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Bridging the Gap in Brazilian Literacy: Kalulu Phonics Provides Gains in 1st Grade Reading

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ABSTRACT

A significant portion of Brazilian students fail to meet basic reading standards. The 2017 National Common Curricular Base (NCCB) marked a pivotal effort by the government to prioritize recognizing phonics in early reading instruction. However, the NCCB lacked clear directives for implementation, resulting in limited adoption in classrooms where teachers were accustomed to constructivist approaches to literacy. To address this shortcoming, we adapted the open-source Kalulu phonics method to Brazilian Portuguese and tested its effectiveness as a supplementary learning workstation during classroom reading instruction. The Kalulu method is available at kalulu.excellolab.org. 184 Brazilian children (97 girls) from 1st year participated, aged 6 to 8 years ($M = 6.59$, $SD = 0.50$). Five schools were assigned randomly to the Kalulu intervention group or a "business-as-usual" control group, and evaluated two times in 2022. Kalulu group showed significant progress, reading an average of 4.9 more words per minute compared to control classes. Improvements were also observed in phoneme verbal fluency and a memory task. Given the strong scientific support for phonics and our encouraging results, we urge Brazil's educational leaders, teachers, and parents to advocate for increased phonics instruction as part of early literacy methods. Explicit phonics instruction, like the Kalulu method, could provide essential help for overcoming the country's ongoing literacy challenges.

In 2000, the National Reading Panel published a comprehensive meta-analysis to resolve debates between advocates of whole-language and phonics reading methods (National Reading Panel 2000). The scientific consensus was clear: early, systematic, and explicit phonics is an essential component of effective beginning reading instruction (Ehri et al. 2001). Of course, it is not the only component. Spelling instruction (Colenbrander et al. 2022) when delivered by skilled teachers (Foorman et al. 1998), is also crucial to deeply acquire and train those early skills. The science of reading also supports the idea that beginning readers have to read decodable texts to automatize word reading (Cheatham and Allor 2012), thereby promoting reading fluency.

For any nation, providing high-quality reading instruction is essential for individual success and societal progress. To achieve this, many countries are increasingly prioritizing phonics as

a core element of their national reading programs (Castles et al. 2018; CSEN 2019; Rose 2006). In Brazil, however, phonics instruction has not yet become standard practice. This is largely due to a historical resistance to traditional teaching methods, in favor of constructivist theories, which arose amid the positive expansion of educational access and the growing concern for supporting underprivileged communities. Supporters of constructivist pedagogy urged teachers to move away from phonics, dismissing it as too mechanical, and instead promoted whole-language methods that emphasized learning to read through exposure to meaningful text (Ferreiro 1999; Goodman 1967). While constructivist methods were well-intentioned in their goal to expand education to previously underserved populations, they overlooked mounting evidence against their effectiveness and ultimately ignored the science of reading. Constructivist theories still dominate reading instruction in Brazil today. This disconnect between the science of reading and classroom practices has become a critical issue, as reflected in Brazil's low ranking of 53rd out of 57 countries in the 2021 Progress in International Reading Literacy Study (PIRLS) (Mullis et al. 2023).

Aiming to help improve this scenario, we present the implementation and results of a year-long reading intervention testing the use of the Kalulu phonics method with 1st-grade students in São Paulo. The Kalulu method is an open-source phonics method that can be downloaded at kalulu.excellolab.org. Our primary question was whether implementing a phonics-based method could enhance reading acquisition among children in the state of São Paulo, Brazil, where whole-word reading approaches still dominate literacy instruction. Additionally, we aimed to assess whether explicit teaching methods and game-based interventions could strengthen working memory.

1 | Framework for Reading Development

The framework for reading development is a dynamic progression from foundational skills to complex linguistic abilities. Two of the most critical predictors of future reading success are letter knowledge and phonemic awareness (Byrne 1992; Castles et al. 2018; Gentaz et al. 2015; National Reading Panel 2000; Snow et al. 1998; Sprenger-Charolles et al. 1998). Understanding letter shapes, names, and sounds forms the core of the grapheme-phoneme relationship—a cognitive link between symbols and sounds that enables children to break into the alphabetic code (Clayton et al. 2020; Foulin 2005; Leppänen et al. 2008). This essential groundwork is further developed through phoneme awareness, which lays the foundation for students to isolate, blend, and manipulate individual sounds to form words (Clayton et al. 2020; Elbro and Jensen 2005). Together, these abilities move learners toward decoding, or "sounding out" words, ultimately enabling them to become expert readers who recognize words automatically (Zoccolotti et al. 2005). This automatic recognition frees up cognitive resources for comprehension, allowing readers to focus on understanding the text (Potier Watkins et al. 2020).

Ehri proposed a theory of reading development in four phases: pre-alphabetic, partial alphabetic, full alphabetic, and consolidated alphabetic (Ehri 2020). The level of a child's grapheme-phoneme conversion knowledge directly determines their stage in reading development. In the pre-alphabetic phase, children create drawings or images, memorizing their meanings as visual information. In the partial alphabetic phase, they begin to associate letters with sounds and perform grapheme-phoneme conversions in a limited capacity. As children progress to the full alphabetic phase, these conversions become more familiar, though reading may still be imperfect, particularly with irregular words. In the final phase, following the consolidation of alphabetic knowledge, children's decoding becomes fluent, extending beyond grapheme-phoneme correspondences to encompass partial or complete syllabic units. In Brazil, Cardoso-Martins and colleagues conducted a few longitudinal studies supporting Ehri's phases, showing that this theory applies to Brazilian Portuguese as well (Cardoso-Martins et al. 2023). Ultimately, it is essential to emphasize that research in the field of education is dynamic. While some studies favor the phonics method, there is still room for refinement and constructive criticism.

2 | Brazil's Current Literacy Challenge: Political Historical Context

To understand Brazil's current literacy challenges and the absence of phonics in classrooms, it is important to consider the historical context of reading instruction and related debates (Mortatti 2019). The early years of the Brazilian Republic (1889—present date) were dominated by a conflict between traditional phonics methods and the then novel analytical methods. This conflict contributed to the use of the term "alfabetização" in 1910 (literacy), defined as the ability to "read and write" (Mortatti 2019), and popularly used to describe skills obtained, or not, by students. Unable to resolve the debate between phonics and analytical methods, São Paulo schools (one of the leading centers of educational development at the time) downplayed the importance of a single approach. During this period, the book *ABC Tests to Verify the Maturity Necessary for Learning to Read and Write* (1934) was published (Lima 2019), introducing tests to assess reading readiness and to organize students into homogeneous classes based on their results. This shifted the focus from debating reading methods to the goal of providing customized literacy instruction tailored to each child's developmental stage, a practice that remained popular until the late 1970s (Mortatti 2019).

In the 1980s, two major developments significantly shaped Brazil's education system. First, the nation emerged from a political dictatorship with a focus on improving social services, sparking a national emphasis on education. Child labor was abolished[1], and elementary schooling became mandatory, resulting in a surge of new students and a move away from tailored educational approaches, which were no longer feasible. Second, constructivist theories gained prominence, heavily influenced by Argentinian psychologist Emilia Ferreiro's research on the psychogenesis of language (Lima 2019). Additionally, Brazilian educator Paulo Freire, known for his seminal work, *Pedagogy of the Oppressed*, advocated for education as a means of liberation, emphasizing a more contextualized method of teaching reading. Freire's contextualized teaching methods, along with Ferreiro's constructivist

approach, deeply influenced Brazilian educators for children as well as for adults. This led to the widespread adoption of constructivist and whole-language instruction, which quickly became the dominant literacy approach in Brazil (dos Santos et al. 2018; Mortatti 2019; Rangel et al. 2017). Amid Brazil's political upheaval, constructivism was embraced as a philosophy aimed at challenging traditional educational practices to empower citizens (Mortatti 2006). Numerous articles, academic theses, books, videos, and methodological suggestions were published to promote constructivist ideas and integrate them into the public education system, shifting reading instruction from a focus on specific skills to prioritizing the social function of written language.

Paulo Freire's return to Brazil after exile and his role as Secretary of Education for São Paulo from 1989 to 1992 cemented his influence, leading to the widespread adoption of reading instruction methods based on constructivist principles in schools (Mortatti 2006). In practical terms, didactic guidance to teachers was eliminated, and traditional assessments of students' reading progress were phased out. The use of grade-appropriate reading materials, known as "readers", viewed as artificial from the standpoint of constructivist theory (Azenha 2006) and as a reinforcement of the a divide between "those who know and those who know nothing" by Freire (Freire 2014), was also discontinued. Freire's views laid the foundation for Brazil's strong preference for contextualized, experience-based literacy, as promoted by constructivist educators (Feitosa 2016).

2.1 | The Current Context

The historical context, spanning the endless disputes between methods in the early 19th century and the two major shifts of the 1980s, has resulted in a dual reality: a positive national commitment to educating all children, hindered by outdated methods that fail to deliver quality reading education. In 2001, a bill assigned states and municipalities the responsibility for executing school content, while federal bodies were tasked with supervising goals such as raising the overall educational level, improving education quality, and reducing social and regional inequalities (LAW N° 010172, 2001). Guidelines were set for education management, financing, professional development, and best practices. In 2003, a research group emphasized the importance of evidence-based literacy practices, contributing to the introduction of the National Common Curricular Base (NCCB) in 2017, which established a standardized educational framework. Building on this foundation, the NCCB launched a National Literacy Policy in 2019, grounded in scientific approaches, which culminated in the creation of the National Reading Panel in 2021 (Brasil 2024). During this period, the Basic Education Assessment System (SAEB) was introduced as a key component of Brazil's National Education Quality Index (IDEB). SAEB evaluates students' performance in reading, writing, and mathematics, and, combined with school dropout rates, contributes to the IDEB score, which is measured on a scale from 0 to 10 across Brazilian schools (IDEB 2024).

However, over the past 20 years, literacy rates have steadily declined, a trend worsened by the COVID-19 pandemic. In 2021, data revealed that 40.8% (see Figure 1) of children aged 6 to 7 years were unable to read or write by the end of 2nd grade, with 51% from the lowest SES population (the poorest 25%) (IBGE 2021). Although Figure 1 highlights the impact of COVID-19 on reading performance, it is important to note that the situation prior to 2020 was already far from ideal. We contend that inappropriate reading methods were already contributing to these difficulties, and the pandemic-induced school closures only exacerbated the problem.

2.2 | Ceará, a Success Story for Reading Progress

We argue that the poor reading outcomes in Brazil stem from outdated constructivist methods, not solely socioeconomic status (SES) issues. This is demonstrated by the case of Ceará, one of Brazil's poorest states, ranked 24th out of 27 in GDP per capita in 2021 (IBGE 2023). In 2005, Ceará's low SES was reflected in its public schools' IDEB scores for early grades, placing the state 18th out of 27 (QEdu 2024). In 2007, Ceará launched the "Literacy Program at the Right Age," a government-led initiative that provided literacy education through teacher training, experience-sharing, monitoring, and resources, including synthetic phonics instruction (Gusmão and Ribeiro 2011; Governo do Estado do Ceará 2024). By 2021, Ceará's literacy scores had improved significantly, raising the state's IDEB ranking to second place, despite its persistently low socioeconomic status.

2.3 | The Current Project

The Ceará example demonstrated the positive impact that science-based reading programs can have on literacy, even in low SES regions. However, this success also involved broader changes, making it challenging to isolate the specific effect of phonics instruction. To address this, the current project was designed to specifically test the effects of phonics instruction. Amid economic challenges, Ceará prioritized structured phonics instruction within a predominantly constructivist national context. This project was implemented in public schools, introducing phonics instruction into schools that previously followed constructivist curricula. To our knowledge, only one prior study in Brazil has shown promising results in reading for 9-year-olds after training teachers used a phonics method; unfortunately, this study only assessed a single school (de Andrade et al. 2014).

To test a fully decodable phonics program without licensing fees or high costs, we adapted the open-source Kalulu method to Brazilian Portuguese. Originally a tablet application, Kalulu is designed for easy translation into alphabetic languages, allowing global educators to provide phonics instruction. It has previously demonstrated improvements in phoneme awareness, fluency, and reading comprehension as an add-on to normal instruction (Potier Watkins et al. 2020; Potier Watkins and Dehaene 2023). Kalulu is thus well-suited for this project's goal of introducing and testing phonics instruction with minimal disruption to teachers' existing practices. Numerous studies have demonstrated the benefits of educational games, including their effectiveness in reading instruction and in developing

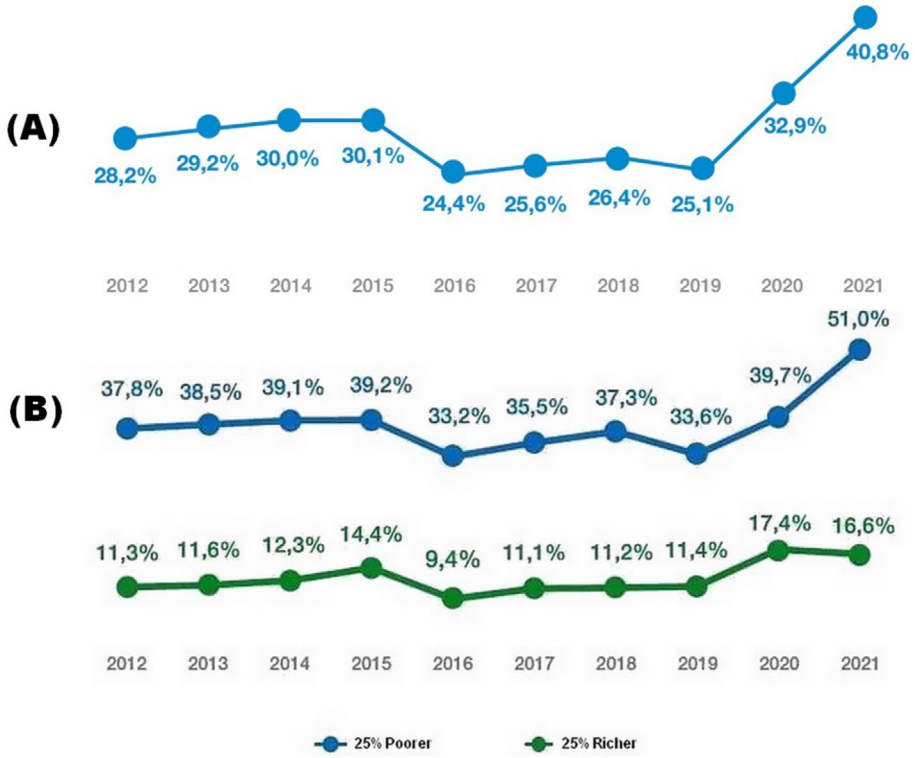

FIGURE 1 | Percentage of children aged 6 and 7 years who cannot read and write in Brazil from 2012 to 2021. Percentage of children aged 6 and 7 years (tested at the end of 2nd grade, 2 years of formal reading education). These statistics are collected from national reading tests. (A) refers to the total percentage of children who cannot read and write in Brazil from 2012 to 2021. In (B), the blue line represents the illiteracy rates for children from the poorest quartile (per capita household income), and the green line represents the illiteracy rates for students from the wealthiest quartile (source IBGE 2021). Illiteracy rates were high and stable since 2012 but saw a dramatic increase during the COVID pandemic.

country contexts (Cancer et al. 2020; Gharibi et al. 2022; Görgen et al. 2020; Gori et al. 2013; Johann and Karbach 2020; Juhani Lyytinen et al. 2021; Neville et al. 2009; Pasqualotto et al. 2022; Patel et al. 2018; Puhakka 2015; Roberts 2021; van de Ven et al. 2017; van Gorp et al. 2017).

Kalulu was adapted for Brazilian Portuguese and context (Olalla 2019). Kalulu provides explicit systematic instruction on grapheme-phoneme correspondences (GPCs), considering their frequency and consistency (Ehri 2020). Each grapheme-phoneme correspondence is instructed in a 3-part series based on evidence-based practices (Figure 2A). The GPC is introduced by an older child who pronounces the sound. Pictures of distinct articulatory gestures underlying each phoneme facilitate the development of early reading (Boyer and Ehri 2011; Castiglioni-Spalten and Ehri 2003). This is followed by an example of the letter sound in a common word with the accompanying picture (e.g., "/b/in ball"). Finally, the child is asked to trace the grapheme. This provides an additional motor code to support memory for grapheme (Bara et al. 2004, 2016; Bara and Gentaz 2011; Longcamp et al. 2005). After the lesson, the child masters the GPC through mini-games (Figure 2B) that require increasingly fast responses. This approach improves grapheme-phoneme consolidation and accelerates the development of the brain's visual word form (Brem et al. 2010; Lassault et al. 2022; Ojanen et al. 2015; Patel et al. 2018). Detailed explanations of the games are provided on the project website kalulu.excellolab.org.

The primary goal of this study was to test the effectiveness of the Kalulu phonics method in improving reading abilities in Brazilian public schools. While all students continued with standard whole-language instruction, those in the Kalulu intervention included phonics instruction three times a week for 15 weeks, totaling about 45 sessions during regular reading periods. Our main hypothesis was that students in the Kalulu group would show greater improvements in reading compared to the business-as-usual (standard school routine) control group. Additionally, we hypothesized that Kalulu would enhance phonological verbal fluency, as phonics training improves sensitivity to letter sounds, compared to semantic verbal fluency. A secondary hypothesis suggested that the use of games for learning would improve working memory. Unlike typical classroom instruction, Kalulu phonics offers a structured approach with consistent GPC mapping, repetition, and recall, which stimulates working memory retention for verbal information (Demoulin and Kolinsky 2016).

Our main finding is that, after controlling for pretest scores, processing speed, and verbal retrieval, children in the experimental Kalulu group read nearly five more words per minute than those in the control group. The Kalulu-based intervention also led to greater improvements in phonological verbal fluency compared to semantic verbal fluency. Additionally, children in the Kalulu intervention outperformed those in the control group on short-term verbal memory tasks, suggesting a broader cognitive benefit beyond reading speed.

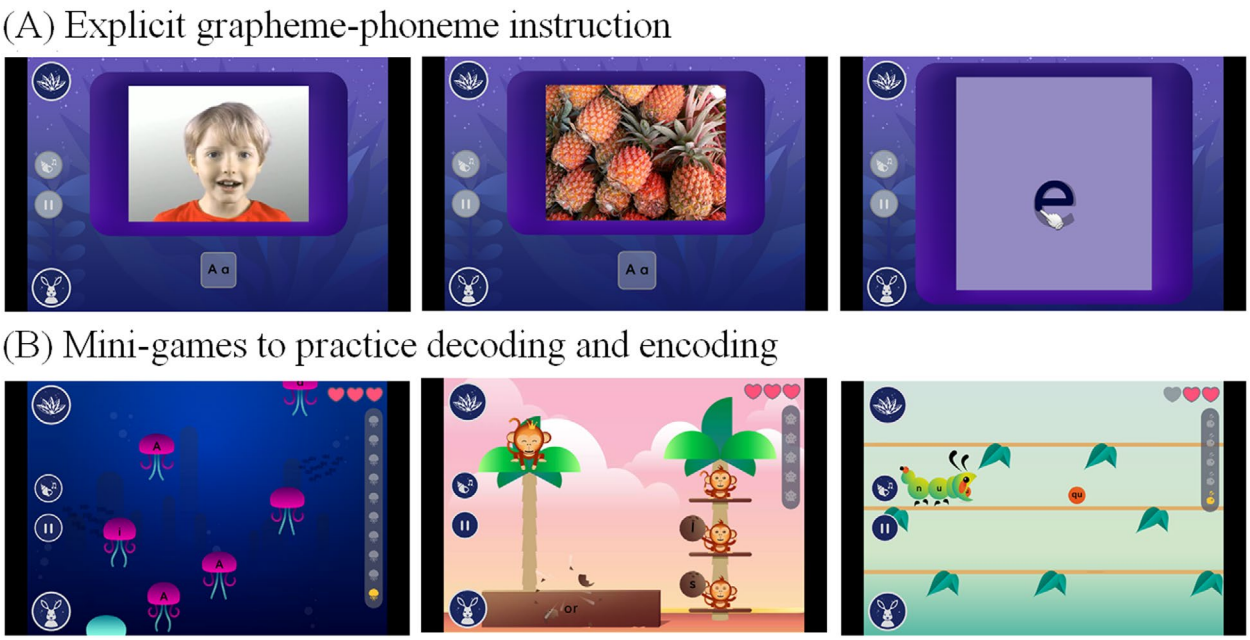

FIGURE 2 | Example of screen screenshots from the Kalulu game application. (A) In the Kalulu game application, each lesson starts with an explicit systematic phonics instruction in the following steps: a child demonstrates how to pronounce the lesson grapheme–phoneme correspondence, the phoneme is pronounced in a word with its associated picture and in the fashion "/a/abacaxi," then the child traces the letter in upper- and lowercase. (B) Once the grapheme–phoneme lesson is done, the player is provided with three mini-games to master the lesson. Games require the player to engage in syllable decoding, spelling, and lexical decision. The game adjusts to the child's ability based on wins and errors made. Adjustments include changes in the number of areas from which stimuli can spawn, the number of distractors presented, and the speed required to click on the correct response before it disappears from the screen. All stimuli presented, including distractors, are decodable for the child according to the lessons completed.

3 | Methods

3.1 | Participants

Our lab collaborated with the Secretary of Education in Santo André to recruit public schools for the project, requiring at least two schools to be low SES with low academic performance as indicated by IDEB scores. Although Santo André is a well-developed city in São Paulo DC, its public schools averaged an IDEB score of 6.1, below the target of 6.9. Five schools (representing 10 classes) volunteered: three schools were assigned to the "Kalulu intervention" group (two mid-SES and one low-SES), and two were placed in the "business-as-usual" control group (one mid-SES and one low-SES) (QEdu 2024). Assignment was done randomly, ensuring that at least one of the low-SES and mid-SES schools would be in each group, with the third mid-SES assigned to the Kalulu intervention.

Two hundred and twenty-two students were initially reported by teachers as participants. However, according to school-provided information, eight students were excluded due to cognitive, motor, or genetic impairments that would hinder participation (e.g., difficulties interacting with tablets or comprehending tasks). Ultimately, 184 children (97 girls) aged 6 to 8 years ($M = 6.59$, SD = 0.50) completed both pre- and post-tests. Legal guardians provided informed consent, as approved by the Ethics and Research Committee of the Universidade Federal do ABC (CAAE: 88208918.4.0000.5594).

3.2 | Materials

3.2.1 | Kalulu Phonics Game Application

The game features a user-friendly interface (Figure 2), with Kalulu the hare guiding players through lessons organized into thematic gardens and minigames. Players progress through one garden at a time, completing 3 to 4 lessons (GPCs) per garden, starting with common and frequently occurring GPCs and advancing to more complex ones. Each GPC is presented in a short lesson followed by three mini-games. The player must score 80% correct to pass the mini-game. Difficulty is adjusted by wins and losses, aiming to help each player understand and complete the mini-games with minimal outside aid. You can learn more about the game and find links for its download in different languages (kalulu.excellolab.org). The game application was developed using the Godot engine (https://godotengine.org), and the game code for the application used in the current project is available at https://gitlab.com/casspw/kalulueducation.

3.2.2 | Kalulu Phonics Paper-Based Games

In addition to the digital game, a series of paper-based activities were developed (Figure 3), including card games, game boards, and homework assignments. These materials align with the game's phonics progression and mimic its playful, game-like aspects. The paper-based activities help children practice GP

FIGURE 3 | Complementary cards and board games. Along with the tablet game app, students also played various phonics-based card and board games including: (A) naming pictures then spelling the word using the cutout letter cards in the panel, (B) using letter cards with images to remember letter sounds and using these cards to spell words; (C) matching words to their pictures on a board; (D) listening to a syllable or word and marking it on a Bingo card. This last game was played in small groups with the winner being the first to have marked five cells in a row. The most recent versions of these games can be downloaded at (kalulu.excellolab.org).

associations, letter recognition, syllable composition, decoding, and reading short sentences. Some activities, such as Bingo, were designed for individual play per card. However, the boards are used collectively in small groups with teacher guidance. Other materials, like letter and naming cards, serve both as activity tools and as support for specific learning challenges, such as reinforcing a lesson taught by Kalulu.

3.3 | Procedure

In early 2022, all five schools participated in a pre-test, with classes divided into experimental and control groups. Teachers from the experimental groups attended two training sessions covering the game's functions, year-long protocol, session frequency, classroom structuring, and support activities. In these training sessions, explanations were given through slides that highlighted and detailed each point and included demonstrations of how the game works on the tablet. Additionally, the teachers' questions were answered, and any potential difficulties from students were anticipated and then clarified. Each teacher also met with a researcher to organize their classroom layout, simulating the project's implementation. Teachers were responsible for informing students, organizing small groups, and managing game time. Researchers also talked to teachers about phonics. It is important to note that all teachers expressed their concern that phonics were boring and not appreciated as a method for reading instruction. During their normal reading instruction time, all teachers used books provided by the selected publishers from the state government focusing on whole-word learning.

Classroom spaces varied across the three schools. Stations with different activities were set up, including one station with the tablets. Each class was divided into 3–4 groups of students. These groups rotated between stations, with one group using tablets while others engaged in paper-based activities. Students using the tablets wore headsets to minimize noise and accessed the game with individual passwords. After 20 min, groups rotated activities. Teachers observed and assisted with support activities while minimally supervising the Kalulu group. The intervention lasted from March to mid-November 2022, with a break for July holidays, totaling around 45 sessions over 15 weeks. Classes used Kalulu materials 2–3 times per week, with each session including 20 min of tablet gameplay followed by 40 min of paper activities. Post-test assessments followed the intervention.

3.4 | Intervention Fidelity

Instruction fidelity was measured through both teacher observations and in-game data. Classroom fidelity observations were consistently conducted by the same project team member, who made regular visits during the Kalulu activity period to ensure consistent implementation across all classes. Additionally, a reading intervention specialist in phonics visited each school weekly to oversee intervention staff, teachers, and assessment processes. Teachers recorded student attendance and the number of completed applications in a spreadsheet and communicated directly with the phonics specialist for assistance with any challenges. In-game data provided further fidelity assurance by recording details for each Kalulu session, including date, time, and duration. The intervention's implementation was periodically reviewed, and weekly monitoring of login data confirmed consistent game use.

3.5 | Measures

This intervention incorporated tests used in another project for observational data collection and memory norming in children. Below, we report only those tests from the battery relevant to assessing the Kalulu intervention. Phonological and semantic verbal fluency tests, part of the Child Brief Neuropsychological Assessment Battery, are subtests from the standardized NEUPSILIN-Inf battery (Salles et al. 2014), widely used in Brazil. From this battery, we adapted a list of words into an oral reading fluency test (Hasbrouck and Tindal 2006), transforming it into a 1-min word reading test. Additionally, we administered the standardized forward and backward digit repetition tasks from the Wechsler Individual Achievement Test-3rd Edition (de Figueiredo and Nascimento 2007) and the Rapid Automatized Naming from the TENA Test (da Silva et al. 2018). Letter name knowledge, using letters from the Brazilian alphabet, was assessed as a visual recognition task.

All assessors were blind to group assignments and trained to administer the battery of tests. To ensure impartiality, post-test evaluations were conducted by different assessors than those who administered pre-tests, with assessments carried out individually in quiet, separate rooms within the schools.

3.5.1 | Predictor Covariable

3.5.1.1 | Rapid Automatized Naming (RAN). RAN was tested at the pre-session to be used as a covariable in our analyses. RAN requires the subject to rapidly retrieve and say the names of visually presented, familiar items in a serial array (Denckla and Rudel 1976; Norton and Wolf 2012). RAN has been shown to be a unique predictor of reading fluency, in particular for children from low-SES backgrounds (Arnell et al. 2009; Caravolas et al. 2019; Clayton et al. 2020; Georgiou et al. 2016; Ozernov-Palchik et al. 2017). This task is closely related to the automaticity and fluency required for efficient reading, as both involve quick retrieval of phonological information from memory. The RAN Colors and Objects were administered, but we chose to analyze only the responses to the common objects task (50 items: bed, cat, hand, pencil, and sun). This decision was made due to difficulties in identifying the brown color in the color test. The raw score, representing the time taken to name all items, was scaled and centered on 0 for use as a predictor variable.

3.5.2 | Intervention Assessment Tasks

3.5.2.1 | One-Min Word Reading. The 1-min reading task was chosen as our primary measure of student reading improvement. Children were presented with 66 words (3, 4, and 5 letters) common for the Brazilian context and given 1 min to read as many words as possible. This task is considered a good measure of fluency primarily because words cannot be guessed through context like with text reading. All the words presented used regular GPCs. The raw score collected was the number of words read correctly in 1 min.

3.5.2.2 | Phonological Verbal Fluency (PVF). Children were given 1 min to name as many words as possible that started with the letter "P." Names and places were not accepted. This task required that the child retrieve the sound of the letter "P," |p|, and then name words that made this same first sound. The raw score was the total number of items named.

3.5.2.3 | Forward and Backward Digit Repetition Task. The child first completed the forward digit span task. In this task, the child was required to verbally recall a sequence of numbers in the same order it was presented (the child hears "5, 9, 7", and must repeat "5, 9, 7"). Following this, they completed the backward digit span task, which required the child to recall the sequence in reverse order (the child hears "5, 9, 7", and must repeat "7, 9, 5"). This standardized task included two sequences of 2 to 5 digits in each measure, for eight test items in each task (8 being the maximum score). Each child was given two trials with feedback on a 2-digit sequence. Once the test started, the child only advanced to the next sequence if at least one item was repeated correctly. We collected the percentage correct separately for forward and backward. The mean percentage correct across the two tasks was then recorded and used in our analysis.

3.5.3 | Control Assessment Tasks

3.5.3.1 | Semantic Verbal Fluency (SVF). Children were given 1 min to name as many animal names as possible. This tests children's vocabulary and ability to recall from a semantic category. The raw score was the total number of items named. This task was used as a control for PVF. Our intervention focuses on teaching children grapheme–phonemes and decoding and encoding these in syllables in words, not on building vocabulary. In fact, all vocabulary used in the program was familiar to children. We would expect that all children would improve in this task, as compared to the PVF task, which should be facilitated by improving grapheme–phoneme knowledge.

3.5.3.2 | Letter Name Knowledge. In Brazilian schools, learning letter sounds is rare, but children do learn their ABCs and letter name recognition. Children were shown all letters

of the alphabet shuffled except "k," "y," and "w" (due to their low frequency in Portuguese) and asked to name the letter. The raw score was the total number of correctly named letters, with a maximum possible score of 21. We expected that all children would improve equally in this test.

3.6 | Statistical Analysis

Several factors guided our choice of model to use to assess pre to post gains comparing students' outcomes depending on their group (Kalulu, or "business-as-usual" control). We also want to consider the variability created by the different teachers in the project. Teachers in Brazil are largely free to teach using the methods that they want, and these teachers were also located in schools with different levels of SES as reported. Finally, children in Brazil enter school with highly variable rates of pre knowledge from their home environment and if they regularly attended kindergarten. For this reason, it was important to include pretest, age, and performance on the RAN task as a key predictor in reading fluency. Taking these factors into account, we opted to use a hierarchical mixed-effects model. A hierarchy considers the nested structure of the data, where students are nested within classes and classes within schools. Mixed-effects includes both fixed effects (predictors that are consistent across all observations) and random effects (accounting for variability at the group level, in this case, school classes), notice that we did not include a random intercept for school. Inclusion of that term does not improve model fit. We used the R Statistical Software (v 4.1.2; R Core Team 2021), package glmmTMB for this analysis. We specified the following hierarchical mixed-effect model:

$$\begin{aligned}\text{Posttest}_{ij} = {} & \beta 0 + \beta 1 \times \text{Pretest}_{ij} + \beta 2 \times \text{Treatment}_{ij} \\ & + \beta 3 \times \text{RAN\_Pre}_{ij} + \text{Age\_Pre}_{ij}) + \text{b0}_j + \epsilon_{ij}\end{aligned}$$

where:

1. Post_{ij} is the post-intervention score for student i in class j.
2. β0 is the fixed intercept.
3. β1 is the fixed effect coefficient for the pre-intervention score (Pretest_{ij}).
4. β2 is the fixed effect coefficient for the treatment group (Treatment_{ij}).
5. β3 is the fixed effect coefficient for the RAN score at pretest (Ran_Pre_{ij}).
6. β4 is the fixed effect coefficient for scaled age at pretest (Age_Pre_{ij}).
7. b0_j is the random intercept for class j, representing the deviation of the class j intercept from the overall intercept β0.
8. ϵ_{ij} is the residual error term for student i in class j.

During the posttest data collection, we collected a high incidence of zero scores in outcome variables. When over 5% of students scored 0 on a task at the posttest, we extended this model to include a zero-inflated negative binomial component. This extension allowed us to account for both overdispersion and the excess zeros observed in the data. This combined model includes:

1. The same fixed and random effects as the initial hierarchical mixed-effects model.
2. A zero-inflated component (ziformula = approximately 1) to model the probability of excess zeros.
3. The negative binomial distribution (family = nbinom2) to handle overdispersion in the response variable.

Results are reported as significant at $p < 0.05$. All scripts and anonymous data can be found on the project OSF account at https://osf.io/6ewd2/.

4 | Results

We first examined the normality of the outcome variables, finding that several distributions were not normal, as to be expected where many students demonstrated persistent difficulties in completing tasks. The RAN pretest predictor variable was missing for one individual. Since all their other outcome scores were collected, we imputed their missing score using a regression model based on age and class. Participant demographics, pre- and post-test means, normality measures, and group differences are presented in Table 1. We used the Shapiro–Wilk test to assess the normality of outcome distributions for all participants on each task. If the distribution was normal, we used a *t*-test to test for group differences. If the distribution was not normal, we applied the Wilcoxon rank-sum test instead.

The Kalulu group had significantly better pretest scores than the control group in the 1-min word reading (Kalulu: $M = 2.55$, SD = 9.95 vs. Control: $M = 0.36$, SD = 1.85; $W = 4246.5$, $p = 0.03$) and letter knowledge tasks (Kalulu: $M = 15.37$, SD = 6.78 vs. Control: $M = 12.05$, SD = 7.18; $W = 4901$, $p = 0.001$). These differences could be attributed to the larger number of mid-SES students in the Kalulu intervention group (2 classes versus 1 in the control group), including 7 mid-SES children who read over 17 words on the 1-min word reading task, making them outliers at 2 SD from the mean. We repeated the analyses excluding these outliers, but the significance of our results remained unchanged (see data and scripts in OSF for outcomes with and without these outliers). Therefore, we included all students in the reported results. We chose this approach because using a general mixed model and entering pretest levels as a fixed effect should control for pretest group differences when estimating intervention effects. Group means and intervention effects are illustrated in Figure 4.

4.1 | One-Minute Reading

Consistent with Brazil's reading crisis, 21% of students did not read a single word at the posttest (Kalulu = 47%, Control = 53%). A zero-inflated negative binomial model was thus used to analyze the data. We report a significant intercept for the zero-inflation component ($\beta = -1.46$, $p < 0.001$), meaning that there were more students reading 0 words than would be expected by chance and, importantly, confirming that zero-inflation was essential in the model.

TABLE 1 | Demographics and pre-post outcomes for retained subjects in the Kalulu and the control group.

	Kalulu	Control	Shapiro–Wilk test for normality	Test for group differences[a]
N (% girls)	115 (55%)	66 (50%)		
Age years:months	6:3 (0.3)	6:2 (0.3)		$t(133) = 2.14$, $p = 0.034$
Pretest: mean (SD)				
RAN in seconds	75.23 (26.43)	69.61 (12.42)	$W = 0.77$, $p < 0.001$	$W = 4059$, $p = 0.44$
1-min word reading	2.55 (9.95)	0.36 (1.85)	$W = 0.23$, $p < 0.001$	$W = 4246.5$, $p = 0.03$
Phoneme verbal fluency (PVF)	1.26 (1.6)	0.97 (1.26)	$W = 0.73$, $p < 0.001$	$W = 4171.5$, $p = 0.24$
Digit-span	0.38 (0.13)	0.39 (0.12)	$W = 0.96$, $p < 0.001$	$W = 3598$, $p = 0.56$
Semantic verbal fluency (SVF)	8.82 (3.9)	9.45 (3.71)	$W = 0.98$, $p < 0.02$	$W = 3482$, $p = 0.36$
Letter name knowledge	15.37 (6.78)	12.05 (7.18)	$W = 0.84$, $p < 0.001$	$W = 4901$, $p = 0.001$
Posttest: mean (SD)				
1-min word reading	20.3 (18.19)	11.39 (14.37)	$W = 0.87$, $p < 0.001$	$W = 4992$, $p < 0.001$
Phoneme verbal fluency (PVF)	4.05 (2.8)	3.12 (2.34)	$W = 0.93$, $p < 0.001$	$W = 4535.5$, $p = 0.03$
Digit-span	0.50 (0.12)	0.47 (0.11)	$W = 0.96$, $p < 0.001$	$W = 4173$, $p = 0.26$
Semantic verbal fluency (SVF)	11.11 (4.14)	10.58 (3.5)	$W = 0.99$, $p = 0.48$	$t(154) = 0.93$, $p = 0.36$
Letter name knowledge	19.57 (3.89)	19.32 (3.34)	$W = 0.47$, $p < 0.001$	$W = 4489$, $p = 0.01$

[a]If data had a normal distribution, we compared group outcomes using a *t*-test. If data were not normal, we compared groups using a Wilcoxon rank-sum test.

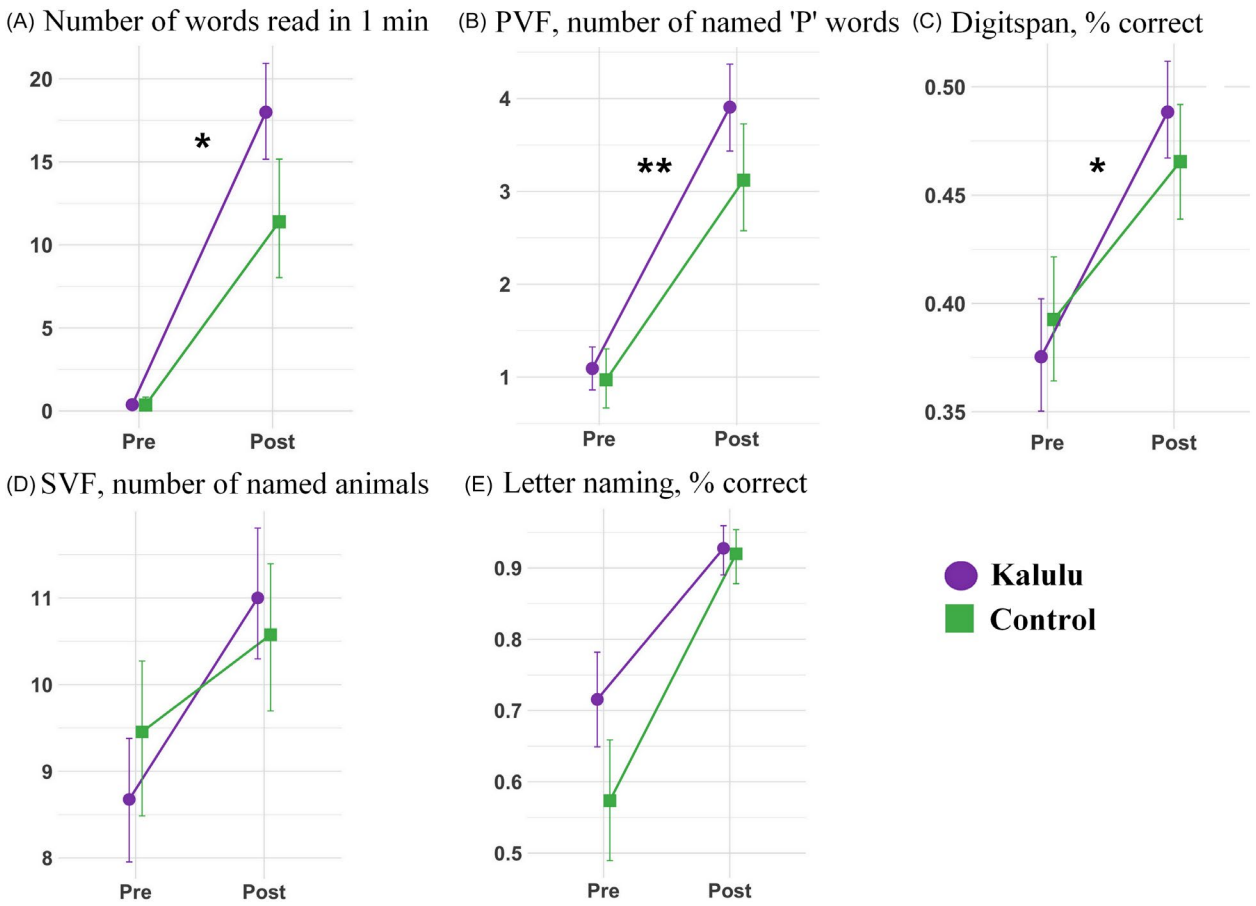

FIGURE 4 | Groups performance improvements. Panels indicate performance in tests of (A) number of words read; (B) phoneme verbal fluency (ability to retrieve words starting with the letter "P"); (C) forward and backward digit span repetition (D) semantic verbal fluency (number of animals named); (E) letter knowledge (number of letters named). All tests improved across time. Significance reported at $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

The pretest word reading score was a significant predictor of how many words students could read after the intervention, meaning that students who read more words before the intervention tended to improve more ($\beta = 0.03$, SE = 0.01, $z = 2.9$, $p = 0.004$). Similarly, students with faster RAN scores at the start also showed better improvement in reading ($\beta = -0.01$, SE = 0.004, $z = -2.59$, $p = 0.01$). However, students' age did not have a significant impact on their reading outcomes.

Participation in the Kalulu program significantly increased the number of words read compared to the control group ($\beta = 0.36$, SE = 0.150, $z = 2.37$, $p = 0.02$). To better understand the practical impact of this intervention, we can exponentiate the coefficient β from the log scale to the original count scale. Exponentiating 0.36 gives approximately 1.43, indicating that students in the Kalulu group are expected to read 1.43 times more words than those in the control group. This translates to a 43% increase in the expected number of words read. Given the control group's baseline average of 11.4 words, this 43% increase means that students in the Kalulu group are likely to read about 4.9 additional words in 1 min compared to their peers in the control group. This result highlights the meaningful improvement in reading performance associated with the Kalulu intervention. However, despite these promising results, posttest performance remains below the desired level. Structured interventions like Kalulu can serve as a valuable model for teachers in Brazil, offering both a research-backed approach and practical tools for classroom implementation. By providing not only the findings but also the complete set of materials for teachers to adopt, such interventions have the potential to help address the ongoing reading crisis.

4.2 | Phoneme Verbal Fluency

Given the lack of explicit phonics instruction in Brazilian schools, 8% of students scored 0 on this task (Kalulu = 71%, Control = 29%). The highly significant intercept in the zero-inflation model ($\beta = -3.59$, SE = 0.80, $z = -4.51$, $p < 0.001$) confirmed the need to account for excess zeros. The number of "P" words retrieved at pretest significantly predicted the number named at posttest ($\beta = 0.13$, SE = 0.03, $z = 4.57$, $p < 0.001$), as did the RAN score ($\beta = -0.01$, SE = 0.003, $z = -3.58$, $p < 0.001$). Age was not a predictor of outcome.

Children in the Kalulu group were significantly more likely to associate the letter "P" with its sound and retrieve words starting with the "p" sound ($\beta = 0.27$, SE = 0.10, $z = 2.68$, $p < 0.01$). We can use this to understand the practical impact of this improvement by exponentiating the coefficient β. Exponentiating 0.27 gives approximately 1.31, meaning that children in the Kalulu group are expected to name 1.31 times more words starting with "p" compared to those in the control group. This may indicate an improvement in the children's vocabulary development.

4.3 | Digit Span

All students were able to repeat at least one sequence, meaning the addition of the 0-inflation component to our model was not needed. The pre-intervention score significantly predicted the post-intervention score ($\beta = 0.55$, SE = 0.05, $z = 10.34$, $p < 0.001$). However, neither RAN nor age at pretest had a significant impact on outcomes.

Children that had used the Kalulu method were significantly more likely to have higher post-intervention scores ($\beta = 0.04$, SE = 0.02, $z = 2.43$, $p = 0.02$). When we transform this β to the original scale, we get an exponentiate of 0.04, meaning a 4% boost in the expected post-intervention digit span outcome for the Kalulu group over the control group. Enhanced working memory capacity facilitates superior retention of information across various cognitive tasks, including reading and listening comprehension.

4.4 | Semantic Verbal Fluency

All but one student was able to name at least one animal. The number of animals named at pretest significantly predicted the post responses, ($\beta = 0.41$, SE = 0.07, $z = 5.88$, $p < 0.001$), as did a child's RAN score ($\beta = -0.04$, SE = 0.01, $z = -2.97$, $p < 0.01$). Age was not a predictor of change. As predicted, all students equally improved in the number of animal names at the posttest ($\beta = 0.99$, SE = 0.59, $z = 1.68$, $p = 0.09$). This result is somewhat expected since Kalulu's training does not focus on vocabulary practice. Additionally, although animal names appear within the curriculum throughout the year, the vocabulary acquisition is neither required nor tested at the end of the first year.

4.5 | Letter Name Knowledge

All students were able to name at least one letter. The number of letters the child could name at pretest significantly predicted letter naming at posttest ($\beta = 0.28$, SE = 0.003, $z = 5.56$, $p < 0.001$) as did pretest RAN scores ($\beta = -0.03$, SE = 0.01, $z = -3.16$, $p < 0.01$). Again, age was not a significant predictor.

We did not find a significant advantage in the ability to name letters provided by the Kalulu intervention ($\beta = -0.45$, SE = 0.48, $z = -0.93$, $p = 0.35$). This finding aligns with expectations, as knowing the names of letters by the end of the first year is anticipated, resulting in no significant difference between the groups. This contrasts with the impact on letter sound knowledge.

5 | Discussion

Brazilian history has seen numerous shifts in teaching methods, often driven by political and social changes, culminating in a move toward constructivist approaches since the 1980s (Lima 2019; Mortatti 2006). Today, exploratory, discovery, and constructivist methods persist despite the overwhelming scientific consensus favoring phonics and explicit instruction (Ehri et al. 2001; Klahr and Nigam 2004; National Reading Panel 2000). These methods overlook evidence that self-directed learning is more effective when learners already have some prior knowledge (Kirschner et al. 2006). This is particularly problematic for students in Brazilian public schools, who often lack foundational skills and would benefit most from explicit, systematic, and structured instruction (Ehri 2020; Fletcher et al. 2021).

The primary goal of the current study was to demonstrate the importance of phonics instruction in early reading education in the Brazilian context. This was challenging because the existing classroom methods could not be replaced, only supplemented. All students received regular instruction from their teachers, but in the Kalulu intervention, teachers also set aside 40-min periods, two to three times a week, for a rotating reading workstation focused on phonics instruction. Our first hypothesis was that students participating in the program, providing structured game-based phonics instruction, would improve specifically in decoding fluency. Our results support this hypothesis: children in the Kalulu group read nearly five more words per minute than those in the control group, after controlling for pretest scores, processing speed and verbal retrieval, and classroom environment. As expected, however, children in the Kalulu group did not significantly outperform the control group in letter name knowledge, with 90% of experimental students and 88% of control students able to name more than 80% of the letters. This highlights that knowledge of letter names alone does not extend to reading proficiency if letter sounds are not also learned.

These results support previous research on the Kalulu app in France (Potier Watkins et al. 2020; Potier Watkins and Dehaene 2023), but they are not isolated to this particular phonics method. Other studies in different countries have pointed to positive intervention outcome with phonics games for reading skills using tablet games: Belgium (Vanden Bempt et al. 2021), India (Patel et al. 2022), the Netherlands (van Uittert et al. 2022), Indonesia (Debataraja et al. 2023), Germany (Berkling et al. 2015) and the United Kingdom (Ahmed et al. 2020). Even in China, where the primary writing system is logographic, game-based teaching of English as a second language has been successful (Xin et al. 2023). Collectively, these results show that quality software with a clear reading goal can be beneficial in reading education. It is also worth noting that pen-and-paper games have proven to be effective in improving reading skills (Chan et al. 2023; Dessemontet et al. 2019; Ehri et al. 2001; Galuschka et al. 2020; Suggate 2016).

The outcomes of this project are crucial for Brazil. Success or failure in acquiring reading skills directly impacts children's development. Many students who struggle with reading early on continue to face difficulties throughout their school years, with these challenges compounding over time (Carlson and Francis 2002). A review of over 16,000 individuals (children, adolescents, and adults) found that poor readers are at a higher risk of developing anxiety and depression compared to typical readers at various stages of life (Francis et al. 2019). Therefore, quality reading instruction is essential to maintaining students' engagement and motivation. Since motivation significantly influences learning (Filgona et al. 2020) and emotions impact the consolidation of important memories (McClay et al. 2023), providing effective reading instruction is critical for literacy, but also keeping kids in school and providing them with the foundational skills to pursue educational goals.

Providing explicit phonics instruction is particularly important in Brazil, especially in low SES public schools, where students are often not tested or given assistance for learning disabilities. In such cases, quality phonics instruction becomes even more crucial. A meta-analysis of randomized controlled trials has shown that phonics instruction is the most effective method for improving reading and spelling performance not only for typical learners but is especially critical for students with reading disabilities, such as dyslexia (Galuschka et al. 2014).

As hypothesized, the Kalulu based intervention also improved students' results on the phonological verbal fluency task (PVF, naming as many words as possible that start with the letter "p"), more than on the semantic task (SVF, naming animals). Kalulu's impact on phonological fluency may indicate an improved mental organization of phonological representations in these children. In this way, Kalulu affected not only reading but also broader phonological skills, aligning with other studies that have used game-based interventions (Amorim et al. 2020; Schmitt et al. 2018). Since initial reading acquisition heavily depends on phonological skills (see review in Melby-Lervåg et al. 2012), early phonological training can have a significant impact on both reading and broader phonological skills, particularly for disadvantaged children (Layes et al. 2022; Wolff and Gustafsson 2022).

The secondary hypothesis tested in this study was related to children's working short term memory (VeSTM), assessed by the digits span task. Children in the Kalulu intervention showed better outcomes. These findings are important because VeSTM is not only related to reading comprehension and decoding (Nouwens et al. 2021) but also overall academic attainment (Alloway and Alloway 2010). Moreover, some studies suggest that the relationship between reading and VeSTM is reciprocal (Miller-Cotto and Byrnes 2020; Peng and Kievit 2020). Considering the VeSTM outcomes alongside the background of the participating children, including their socioeconomic level and the pedagogic aspects of Brazilian public schools, all these factors may contribute to the persistent failure of literacy efforts in Brazil. The effect of socioeconomic level on VeSTM has been highlighted by a meta-analysis linking poverty to low working memory scores in developing countries (Nugroho et al. 2023). Additionally, children with low VeSTM scores, or smaller memory spans, seem to benefit more from interventions (for review see Diamond and Ling 2020). Therefore, it is possible that children who played Kalulu improved their VeSTM due to the game's explicit training of strategies and composition, which required players to retain sounds (phonemes) and word spellings in memory while strategically dismissing distractions, all within the time constraints of the game's animations. Specific training of working memory, combined with executive functions, has shown benefits in Brazilian public school students from low SES backgrounds, but not in private school students (Weissheimer et al. 2020). This is consistent with findings of low executive function skills in low SES communities, detectable even before formal education begins (Lipina et al. 2005). It should be studied in future iterations of Kalulu if these benefits came from the game or specifically from learning how to read.

5.1 | Limitations and Future Research Directions

Several limiting factors can be found in this work. First, the present study involved only five schools, with uneven numbers of students coming from low and mid SES backgrounds. In the

future, a randomized control trial, with a larger and more diverse sample of schools would be important to truly capture the potential benefits of the program.

Another limitation fell with our ability to communicate and train teachers to the importance of phonics (even so, there was an effect of the intervention). Kalulu was integrated into the school routine with 2 to 3 sessions of 40 min per week, while the whole language method continued to dominate the rest of the school period. The teachers were largely unfamiliar with phonics methods and digital tools, which sometimes led to reduced involvement and interest in the project. When our team presented the positive results at the end of the program, we encountered skepticism about their validity.

Moving forward, it is essential to improve communication and provide comprehensive teacher training. To ensure successful implementation, it is crucial to involve school administrators and directors in supporting the shift to phonics instruction. This shift should be framed not as an admission of past mistakes, but as a progressive change to enhance student outcomes. Many teachers still perceive phonics as an "old and boring" method. Overcoming this perception through effective communication and training is key to gaining acceptance. It is vital that teachers feel excited and confident about the knowledge, skills, and tools they bring to the classroom, as their enthusiasm directly influences student engagement and success.

These two factors combined also underpin an important criticism of the project, which is that at the end of the year, 16% of students in the Kalulu intervention were unable to read 1 word on our test. While this is almost half of the number of students in the control (30% of students were unable to read 1 word), we would have hoped that all students that used Kalulu might have started decoding the highly regular words presented on the test list. We believe that this could have been because both the computer and the card and board games were overly focused on the task of listening to a syllable or word and matching it to a written stimulus, a task that did not require students to read aloud. Reliable child voice recognition is not available, so Kalulu never requires that the child read aloud. All the games are based on hearing a syllable or word and matching it to its written form. This was similar in the group paper-based games, children heard words or saw pictures and then wrote them out or marked them on their bingo card. The game board required silent reading. These types of hearing and matching tasks were used because they were easy to coordinate in a group environment. Reading aloud requires that an adult listens actively, guiding the child in decoding words accurately and ensuring comprehension. Typically, this is the teacher's role. However, since our teachers lacked experience in prompting children to decode words, this essential skill was not adequately practiced in the intervention. Consequently, students may not have fully engaged in reading aloud with a focus on meaning—a fundamental aspect of reading theory. According to the triangle (or connectionist) model of reading, reading development relies on three interconnected systems: orthography (spelling), phonology (sounds), and semantics (meaning), all of which must work in concert to foster word recognition and comprehension (Seidenberg and McClelland 1989). This model suggests that learning to read depends on strengthening connections between these systems, allowing for fluent word recognition and comprehension. While Kalulu has likely helped students master grapheme-phoneme correspondences and spelling, we may have overlooked the importance of encouraging reading aloud. This practice, which fosters confidence, fluency, and comprehension, through adult feed-back might be crucial for developing automaticity in reading.

We aim to address these last two criticisms in future research. Currently, Kalulu has evolved into a comprehensive reading method, incorporating read-aloud books and, crucially, teacher training. Any future intervention will prioritize building teacher acceptance of the complete phonics method and, more importantly, enhancing teacher training to support students' reading development. This includes dedicated time for listening to students read aloud from decodable books, fostering their reading fluency and comprehension skills.

6 | Conclusion

The results following the use of the Kalulu phonics game showed a significant improvement in children's reading performance, consistent with outcomes observed in France and supported by the broader literature on phonics interventions. Given Brazil's unique socioeconomic and educational context, integrating Kalulu into schools as a literacy support tool could help bridge the gap between struggling readers and their peers. Further research and robust data are essential to persuade teachers and educational stakeholders of the critical need for targeted reading interventions. However, Kalulu alone is not sufficient; teachers play a pivotal role in promoting literacy effectively. Learning to read must be embedded within the curriculum, not treated as an add-on.

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Ethics Statement

Legal guardians provided informed consent for participating and publication, as approved by the Ethics and Research Committee of the Universidade Federal do ABC (CAAE: 88208918.4.0000.5594).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are openly available at https://osf.io/6ewd2/.

Endnotes

[1] Child labor has been illegal in the country since the enactment of the 1988 constitution.

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