children aged between 4.0 and 7.0 years. Additionally, the study investigates how factors such as age, biological sex, and language impairment contribute to the manifestation and prevalence of these latent literacy profiles.

Methods: Utilizing latent class analysis on a diverse sample of 285 children, we administered a prototype of the EuLeApp© assessment tool to measure early literacy skills (i.e., print awareness, concepts of print, word awareness, phonological awareness, alphabet knowledge, and narrative skills). The sample included children aged between 4.0 and 7.0 years from various demographic backgrounds. Analysis involved identifying distinct early literacy profiles based on the assessment results. We also examined the influence of age, biological sex, and language impairment on the manifestation and prevalence of these profiles.

Results: The analysis revealed four stable and interpretable early literacy profiles: Exceptional Performers (17%), Typical Performers (41%), Marginal Performers (35%), and Subpar Performers (7%). These profiles were found to be shaped by the complex interplay of age, biological sex, and language impairment status among the children.

Discussion: These findings underscore the importance of employing person-centered methodologies to characterize early childhood literacy profiles, providing a framework for tailoring intervention programs to suit the unique characteristics and requirements of individual children.

KEYWORDS

early literacy, kindergarten, language impairment, latent class analysis, mobile application

1 Introduction

Although an overwhelming majority of illiterate individuals live in developing countries (World Literacy Foundation, 2018), low literacy and numeracy proficiencies are also observed in developed nations. For example, a 2018 study conducted in Germany reported low literacy skills in 12.1% of the German-speaking adult population (Buddeberg et al., 2021). Additionally,

literacy difficulties have been identified among German children, with Wittig and Schneider (2022) reporting that nearly 18.8% of all fourth-grade children in Germany (around 10 years of age) fail to achieve the minimum reading standard, and approximately 30.4% falling short of the minimum spelling standard.

The existing body of literature strongly establishes that the acquisition of reading and writing skills takes place long before formal education begins. Known as emergent or early literacy (Clay, 1966), it involves various foundational skills (e.g., alphabet knowledge, recognizing the link between spoken and written language, grasping the foundational phonological structure of a language, as well as oral linguistic abilities such as vocabulary and grammar), that are necessary prerequisites for future reading success. One view of emergent literacy, forwarded by Lonigan and colleagues (Whitehurst and Lonigan, 1998; Lonigan and Shanahan, 2010) describes the construct of emergent literacy as consisting of two interdependent components: outside-in and inside-out dimensions. Outside-in processes encompass children's understanding of print conventions, their emergent reading (e.g., reading environmental print), vocabulary, and narrative skills. In contrast, the inside-out component refers to children's letter-name and letter-sound knowledge, their phonetic (i.e., invented) spelling, as well as language-based components (e.g., phonological and syntactic awareness). These various factors of early literacy skills influence the development of reading skills in different ways and at different times. While alphabet knowledge, word awareness, and phonological awareness are fundamental for the development of word reading skills (Lonigan et al., 2000; Roth et al., 2002; Lenel and Knopf, 2015; Hjetland et al., 2019), oral language (such as narrative skills and vocabulary) predict later reading comprehension skills (Sénéchal et al., 2001; Roth et al., 2002; Hjetland et al., 2019; Babayiğit et al., 2021). As such, it is argued that kindergarten narrative skills and vocabulary enhances future reading comprehension (Sénéchal et al., 2001; Babayiğit et al., 2021).

To address the early identification and support of children vulnerable to reading and spelling difficulties, it is imperative to transcend the prevailing reactive approach and broaden our efforts by creating and implementing preventative strategies (Murphy et al., 2016). Effective implementation of evidence-based instructional practices and progress monitoring assessments is paramount, particularly in early childhood education, necessitating the use of accurate and valid assessment tools (Gorman et al., 2016; Antoniou et al., 2022). Embracing principles of primary and secondary prevention, it is crucial to detect the underlying causes and initial indicators of future reading challenges at the earliest possible stage, well before these difficulties manifest. Subsequently, a personalized and focused intervention should be employed to improve literacy outcomes (Hudson et al., 2023). Scholarly discourse underscores the initiation of screening and support processes during kindergarten, a pivotal stage for foundational reading skill development (Wanzek and Vaughn, 2007; Gaab and Petscher, 2022). Empirical evidence highlights literacy achievement disparities emerging as early as kindergarten, persisting and widening between typical and atypical readers through 12th grade in the absence of intervention (Ferrer et al., 2015). Consistent with these findings, interventions targeting reading skills in kindergarten yield notably higher effect sizes (across studies Cohen's d: 0.18–0.84) compared to those initiated later in second or third grade (across studies Cohen's d: −0.05 to 0.27) (Wanzek and Vaughn, 2007).

Furthermore, a reciprocal relationship between reading self-concept and competence emerges as early as 5 years of age (Morgan et al., 2008; Walgermo et al., 2018a,b) and persists through middle childhood (e.g., 11 years, Sewasew and Koester, 2019). For example, Morgan et al. (2008) reported that within just 6 months of starting the first grade, students with poorer early literacy skills exhibited less confidence in their reading abilities compared to their peers, a discrepancy that endured for 3 years. These empirical findings suggest that children with weaker reading self-concept often demonstrate poor reading abilities, leading to avoidance of reading-related tasks due to the anticipation of failure. Consequently, they struggle to find ways to develop proficient reading skills, and often remain low-performing readers as they mature. Early identification and intervention targeting both reading and spelling skills, along with precursor skills like early literacy, have the potential to significantly reduce the prevalence of reading challenges among young learners, thereby enhancing adult literacy rates.

Another factor that shapes a child's early literacy skills is their level of language (Cabell et al., 2010; Justice et al., 2015). For instance, compared to their peers who are developing typically, children with language development disorders [e.g., Specific Language Impairment (SLI)] typically exhibit lower proficiency in several aspects of early literacy such as phonological awareness in a broader sense (e.g., rhyming), productive knowledge of letters (including letter names), writing skills, and various facets of storytelling abilities (Cabell et al., 2010; Justice et al., 2015; Pavelko et al., 2018). In addition, children with SLI commonly encounter difficulties with reading fluency, reading comprehension, and other academic tasks that rely heavily on language skills, with difficulties persisting into primary school grades and beyond (Snowling et al., 2016).

Clustering approaches have emerged as a useful analytic tool to identify the linguistic profiles of children with SLI (e.g., Cabell et al., 2010, 2011, 2013; Justice et al., 2015), which may be informative for examining and understanding variability in the literacy skills. For example, Cabell et al. (2010) used K-means cluster analysis to group 59 pre-school aged children (48–60 months, ~4–5 years) with SLI based on their emergent literacy skills and oral language skills. Their analysis revealed three distinct early literacy clusters arising from the data, characterized by a combination of age, language proficiency, and receptive and expressive language competencies. Similar results were obtained by Justice et al. (2015) who employed latent profile analysis to explore early literacy profiles of 218 three-to five-year-old children with language impairment, with four profiles emerging that distinguished by variations in early literacy scores and spoken language skills. These analytical approaches offer the potential to move beyond broad group-based generalizations concerning early literacy skills and ascertain whether distinct profiles exist to delineate early literacy development. This differentiation could, in turn, provide insights into the risk factors and resilience factors shaping the journey of young children as they progress toward becoming proficient readers.

1.1 The evaluation of early literacy

In the Anglo-Saxon (e.g., the United States, the United Kingdom) literature, early literacy knowledge and skills can be comprehensively evaluated using paper and pen assessments, such as the Dynamic Indicators of Basic Early Literacy Skills (DIBELS, Good and Kaminski,

2002), the Test of Preschool Early Literacy (TOPEL, Lonigan et al., 2007), or the Phonological Awareness and Literacy Screening PreK (PALS-PreK, Invernizzi et al., 2004). Until recently, a comprehensive standardized German language early literacy assessment had been lacking, with empirical studies having to adapt existing English tests to measure various early literacy components (Niklas and Schneider, 2013; Fricke et al., 2016). Inspired by the absence of a suitable tool, Meindl and Jungmann (2014) embarked on the creation of a novel German-language assessment tailored to evaluate early literacy and narrative skills among children aged 4 to 5 years (EuLe 4–5; Erzähl-und Lesekompetenzen erfassen bei 4-bis 5-jährigen Kindern). The EuLe 4–5 is aligned with the component model proposed by Whitehurst and Lonigan (1998) and evaluates five early literacy factors: concepts of print, print awareness, word awareness, alphabet knowledge, and narrative skills. The internal consistency of the EuLe 4–5 varies between 0.78 (print knowledge scale) and 0.95 (alphabet knowledge scale) (Meindl and Jungmann, 2015).

The conventional paper-and-pen formats used in early literacy assessment present several challenges, including difficulties in engaging children due to the static nature of paper-based assessments, challenges in achieving standardized administration due to the diverse range of children's abilities and behaviors, and the labor-intensive nature of manual scoring, which can lead to delays in delivering timely feedback and interventions. However, the proliferation of smartphones, tablets, and other portable devices, along with improvements in internet connectivity, cloud computing, and advanced data analytics technologies, has facilitated the implementation of school-based assessments on a large scale. Digital assessment tools offer distinct advantages over traditional paper-and-pen exams (Hipkins and Cameron, 2018). They allow for dynamic adjustment of question difficulty based on students' responses, provide immediate feedback on students' performance, progress, and areas of difficulty, and adhere to established guidelines and criteria, ensuring consistency and reliability across diverse testing conditions.

In response to the identified gap in available resources and in alignment with the objectives outlined in the German Digital Strategy 2025 (Federal Ministry for Economic Affairs and Energy, 2016), we have embarked on the modernization of the pen-and-paper-based EuLe 4–5 assessment into a tablet-based tool, known as the EuLeApp© (Meindl et al., 2022). As a pivotal aspect of our ongoing efforts, our goal is to explore whether a prototype of this newly developed digital assessment possesses the capability to distinguish between various latent early literacy profiles among children enrolled in German Kindergartens. In this study, we utilize a person-centered Latent Class Analysis (LCA) approach to identify profiles and their prevalence in early literacy skills among this sample of children. Furthermore, we endeavor to elucidate how factors such as a child's age, sex, and language impairment relate to the variety and occurrence of these latent literacy profiles. By employing a person-centered clustering technique and considering diverse influencing factors, our aim is to deepen our understanding of early literacy development and inform the design of tailored interventions to support children's literacy skills.

2 The German early childhood education and care system

The considerable disparities in educational frameworks between the Anglo-Saxon world and Germany raise the possibility that the aforementioned outcomes may not extend to children who undergo their initial educational experiences in German early childhood education and care (ECEC) centers.

Within the German ECEC landscape, two primary programs are prominent. Traditionally, facilities designed for children aged 0–3 are referred to as Kinderkrippen or simply Krippen (crèches), while those catering to children aged 3–6 are known as Kindertagesstätte (commonly colloquialized as Kita or Kindergarten). German ECEC services prioritize nurturing children's independence, fostering critical thinking skills, encouraging ownership of the learning process, and promoting creative problem-solving abilities. While formal reading instruction does not occur in kindergarten, children may encounter reading and writing activities during craft projects, story-time sessions, local excursions, and outdoor play. Formal schooling typically commences around the ages of six to seven when children enter Grundschule (equivalent to primary school) and embark on the formal journey of learning to read and write (Mann and Wimmer, 2002).

Governance over German ECEC is a collaborative effort among federal, state, and municipal authorities (Deutscher Bildungsserver, 2023), with the federal government mandating that ECEC services (1) promote the development of the child into a self-determined, independent, and socially competent personality, (2) support and supplement upbringing and education in the family, and (3) help parents to better reconcile employment, child rearing and family care (Section 22 subsection 2 SGB VIII; Bundesministerium der Justiz, 1990). Thus, education in German ECECs can be viewed as providing both education and care, rather than being primarily focused on enhancing school readiness (European Commission, 2023).

The decentralization of ECEC services gives rise to a diverse array of pedagogical curricula and practices (Resa et al., 2016; European Commission, 2023). However, this decentralization has also resulted in varying quality standards, often falling short of evidence-based recommendations (Viernickel et al., 2015), with actual conditions frequently failing to align with evidence-based recommendations (Bock-Famulla et al., 2017). Consequently, despite high attendance rates in kindergartens, significant variations exist in the early literacy skills of children as they start primary school (e.g., Brügelmann, 1998). These differences can be attributed to the inconsistent exposure children receive to early literacy activities in ECEC environments (Tietze et al., 1998; Wirts et al., 2017). For example, Wirts et al. (2017) explored literacy-related activities within 34 German ECEC settings and reported that pedagogical staff incorporated picture book activities into the daily schedule 0.895 times per day (SD = 1.0) lasting 14 min on average (SD = 9.09), with such activities initiated by one or more children in 53% of instances. Phonological awareness and early writing activities were even more rarely found, occurring only 0.485 times per day (SD = 0.55), and lasting 15 min on average (SD = 15.37).

In addition, significant regional disparities exist in the availability of early childhood education and care (ECEC) slots across German states, counties, and municipalities. For example, among children aged 3–6 years, 90% of children in Thuringia attended an ECEC institution for more than 7 h a day, whereas only 24% of children in Baden-Wuerttemberg met this criterion (Statistisches Bundesamt, 2018). Furthermore, the inadequate number of ECEC facilities often fails to meet the demand for childcare, resulting in lengthy waiting lists and delays in securing placements. Consequently, it is not uncommon for children to enter German ECEC centers at the age of four or even 5 years old.

3 Methods

3.1 Participants

Kindergartens from the Lower Saxony and Mecklenburg-West Pomerania states of Germany were recruited for the present study. Eligibility for the study required that the children: (1) had parental consent to participate, (b) were between the ages of 3.11 and 6.11 years, (c) demonstrated sufficient German language proficiency to comprehend the instructions in the language and literacy assessments (assessed via a picture search task, Petermann et al., 2016), and (d) had no cognitive and communicative disabilities (e.g., Down syndrome, autism spectrum disorder). To mitigate selection bias and ensure the representativeness of the target population, recruitment strategies employed a two-stage sampling method. Kindergartens in Lower Saxony and Mecklenburg-West Pomerania received invitations via both regular mail and email, accompanied by a study pamphlet and a link to the study webpage for detailed information. Persistent efforts, including telephone follow-ups and personal visits, were made in cases of non-response from kindergartens. Upon obtaining consent from kindergarten directors, recruitment materials, comprising informed consent forms and study pamphlets, were distributed to parents/caregivers by kindergarten teachers, outlining comprehensive study details.

The study sample consisted of 285 children from 14 local Kindergartens in the Lower Saxony and Mecklenburg-West Pomerania states of Germany. Fifty four percent of the participants were males, and the average age of the children was 62.37 months (range 47–78 months, SD = 7.39). The experiment conformed to the declaration of Helsinki and was approved by the local school authorities and the institutional review boards of University of Rostock and Carl-von-Ossietzky University of Oldenburg. Informed consent was obtained from the parents of the children prior to participation in the experiment.

3.1.1 Early literacy measures

To assess early literacy skills, we administered the prototype of a newly developed assessment tool, the EuleApp© (Meindl et al., 2022). It allows for the assessment of six different early literacy skills: concepts of print, print awareness, word awareness, phonological awareness, alphabet knowledge, and narrative skills. The order of sub-tests was consistent across participants [in the order below], with questions presented in ascending order of difficulty within each sub-test. Raw scores from the EuleApp© subtests were saved in the app, but subsequent data analysis was conducted using custom Python scripts.

The assessment of children's print awareness comprised a 40-item subtest, wherein children were tasked with distinguishing words from pictures, numbers, and symbols ("Tap on the letter"; "Tap on writing"). Each child was presented with four pictures, one being the target and the other three serving as distractors, and they were required to tap either on the word or the letter corresponding to the target. The internal consistency for correct items ranged between $\alpha = 0.93$ and $\alpha = 0.94$.

Children's concepts of print were assessed using a 19-item measure involving print-related tasks, such as identifying reading direction ("Where do you begin reading? Touch it") or recognizing the front of a book. The internal consistency for correct items ranged between $\alpha = 0.75$ and $\alpha = 0.77$.

Children's word awareness was measured using a 21-item measure that increased in difficulty across items. Children's word awareness was measured with a 21-item measure that progressively increased in difficulty. During this assessment, children encountered short texts and were directed to tap on specific elements, such as the first word, the second word, or the space between two words ("Tap on the space between two words"). The reliability score for correct items ranged between $\alpha = 0.74$ and $\alpha = 0.75$.

The phonological awareness subtest comprises 21 items and assesses two key components: the synthesis of syllables and phonemes to form words, and the analysis of the syllabic and phonemic structure of words. For example, tasks include identifying the initial sounds of words (e.g., "Here you can see three pictures: Grandma, Mum, Apple. Touch the picture that starts with /m/"). During this subtest, children were presented with three pictures, one being the target and the others serving as distractors, and they were required to select the appropriate picture representing the correct answer. The internal consistency for correct items ranged between $\alpha = 0.67$ and $\alpha = 0.72$.

To assess children's receptive alphabet knowledge, phonetic realizations of letters were presented, and the children's task was to select the corresponding letter from a set of four options (e.g., "Tap the /m/"). In the productive segment, children were asked if they could name the 26 letters of the alphabet. Children's first receptive and productive reading abilities on the syllable and word level were assessed using items such as "Tap on /am/", "Tap on /mama/" (receptive segment), and "What is written here?" (productive segment). The internal consistency for correct items ranged between $\alpha = 0.95$ and $\alpha = 0.96$.

The "Hungry Seagull Marius" story, consisting of seven pictures, was developed to evaluate children's narrative skills. Initially, the story's pictures were presented to the child to provide an overview. Subsequently, the pictures were shown in pairs, with the instruction for the child to tell the story. We analyzed the macrostructure (story grammar) of the narratives, including components such as setting, characters, initiating event, internal response, plan, attempts, direct consequence, and resolution (with a possible score range of 0–21). Inter-rater reliability was confirmed by double scoring a random selection of 30% of the audio samples and resulted in Kendall's Tau of 0.84.

3.1.2 Defining language impairment

To identify children with language impairment, we utilized either the "Language level test for children aged 3–5 years" (Sprachentwicklungstest für Kinder 3–5 [SET 3–5]; Petermann et al., 2016) or the "Language level test for children aged 5–10 years" (Sprachentwicklungstest für Kinder 5–10 [SET 5–10]; Petermann, 2018), depending on the child's age. The SET 3–5 comprises 12 subtests that measure a child's receptive language processing skills (understanding, recording), productive language processing skills (own speech acts), and auditory memory skills (language memory). Similarly, the SET 5–10 consists of 8 subtests that measure a child's vocabulary, semantic relations, processing speed, language comprehension, language production, grammar/morphology, and auditory memory. The internal consistency for administered subtests from the SET 3–5 ranged between $\alpha = 0.70$ and $\alpha = 0.93$ (Petermann et al., 2016), while it ranged between $\alpha = 0.71$ and $\alpha = 0.91$ for the SET 5–10 (Petermann, 2018). Raw

scores obtained in each subtest were converted into standardized T-scores (mean: 50, SD: 10). Children scoring at or below the 10th percentile in at least two subtests were classified as language impaired.

3.1.3 Procedure

All children were tested individually in a quiet room at their respective kindergarten. The tasks were administered by a trained experimenter according to the procedures of the EuLe-F and SET manuals and was the same for all children, which served to reduce bias during data collection and analysis. Each child participated in two sessions lasting between 20 and 30 min each. During these sessions, half of the children completed the EuLeApp© early literacy measures initially, followed by the SET 3–5/5–10 assessment, while the remaining children followed the reverse order.

3.2 Data analysis

Data was analyzed using the person-centered latent class analysis (LCA) approach (Lazarsfeld and Henry, 1968; Bergman and Trost, 2006; Collins and Lanza, 2010). LCA is a form of mixture modeling that allows for the identification of unobserved classes based on their response patterns on a set of variables. One of the primary assumptions of LCA is that homogenous sub-groups exist within the dataset, have distinct probability distributions, and that class assignment is mutually exclusive (Bergman and Magnusson, 1997).

Before conducting the LCA, the dataset underwent several preprocessing steps. First, the data were examined for the number and patterns of missing values, and normality tests were performed by calculating skewness and kurtosis. Additionally, potential outliers were identified. Children with missing data on one or more of the predictors were excluded from the analysis, resulting in the removal of 14 students (less than 4.9% of the sample). There were no specific issues regarding normality or outliers.

Class-defining variables for the LCA included the early literacy scores (obtained from the EuleApp©), presence of language impairment (obtained from either the SET 3–5 or SET 5–10), as well as the child's age and biological sex. The modeling process began by estimating the one-class model. Subsequently, we progressively examined model fits by successively increasing the number of classes until we obtained a model where a class comprised less than 5% of the total sample (Nylund-Gibson and Choi, 2018), or model estimation errors occurred.

Consistent with best-practice guidelines, a holistic evaluation of multiple fit statistics was used to determine the best fitting model (Masyn, 2013; Nylund-Gibson and Choi, 2018) and included information criterion, relative fit indices, and substantive interpretability by the project team. The relative model fit for each class model was evaluated using four information theory-based metrics including the Bayesian Information Criterion (BIC; Schwarz, 1978), sample-size adjusted BIC (SABIC; Sclove, 1987), and Consistent Akaike Information Criterion (CAIC; Bozdogan, 1987). In interpreting these criteria, the lower the BIC, AIC, and CAIC values, the better the comparative fit of the model to the k-1 class model. Absolute model fit was assessed using the log-likelihood, where a higher value (closer to 0) represents a better fit. In the case that the information theory-based metrics continued to decrease as each additional class is added (i.e., there was no global minimum), the selected information criteria was plotted and the "elbow" of the plot indicating the point of diminishing returns was selected as the best solution (Nylund-Gibson and Choi, 2018). Model fit was also examined using the Lo-Mendell-Rubin adjusted likelihood ratio test (LMR-LRT; Lo et al., 2001; Nylund-Gibson et al., 2023), with a significant *p*-value signifying that the estimated model with k classes fits the data better than the simpler k-1 model. In addition to quantitative criteria, the principles of parsimony and substantive interpretability of the latent class solutions were used to guide model criteria (Masyn, 2013). These complementary approaches ensured that the chosen latent class solution balanced statistical complexity with meaningful interpretation.

After identifying the best-fitting class solution, the extent to which the classes could be differentiated was examined using multiple metrics: relative entropy, average posterior probabilities, substantive knowledge and expertise by the project team, and univariate statistics. Relative entropy was used as the primary measure to determine how well the classes are differentiated (Masyn, 2013; Nylund-Gibson and Choi, 2018), and can be considered as an omnibus metric of classification accuracy (range 0–1; Celeux and Soromenho, 1996), where values > 0.80 indicate "good" assignment of individuals into classes (Ram and Grimm, 2009). This was complemented by examining the average posterior probabilities, with values > 0.70, indicating high classification precision (Nagin, 2005). Subsequently, univariate statistics (chi-square for categorical variables, ANOVAs for continuous variables) were employed to detect differences between latent groups in demographic information (e.g., biological sex, age) and language performance. Tukey *post-hoc* analysis was conducted following significant main effects in ANOVAs. Finally, the project team convened to define meaningful child profiles derived from the LCA results. These profiles were informed by the team's practical experiences working with diverse kindergarten children in educational and clinical settings.

Statistical analyses were performed in Python 3.10.9 (Python Core Team, 2019) using the Pandas (McKinney, 2010), NumPy (Harris et al., 2020), and StepMix libraries (Morin et al., 2023), as well as the tidyLPA package in r (Rosenberg et al., 2018) using a Windows 10 operating system.

4 Results

4.1 Determination of latent classes

The model fit indices are shown in Table 1. To decide on the model that best described the heterogeneity in kindergarten literacy performance, the project team holistically considered the information theory-based, classification accuracy, and substantive interpretability.

Although the log likelihood favored a 6-class solution, it was noted that one of the profiles comprised only 3% of the total sample, suggesting over-extraction (Nylund-Gibson and Choi, 2018). The LMR-LRT *p*-value for the 5-class model was statistically significant, but it had higher Akaike information criterion (AIC), Bayesian information criterion (BIC), consistent Akaike information criterion (CAIC), and lower entropy values compared to the 4-class model, indicating potential instability and over-extraction. The *p*-value of the Lo-Mendell-Rubin likelihood ratio test (LMR-LRT) for the 3-class

TABLE 1 Goodness of fit indices for the competing LCA models.

Classes	Log likelihood	AIC	BIC	CAIC	SABIC	Entropy	aLMR-LRT	Smallest class size (%)
1	−1839.01	3710.03	3767.66	3783.66	3806.57	−inf	–	1.00
2	−1539.96	3145.92	3264.79	3297.79	3345.03	0.87	**p < 0.001**	0.50
3	−1436.53	2973.05	3153.16	3203.16	**3274.73**	0.85	**p < 0.001**	0.20
4	−1371.54	**2877.08**	**3118.42**	**3185.43**	3281.33	0.86	**p < 0.001**	0.07
5	−1355.53	2879.06	3181.64	3265.64	3385.88	0.83	**p = 0.035**	0.07
6	**−1316.09**	2834.19	3198.00	3299.00	3443.57	0.85	$p = 1.000$	0.03

Bolded values in the tables indicate the model that was preferred by the given fit index.
aLMR-LRT Lo-Mendell-Rubin adjusted likelihood-ratio test for k-1 versus k classes.

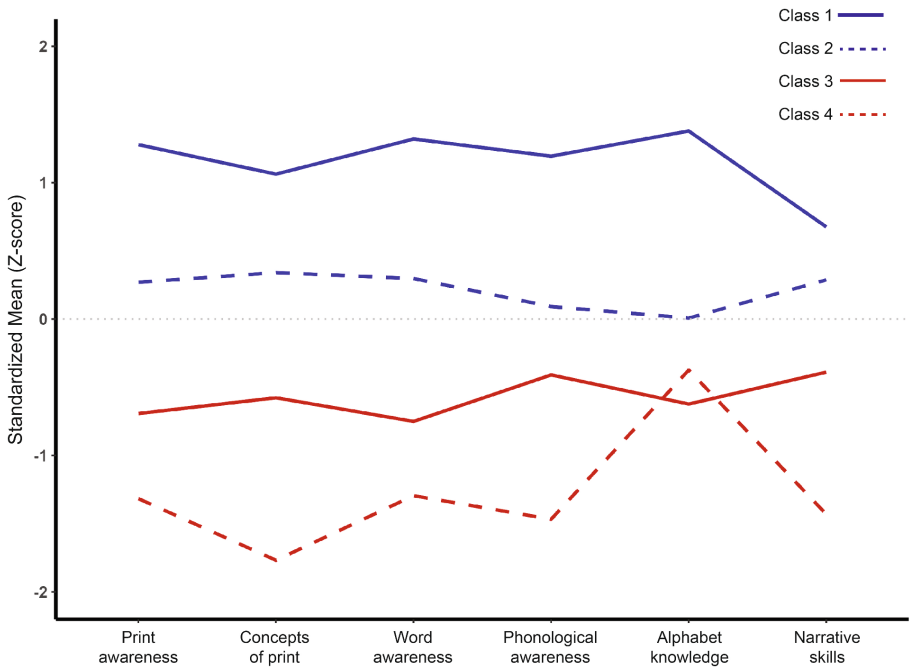

FIGURE 1
Latent profiles of kindergarten children, presented as z-scores.

model was statistically significant, and it exhibited the lowest sample-size adjusted Bayesian information criterion (SABIC) value among all tested models. In contrast, the 4-class solution exhibited lower overall information criteria values (i.e., AIC, BIC, and CAIC values), a statistically significant *p*-value using the LMR-LRT, while also yielding the most meaningful classes relevant to the research questions being investigated as evaluated by the project team. Considering all factors, the 4-class solution was deemed as the most parsimonious model and explored in further depth.

4.2 Latent class descriptions

The profiles of early literacy ability in the four classes are presented in Figure 1. Within-class classification was good (Masyn, 2013), as indicated by a relative entropy value of 0.86 and average posterior probabilities ranging from 0.65 (Subpar Literacy Performers) to 0.95 (Typical Literacy Performers).

Table 2 provides descriptive statistics for the early literacy skills subtests measured using the EuLeApp© for the entire sample, while Table 3 displays the distribution of sociodemographic characteristics and literacy performance according to latent class membership. There were significant differences across classes with respect to age [$F(3, 267) = 20.35$, $p < 0.001$], with Tukey *Post-Hoc* tests revealing that the age of children was similar for Classes 1 and 2 ($p = 0.95$) versus Classes 3 and 4 ($p = 0.11$). There was also a significant difference in the proportion of boys and girls across classes, with a larger proportion of boys for Class 4 than any other class [$\chi^2(3, N = 271) = 22.16$, $p < 0.001$]. The proportion of children with language impairment also differed between classes, with a far higher proportion of language impaired children in Class 4 (94.74%) and a lower proportion of language impaired children in Class 1 (10.64%) when compared to Classes 2 and 3 (36.94 and 52.13%, respectively) [$\chi^2(3, N = 271) = 76.16$, $p < 0.001$].

One-way ANOVAs revealed significant differences in the scores on the six tested literacy components across classes (all *p*'s < 0.001). These findings indicate that the classes exhibited distinct patterns of

TABLE 2 Descriptive statistics for the early literacy skills subtests measured using the EuLeApp©.

Subtest	Mean	SD	Min	Max
Print awareness	22.78	10.35	4.00	40.00
Print knowledge	11.82	3.77	1.00	20.00
Word awareness	5.13	3.11	0.00	12.00
Phonological awareness	18.42	4.09	8.00	28.00
Letter knowledge	22.88	13.65	0.00	80.00
Narrative skills	6.38	3.69	0.00	15.00

TABLE 3 Model-estimated, class-specific means and standard deviations based on latent class membership.

	Class 1 (exceptional performers)	Class 2 (typical performers)	Class 3 (marginal performers)	Class 4 (subpar performers)
N, %	47 (17%)	111 (41%)	94 (35%)	19 (7%)
Participant characteristics				
Age (mean, SD)	66.74 (5.69)	64.15 (7.12)	58.94 (6.17)	58.05 (8.41)
Biological males (%)	40.43%	52.25%	55.32%	89.47%
Language impairment present (%)	10.64%	36.94%	52.13%	94.74%
Literacy raw scores				
Print awareness	36.02 (4.17)	25.58 (7.89)	15.62 (6.15)	9.16 (4.09)
Print knowledge	15.83 (2.03)	13.11 (2.43)	9.65 (2.65)	5.16 (2.61)
Word awareness	9.23 (1.91)	6.05 (2.17)	2.80 (1.46)	1.11 (0.99)
Phonological awareness	23.30 (2.77)	18.79 (3.21)	16.74 (2.99)	12.42 (2.50)
Letter knowledge	41.70 (15.41)	22.98 (9.15)	14.38 (4.07)	17.79 (16.13)
Narrative skills	8.87 (3.75)	7.44 (3.33)	4.95 (2.62)	1.11 (1.29)

literacy performance levels in kindergarten children and that the classes were correctly clustered according to the specific features of literacy performance.

Data from Figure 1 and Table 3 were reviewed and discussed by the project team. The group agreed on the final descriptive labels for the four kindergarten literature profiles shown in Table 3.

4.2.1 Class 1: exceptional literacy performers (*n* = 47, 17%)

Class 1 comprised 17% of the total sample and had an average age of 66.74 months. Overall, these children excelled in all aspects of early literacy, scoring notably higher in literacy measures compared to the other classes (0.68–1.38 SD above the average). Consequently, they have been categorized as having a low risk of encountering future reading difficulties. This class had the lowest proportion of children with language impairment of all groups (10.64% vs. 61.27%). Differences due to language impairment were apparent for the Alphabet Knowledge measure (difference = 0.65), but comparable for all other measures (mean difference = −0.09).

4.2.2 Class 2: typical literacy performers (*N* = 111, 41%)

Class 2 comprised the largest portion of children, accounting for 41% of the entire sample. The mean age of children in this class was 64.15 months, which was similar to Class 1 (66.74 months), but significantly higher than Classes 3 and 4 (average = 58.50 months). As can be seen in Figure 1, Class 2 was characterized by average achievement on all variables (range = 0.01–0.34). While 36.94% of children in this sample exhibited a language impairment, the presence of impairment did not influence performance on any of the tested literacy measures (mean difference = 0.70).

4.2.3 Class 3: marginal literacy performers (*n* = 94, 35%)

Class 3 encompasses 35% of the overall sample. The children in Class 2 had an average age of 58.94 months, which was significantly younger than those in Classes 1 and 3 (average = 65.45 months), but quite similar to that of Class 4 (58.05 months). Overall, the performance of children in Class 3 exhibited below average performance on all measures, especially for Word Awareness (−0.750), Print Awareness (−0.69), and Alphabet Knowledge (−0.62). There was a nearly equal distribution of non-language impaired children (47.87%) and language-impaired children (52.13%) in this class. The presence of language impairment influenced performance on the Narrative Skills measure (difference = 0.29), but none of the other tested literacy measures (mean difference = 0.002, Figure 2, bottom left panel).

4.2.4 Class 4: subpar literacy performers (*n* = 19, 7%)

The fourth class comprised 7% of the entire sample. As with Class 3, children in this class were younger (58.05 months) than children in the first two classes (average = 65.45 months). Except for Alphabet Knowledge (−0.37), the literacy performance of children in

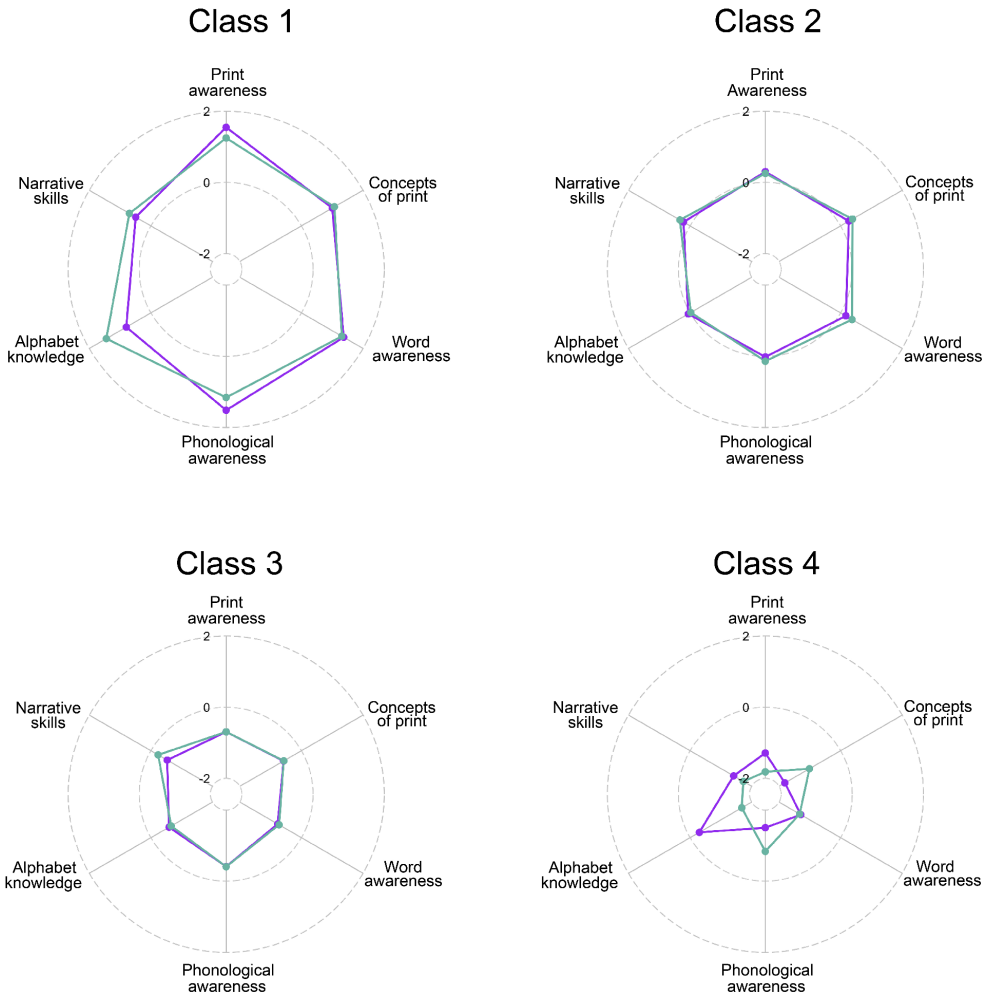

FIGURE 2
Latent profiles of kindergarten children as a function of whether they have a language impairment (purple) or not (green), presented as z-scores.

this class was below average (mean = −1.43). In comparison to the other latent classes, literacy performance was higher than Class 3 for Alphabet Knowledge (difference = 0.250) but lower than Class 3 for all other measures (mean difference = −0.892). It was lower than Classes 1 and 2 on all tested measures (mean difference = −2.43 and −1.49, respectively). Class 4 stood out with a notably greater percentage of language-impaired children when compared to other groups (94.74% vs. 33.24%). As can be seen in Figure 2, performance on the Word Awareness measure was consistent regardless of language impairment (mean difference = −0.036). However, variations between subgroups were evident in all other assessments. Non-language-impaired children exhibited stronger performance on the Concepts of Print and Phonological Awareness subscales (with mean differences of 0.80 and 0.67, respectively) but performed less well on the Print Awareness (−0.53), Alphabet Knowledge (−1.38), and Narrative Skills subscales (−0.32).

5 Discussion

Researchers recognize the period preceding formal school entry as a crucial stage for providing support to children at risk of future literacy challenges. In the context of primary and secondary prevention, it is imperative to proactively identify and address potential literacy difficulties before difficulties become intractable (Wanzek and Vaughn, 2007; Ozernov-Palchik and Gaab, 2016). Digital early literacy screening and assessment tools offer an engaging approach to identify at risk children, while also streamlining the assessment workflow, reducing administrative burdens on educators, and facilitating quicker grading and feedback dissemination. Hence, one of the aims of this current study was to evaluate the capacity of the EuLeApp© prototype to distinguish between different latent profiles among kindergarten children with the person-centered LCA approach. Additionally, given that children's early literacy proficiencies are influenced by various factors (Aaron et al., 2008; Cabell et al., 2010), a second aim was to investigate the impact of age, biological sex, and the presence of language impairment on these profiles (Table 3).

The LCA approach revealed four distinct classes of early literacy performance measured by the EuLeApp© prototype—Class 1: exceptional early literacy performers (prevalence = 17%), Class 2: typical early literacy performers (41%), Class 3: the marginal early literacy performers (35%), and Class 4: subpar early literacy performers (7%). As the name suggests, children in the *Exceptional*

Performers class excelled in all aspects of early literacy and were noteworthy for having fewer children with a language impairment but were older in age. The *Typical Performers* class exhibited average achievement on all variables, had older aged children, approximately equal proportions of boys and girls, and 37% of children classified with a language impairment. The *Marginal Performers* class exhibited below average literacy skills, younger aged children, and were balanced with respect to biological sex and language impairment. The *Subpar Performers* class exhibited well below average literacy skills, was composed of younger aged children, and was noteworthy for having a large proportion of boys and children classified as having a language impairment. Entropy was 0.86, indicating a high level of discrimination among the four latent classes.

The four distinct classes were identified based on their early literacy skill levels, yet they also exhibited unique profiles influenced by the interplay of input variables, including age, the presence of language impairment, and to a lesser degree, biological sex. Prior research studies from English-speaking samples have indicated that age is a predictor of early writing skills group membership (Cabell et al., 2010; McWayne et al., 2012; Guo et al., 2018). Our findings also indicate that age played a role in shaping the latent classes, with the two highest-performing early literacy groups primarily composed of older children, while the two lowest-performing classes consisted mainly of younger children. However, while age may account for some of the observed differences among the classes, the identification of more than two latent classes through LCA suggests that age is unlikely to serve as the sole determinant of the latent structure.

Interestingly, children with language impairment were present in all four groups. That said, it did appear to be a contributing factor to class differentiation. For instance, Class 1 (the *Exceptional Performers*) had only 10.64% language impaired children, whereas Class 4 (the *Subpar Performers*) had a significantly higher proportion (94.74%). This observation aligns with previous studies (Cabell et al., 2010; Justice et al., 2015), suggesting that while language abilities influence early literacy development, they do not solely determine class assignments. Regarding the impact of language impairment on early literacy, it was observed that performance was similar for most literacy measures for the *Exceptional Performers* class, except for Alphabet Knowledge. In contrast, the *Typical Performers* class exhibited uniform performance across the assessed literacy subscales, regardless of the presence of language impairment. The *Marginal Performers* class similarly demonstrated consistent performance in relation to the presence of language impairment, except for Narrative Skills, which exhibited lower early literacy scores among children with language impairment. The distinctions in early literacy related to language impairment categorization were most pronounced for the *Subpar Performers* group. Although Word Awareness performance was similar irrespective of language impairment, Concepts about Print and Phonological Awareness scores were notably lower for children classified as language impaired, but higher for Print Awareness, Alphabet Knowledge, and Narrative Skills scores.

The subsequent section will focus on delineating the distinctions in early literacy skills between language-impaired children and their non-impaired counterparts within each class individually. In class 1, the proportion of children with and without language impairments was unbalanced (10.64% of children with a language impairment). Therefore, the differences based on language impairment observed in the polar plots (Figure 2) should therefore be interpreted with caution. Non-language-impaired children outperformed language-impaired children in the Alphabet Knowledge domain. This might be explained by the moderating variable of environmental factors on language-and early literacy development. Studies have reported that kindergarten knowledge of the alphabet can be explained primarily by underlying environmental factors or the Home Literacy Environment (HLE) (Lemelin et al., 2007; Lehrl et al., 2012). For example, Lehrl et al. (2012) showed that Letter Knowledge can be predicted by the frequency of parental teaching of literacy (e.g., "Using simple words, I encourage my child to recognize or read letters and words"). In the present study, extensive questions on HLE were asked, which unfortunately due to the high rate of missing values, were not included in the analyses. However, it can be assumed that these influencing variables play an important role in the development of early literacy skills, and in particular Alphabet Knowledge (e.g., Cabell et al., 2011; Lehrl et al., 2012).

In Class 3, the presence of language impairment influenced only the Narrative Skills domain. In contrast, Narrative Skill performance was similar across language impairment for Classes 1 and 2. While speculative, this finding may be related to the scoring procedures used to measure performance, which focused on the macro-structure rather than the micro-structure of storytelling. For instance, we assessed the number of verbalized structural elements in the story (e.g., "Does the child mention the place, the people involved, or the attempted solution in the story?"). This emphasis on macro-structure assessment might have influenced the observed differences in narrative skills between language-impaired and non-impaired children. Interestingly, a recent review by Andreou and Lemoni (2020) indicate that language impaired children produce stories of varying strength, such that they either produce high-quality content that is grammatically weak or master the grammatical challenges but then produce short stories with inadequate content. It can be assumed that children with language difficulties in Class 3 may have different or greater weaknesses in vocabulary and/or grammar than language impaired children in Classes 1 and 2. These findings suggest that children in Class 3 may fall below a certain threshold that exceeds the requirements and cumulative load of creating a story (Duinmeijer et al., 2012)

Class 4 also shows differences due to language impairment. However, because there is only one non-language-impaired child in this class we exercise caution in making definitive statements about the specific effects on sub-tests. Nevertheless, this aspect underscores that non-language-impaired children can also be included in this profile. Moreover, all the aspects mentioned above can be used to explain different profile strengths and weaknesses. In addition to the causes and manifestations of language impairment, there are also the influencing factors that affect the development of early literacy skills and can sometimes lie in the child's proximal and distal environment (Hill, 2001; Lemelin et al., 2007; Aaron et al., 2008; Lehrl et al., 2012).

In summary, we posit that both the composition of children within each latent class and the differing early literacy profiles between children with and without language difficulties stem from the inherent heterogeneity within the group of children with language impairment. Conti-Ramsden et al. (1997), for example, identified six different subgroups within a sample of children with SLI, characterized by variations in impaired linguistic domains, presence of receptive and/or expressive difficulties, or different

combinations of these parameters. In this context, the profiles and especially the polar plots (Figure 2) might have looked different with a different sample. Future research with larger and more diverse samples of children with various types of SLIs could provide further insights into the interplay between early literacy performance and language impairment.

Finally, in the context of this study, the biological sex distribution was highly skewed in favor of boys in Class 4, characterized by subpar early literacy performance. Previous research examining biological sex disparities in the development of reading skills has consistently noted a female advantage, evident as early as kindergarten (Chatterji, 2006) and becoming more pronounced over childhood and adolescence (Camarata and Woodcock, 2006). However, while our findings suggest that boys may exhibit poorer early literacy performance, this interpretation is nuanced by the observation that the *Exceptional Performers* class displayed a relatively balanced sex distribution. If biological sex exerted a significant influence on latent profiles, one might anticipate a higher proportion of females in this class. Moreover, the *Subpar Performers* class consisted of only 7% of the total sample, emphasizing the need for caution when drawing inferences related to the effects of sex on early literacy profiles. Therefore, while our results hint at potential sex-related differences, further research with larger and more diverse samples is warranted to explore this relationship more comprehensively.

5.1 Class-specific literacy recommendations

The LCA approach utilized in the present study allowed for the classification of children into latent classes with distinct attributes, offering the opportunity to formulate both general and class-specific literacy recommendations (Table 4). In accordance with the CELL Early Literacy Learning Model (Dunst et al., 2006), it is recommended that general literacy activities be incorporated into routines, ideally occurring daily or as frequently as possible. These activities should be varied, taking place in both planned and spontaneous contexts, and should employ adaptive and playful strategies to actively engage children and cultivate a sense of joy and enthusiasm for language learning.

Furthermore, learning must take place in the zone of proximal development (ZPD; Vygotsky, 1987), which in the context of early literacy can be conceptualized as the gap between what a child can achieve independently and what they can accomplish with appropriate support, whether from an adult or a more skilled peer. From an applied perspective, the ZPD serves as a framework that defines both the lower and upper limits within which instruction should be delivered and encompasses activities or tasks that are slightly beyond the child's current abilities. Designing reading and writing tasks that are within reach with minimal support (i.e., giving hints and cues to guide pupils' task responses) empowers children to recognize and appreciate their progressing literacy abilities, enhancing their innate drive to engage in reading and writing activities. As children advance in their literacy proficiency, they become proficient in completing tasks independently, leading to a shift in the complexity of literacy activities aligned with their ZPD.

As such, the ZPD, as well as the specific reading and writing activities used to promote intrinsic motivation and maximum literacy growth, will differ based on the attributes of each latent class (Table 4, column 2). To preface these recommendations, we provide a brief explanation of dialogic reading which is one possible approach to foster early literacy skill or enhance first experiences with a written text. Dialogic reading enhances interactive learning and comprehension through active dialog and engagement and involves a dynamic interaction between a reader and one or more participants, where the reader encourages discussion, asks questions, and prompts reflections on the text being read.

The *Exceptional Performers* (Class 1) and *Typical Performers* (Class 2) should be given age-appropriate reading and writing materials of higher difficulty and encouraged to participate in storytelling. In the context of dialogic reading, the children in these classes should be motivated to continue telling the stories on their own or to present them in a theater format. In addition, individual letters can be discovered and named. In contrast, children from Class 3 (*Marginal Performers*) and class 4 (*Subpar Performers*) require other situational adaptations (Campbell et al., 2008) that enable them to learn in the ZPD. They would probably benefit more from picture books (or books with only a little text) fostering visual literacy as a precursor to literacy, dialogic "reading" of wimmelbooks or hidden picture books with humans, animals, and objects to discover and to talk about (e.g., "My Big Wimmelbook," "Antonia war schon mal da" [Antonia has been there before], "Die Torte ist weg" [the cake is gone]). The emphasis here is not on independent storytelling or letter recognition, but on comprehending language and learning book handling skills. In this context, visual media primarily serves as a linguistic tool for communication, idea exchange, and navigating our complex world. Therefore, books could be used to explore writing in comparison to images, practice rhyming, or enhance receptive and productive vocabulary skills. Consequently, one could pose questions about the pictures and subsequently search for answers within the text or pictures.

5.2 Limitations

Despite the implications of these findings, it is important to acknowledge several limitations of our work. First, our research was confined to a sample of 15 daycare facilities in two German states, deliberately excluding children with limited German language proficiency. Additionally, unlike previous studies that focused on children with language disorders and/or low SES background (Cabell et al., 2010, 2011, 2013; Justice et al., 2015), we aimed for our sample to reflect the heterogeneity present in typical German kindergartens. Consequently, the age range of our sample was broad, and included children with normal language acquisition and educated households. Consequently, it's important to recognize that the results may not be applicable to all children of this age group, those from different geographic regions, or children who exhibit language impairment or varied SES.

Second, we acknowledge that the educational systems of different German states or countries could play a significant role in determining the early literacy profiles. It is important to note that while LCA is a methodologically rigorous and data-driven approach, the derived classes are influenced by the demographic composition

TABLE 4 Proposed literacy recommendations during dialogic book reading for the identified latent classes.

Latent classes	Intervention suggestions	Implementations in dialogic book reading
Exceptional performers	• Cultivate and maintain enthusiasm for books and reading • Nurture and sustain enjoyment and motivation for storytelling • Engage in daily higher difficulty level reading and writing activities that are playful and progressively challenging	• **Phonological Awareness:** Employ dialogic reading to enhance phonological awareness, focusing on tasks such as analyzing sounds within words, manipulating sounds within words, and synthesizing sounds to form words • **Alphabet Knowledge:** Engage children in identifying both familiar and unfamiliar letters within the text, encouraging them to recognize the visual and auditory characteristics of individual letters ("Which letters have a curved shape?") • **Narrative Skills:** Encourage children to create their own stories or contribute to completing existing narratives
Typical performers	• Maintain enthusiasm for books and reading over time • Cultivate and maintain joy and motivation for storytelling • Integrate daily playful language and communication activities to promote language development • Integrate playful daily reading and writing activities at a moderate difficulty level	• **Word Awareness:** Help children recognize differences between short and long words, and identify identical words consistently • **Phonological Awareness:** Implement dialogic reading techniques to enhance phonological awareness, particularly focusing on recognizing initial sounds • **Alphabet Knowledge:** Introduce children to the first letters they learned, including those of their own name, to reinforce alphabet familiarity • **Narrative Skills:** Encourage children to retell stories or speculate on potential story continuations ("How do you think the story might continue?")
Marginal performers	• Cultivate joy and motivation for storytelling • Integrate playful language and communication activities to enhance language development • Include daily playful activities aimed at promoting word awareness, print awareness, and alphabet knowledge at levels ranging from low to medium difficulty	• **Word Awareness:** Explore words within the book, distinguishing between long and short words and discussing how word length relates to meaning (e.g., comparing "honeybee" to "bear") • **Phonological Awareness:** Engage in dialogic reading to develop phonological awareness broadly, including activities such as identifying rhyming words ("What rhymes with mouse?") • **Alphabet Knowledge:** Connect letters to corresponding images and help the child identify the initial letter of their name with the assistance of the teacher or caregiver • **Narrative Skills:** Talk about the story structure (e.g., sequencing story sections) and practice shifting perspectives; prompt discussions by asking questions about the story
Subpar performers	• Implement daily playful language and communication activities to nurture language development • Beyond understanding meaning, also focus on drawing the child's attention to the form and structure of language • Integrate playful daily activities to promote alphabet knowledge at a low level of difficulty • Integrate playful daily activities to enhance print awareness, concepts of print, word awareness, and narrative skills at a low level of difficulty	• Utilize picture books and promote visual literacy • Cultivate a sense of enjoyment and familiarity with reading • **Print Awareness:** Collaboratively search for and identify words and text within a book alongside images • **Concepts about Print**: Introduce writing conventions together, prompting questions such as "Where is the title of the book?" and "Where do we begin reading?" • **Phonological Awareness:** Employ dialogic reading to enhance phonological awareness more broadly, incorporating activities like syllable clapping and identifying rhymes • **Alphabet Knowledge:** Connect letters to corresponding images and assist the child in identifying the initial letter of their name with the support of the teacher or caregiver • **Narrative Skills:** Stimulate discussions about the story or the book cover, asking questions such as "What do you think the story is about?" and "Where do you think the story takes place?"

of the sample. The obtained profiles reflect the abilities of the specific sample and must be interpreted as such. To establish the robustness of our findings, replication with independent sample sharing is necessary.

Third, scholars unanimously agree that the acquisition of emergent literacy skills involves a complex interplay of fundamental literacy elements (Mason and Stewart, 1990; Whitehurst and Lonigan, 1998; Sénéchal et al., 2001), in which each component follows its own development trajectory, supports and influences the development of the other components, and is shaped by the dynamic interplay of sociocultural, environmental, and demographic factors (Rohde, 2015). In this study, we focused on how factors such as age, biological sex, and language impairment influence the variety and occurrence of these latent literacy profiles. Cabell et al. (2010, 2011) mentioned three possible reasons that explain the identified patterns, all of which emphasize the importance of children's literacy learning environment to their growth in literacy. Although we did query the Home Literacy Environment (HLE, Niklas et al., 2020) using a paper-based questionnaire, there was insufficient participation for those particular questions and thus we did not include it in the analysis.

Fourth, it's important to note that the classification accuracy for Class 4 (*Subpar Literacy Performers*), as indicated by the average posterior probabilities, did not meet the threshold for robust classification. Therefore, interpretations regarding this smaller class should be approached cautiously, pending replication and additional validation. It is plausible that the observed patterns within this group may be specific to the sample under study and may not generalize to broader populations.

5.3 Future directions

In the second phase of the project, we will evaluate the effectiveness of the EuLeApp© assessment tool and the adaptive, playful everyday intervention in promoting early literacy skills. Following the baseline assessment, the EuLeApp© will provide an individualized profile outlining each child's strengths and weaknesses across various early literacy components. Subsequently, pedagogical specialists will have the option to manually select exercises targeting specific early literacy components from a collection of 95 games and 28 impulse cards contained within a wooden box. These games, designed for group settings, are categorized into three levels of difficulty to accommodate each child's ZPD. Additionally, the games are seamlessly integrated into the children's daily schedule, with labels indicating suitable times of the day (e.g., morning circle, naptime, mealtime, etc.). At the conclusion of the four-month intervention period, we will employ latent transition analysis (Nylund-Gibson et al., 2023) to study the movement of children between groups across several time points. This will allow us to understand the dynamics and patterns of stability and change after the intervention implementation, especially as it pertains to specific literacy skills (e.g., Print Awareness, Alphabet Knowledge, Narrative Skills), latent class, or language impairment.

In addition, we have refined our data collection protocol to enhance compliance with the completion of HLE questions by using electronic survey software that forces respondents to answer each question before survey progression and tying a portion of the remuneration to survey completion. An additional methodological enhancement slated for the next project phase is the inclusion of a standardized non-verbal intelligence test to assess the cognitive abilities of children [i.e., the Snijders-Oomen Nonverbal Intelligence Test 2.5–7 Revised (Tellegen, 1996)].

Furthermore, research should prioritize examining Germany's most vulnerable populations, such as first-generation migrants and refugees, many of whom enter Germany without prior knowledge of the language. We believe that the EuLeApp© could serve as a valuable tool by which early literacy skills and cultural knowledge can be imparted to kindergarten-aged children. This, in turn, can support the cultivation of social connections and active participation in their new host communities, contributing to their success and integration in society.

6 Conclusion

LCA and the EuLeApp© prototype effectively distinguished between different latent early literacy profiles in German kindergarten children, reflecting the influence of factors such as age, biological sex, and language impairment. These findings provide valuable insights for future research endeavors and underscore the importance of supporting early childhood professionals in adapting their daily practices to meet the unique needs of young learners in the realm of early literacy.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Research Ethics Committee of the Carl von Ossietzky University of Oldenburg. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

CS: Investigation, Supervision, Writing – original draft, Writing – review & editing. MY: Methodology, Writing – original draft, Writing – review & editing. MM: Conceptualization, Funding acquisition, Project administration, Writing – review & editing. TJ: Conceptualization, Funding acquisition, Project administration, Writing – original draft, Writing – review & editing. CH: Data curation, Formal analysis, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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