Asia Pacific Journal of Developmental Differences
Vol. 9, No. 2, July 2022, pp. 248—278
DOI: 10.3850/S2345734122000152

Effectiveness of Mobile Assistive Technology on Improving the Self-Perceptions of Students with Dyslexia in Singapore

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Abstract

Assistive Technology (AT) has become a prevalent form of dyslexia intervention for addressing students' challenges in reading and learning. Besides improved reading and learning outcomes, AT use can also help to address students' psycho-social and behavioural needs. Lexicaid is a novel mobile application that was developed collaboratively based on input from various dyslexia stakeholders. To determine the efficacy of Lexicaid, a preliminary user study was conducted with students undergoing formal dyslexia remediation at the Dyslexia Association of Singapore. As part of a home-based study, a final number of 31 students (M_{age}=10.84 years, SD=1.39) participated in a user study involving Lexicaid over a period of six weeks whilst completing daily reading and learning activities. Participants were assessed on their reading motivation, self-perception, and reading and language skills before and after the intervention period. Although no significant effects were found between the experimental (n=18) and control (n=13) groups' pre and post scores on measures of reading and language, we found significant improvements in students' self-perception of writing and overall findings suggest that students saw improvements in their self-perception of writing and reading capabilities as well as a greater value in reading after the intervention using Lexicaid.

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Keywords: dyslexia, Singaporean students, assistive technology, mobile intervention

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INTRODUCTION

Dyslexia

Dyslexia is a prevalent specific learning disability that approximately affects 10% of the population (Hulme & Snowling, 2016). According to the Ministry of Education, about 3.5% of Primary 3 students in Singapore were reported as having dyslexia, with an additional 1% of the population being diagnosed by Secondary 1 (Wee, 2021). Individuals with dyslexia typically experience impairments in the development of their reading and spelling abilities. Other deficits in phonological processing and decoding can contribute to inaccurate word reading, which subsequently impedes students' reading comprehension and other academic abilities (Snowling, 2012; 2013). Early and appropriate interventions are thus necessary to better address the academic and emotional consequences of dyslexia (Galuschka et al., 2014).

Socio-Emotional and Behavioural Outcomes

Dyslexic individuals face challenges in word decoding, which subsequently affects their reading fluency and comprehension. This conversely can negatively impact their reading motivation, reading self-concept and willingness to engage in reading-related activities (Barber & Klauda, 2020; Mihandoost, 2012). Thus, compared to their typically developing (TD) peers, dyslexic individuals also face a higher risk of negative emotional outcomes such as having higher anxiety and poorer levels of self-perception and motivation, which may further result in additional avoidance of reading activities and schoolwork (Carroll & Iles, 2006; Terras, Thompson, & Minnis, 2009). Such reduced exposure to reading and language further exacerbates the achievement gap between dyslexic students and their TD peers (Carroll & Iles, 2006; Terras, Thompson, & Minnis, 2009). Given the bi-directional relationship between student motivation and academic achievement, encouraging students' intrinsic motivation and sense of academic self-efficacy can contribute to improved academic outcomes (Niehaus, Rudasill & Adelson, 2012).

Assistive Technology

Assistive Technology (AT) can be defined as an equipment or software that enables one to overcome their disabilities, improve their functional capabilities or perform specific tasks (Ahmad, 2015). On one hand, ATs for dyslexic individuals that utilized technology such as Text-to-Speech (TTS) and Optical Character Recognition (OCR) reduce the need for decoding in word reading and have been used in existing inventions with promising reading outcomes for dyslexic individuals (Harper et al., 2017; Landulfo et al., 2015; Lindeblad et al., 2016; Nordström et al., 2018; Wood et al., 2018). On the other hand, ATs that utilized other technologies, such as smartphone applications, screen readers, flatbed scanners, e-Book readers, and embossers, are considered to have slow processing speeds, poor accuracy, cumbersome usability or limited functionality (Alghabban et al.,

2017; Nelson et al., 2003; Zakopoulou, et al., 2017). Although there is growing interest in technology-based interventions, as reflected in the large number of mobile apps available for download on various app stores (Dawson et al., 2016; Jamshidifarsani et al., 2019), many of the existing mobile applications have a limited or incomplete perspective of dyslexia and its interventions (Dawson et al., 2016; Wood et al., 2018). The use of more specialized assistive technologies is also limited by the lack of affordability, lack of skilled personnel for training support or lack of knowledge on implementing AT interventions (de Witte et al., 2018; LoPresti et al., 2008). Importantly, Dawson et al. (2016) found that not many apps had been developed with input or collaboration from dyslexia experts and stakeholders. Rather, a significant portion of apps has been developed with an oversimplified concept of dyslexia and failed to account for the importance of multisensory and holistic learning approaches.

In order to develop an AT platform that would accurately meet the needs of various dyslexia stakeholders, Yow et al. (2019) conducted focus group discussion sessions with Educational Therapists (EdTs) to better understand the challenges faced by dyslexic children, their experiences, feedback and concerns with AT platforms, as well as existing intervention methods. The lack of resources, knowledge, and support beyond the classroom were highlighted as the key challenges faced in the current classrooms for AT adoption. The EdTs highlighted that a customisable multi-sensory learning tool for efficient identification of word and meaning would increase user-engagement and knowledge retention. The overall recommendation was for an AT to provide options for the user to access different learning features, such as word definition and examples in the forms of images or sentences. The AT output should incorporate both auditory and visual stimuli to facilitate multisensory learning. Auditory output should also be adjustable for aspects such as speed, volume, accent or gender of the voice output.
Given these prior findings, Lexicaid was subsequently developed to enable single-word identification of printed texts with customisable word-learning features and multi-sensory design (e.g., provision of word definition, spelling, and flashcards). The present study thus aims to investigate the efficacy of Lexicaid as an AT platform for dyslexic students. Reading and language outcomes, reading motivation and student self-perception were explored following a six-week intervention using Lexicaid.

METHODS

Participants

Forty-five children, who were attending formal dyslexia remediation at the Dyslexia Association of Singapore (DAS), were recruited for the study at the end of their school year. At the point of participant recruitment, the students' grade levels ranged from Primary 2 to Primary 6. Throughout the study, eight families were no longer responsive and could not be contacted for further participation in the study. Six additional students dropped out of the study, citing a lack of time or did not complete the study, leaving a

final sample size of 31 participants (M_{age}=10.84 years, *SD*=1.39, range=7.96 -12.79 years; 20 males & 11 females). All participants were also attending mainstream primary schools in Singapore (see Table 1), and had been formally diagnosed with dyslexia.

Table 1: Demographic characteristics of participants.

	Experimental	Control
No. of Participants, *n* (%)	18	13
Primary 2	2 (11.1)	1 (7.7)
Primary 3	3 (16.7)	4 (30.7)
Primary 4	1 (5.5)	0 (0.0)
Primary 5	5 (27.8)	2 (15.4)
Primary 6	7 (38.9)	6 (46.2)
***Mean* Age in years (*SD*)**	10.90 (1.48)	10.76 (1.37)
Gender, *n* (%)		
Female	6 (33.3)	5 (38.5)
Male	12 (66.7)	8 (61.5)

Materials

Technology Familiarity Questionnaire (TFQ)

The TFQ (see Appendix A) was adapted from the ICT Familiarity Questionnaire for Programme for International Student Assessment (PISA) by the Organisation for Economic Co-operation and Development (OCED) in 2018. The questions aimed to explore the different aspects of digital media and digital devices including age of access, type of ICT available at home and in school, as well as the frequency of ICT use at home and in school. The digital media and digital devices listed in the ICT Familiarity Questionnaire included desktop computers, laptops, smartphones, mobile or tablet devices and gaming consoles. In line with our study interest on the use of technology as a tool for facilitating reading and learning, we also included "specialised reading devices or tools - such as a reading pen" in our questionnaire. Scores for technology available for use range from 0 to 27, where higher scores indicate more technology available for the student to use, and scores for frequency of use range from 0 to 45, where higher scores indicate higher frequency of use.

Motivation to Read Profile-Revised (MRP-R) (Malloy et al., 2013).

The MRP-R is a two-part measure that consists of a self-report reading survey and a conversational interview. The reading survey consists of 20 items, where participants rated their perceptions on a four-point Likert scale. It measures an individual's perceived value of reading and self-concept as a reader. To facilitate the younger students' completion of the survey, the MRP-R response section was modified to include an accompanying smiley-face scale (see Figure 1). All items were read out loud to respondents, and they had to indicate which response was the best for them. Survey responses were all recorded via Qualtrics. Following the reading survey, a conversational interview was carried out to further understand the student's perception of reading, and complement the understanding of the child's reading survey responses. The interview also had two sections on the value of reading (e.g., "What kind of books do you like to read? Tell me about them (topics, genres, information and /or narrative?)") and reader's self-concept (e.g., "What kind of reader are you?").

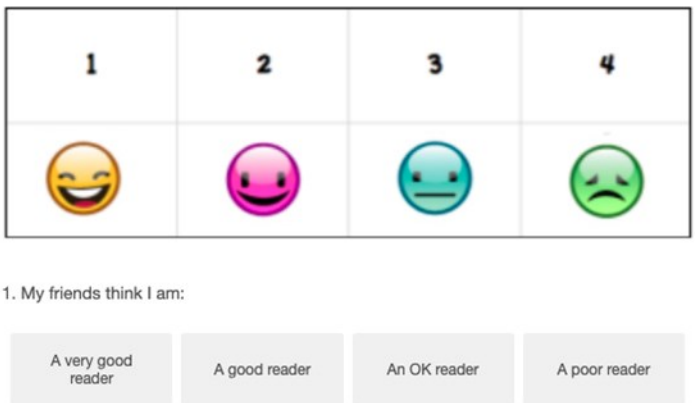

Figure 1: Sample MRP-R reading survey item with smiley-face scale

Self-Perception Profile for Learning Disabled Students (SPPLD) (Renick & Harter, 2012).

The SPPLD is a self-report measure that assesses children's self-perception of their competency or adequacy in specific domains, as well as their perceived self-worth and esteem. The SPPLD was developed for use by learning disabled children, but can also be administered for normally-achieving students (Harter, 1988). It assesses children's self-perception on the following ten domains of General Intellectual Ability, Reading Competence, Writing Competence, Spelling Competence, Math Competence, Athletic Competence, Social Acceptance, Physical Acceptance, Behavioural Conduct and Global Self-Worth (see Appendix B). Two opposing statements (e.g., "Some kids are sure that they are pretty smart in school" and "Other kids are not so sure that they are all that smart in school") were read out loud to respondents, who had to determine which statement was more like them. Respondents had to subsequently determine if the

selected statement was "Really true for (them)" or "Sort of true for (them)". Responses were all recorded via Qualtrics. Items were then scored to reflect their self-perception on a four-point scale with 1 being the least competent and 4 being the most competent.

Wechsler Individual Achievement Test, 4th Edition (WIAT-IV)

The WIAT-IV is an individually administered achievement test that can be used to measure academic achievement for young childhood to adulthood. Six selected subtests were used in this study for measuring reading and language: Spelling, Word Reading, Reading Comprehension, Orthographic Fluency, Pseudoword Decoding, and Decoding Fluency (see Appendix C). Due to Covid-19 restrictions, the WIAT-IV subtests were administered remotely via Zoom for 23 students. However, to accommodate the participants' school restrictions and schedules, an allied educator administered the tests in-person for the remaining 8 students. Except for the spelling subtest, all other subtests were audio recorded to clarify participants' responses where needed. All items were scored manually based on a standard procedure. The scoring was also discussed between researchers to ensure inter-rater reliability and to account for any discrepancies or disagreements surrounding ambiguous response items.

Lexicaid

Lexicaid is a mobile application developed by the research team that aims to facilitate independent word reading and learning among primary school-aged dyslexic students. Taking into account input from dyslexia professionals and intervention therapists, Lexicaid has two key uses – (i) a word scanning module and (ii) a flashcard module. The word scanning module enables the user to take a picture of a text passage or word (see Figure 2). Using OCR and TTS technology, the single word selected by the user can then

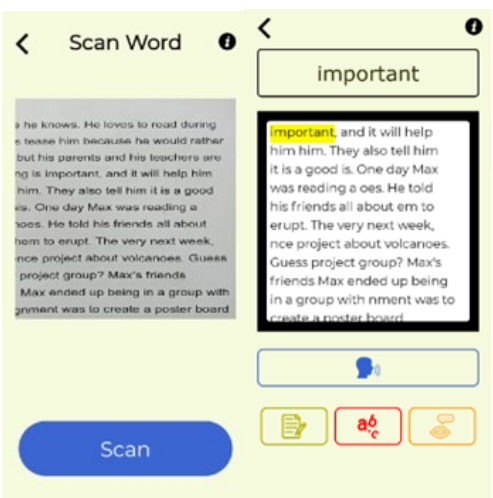

Figure 2: Word scanning module and selected word 'important'

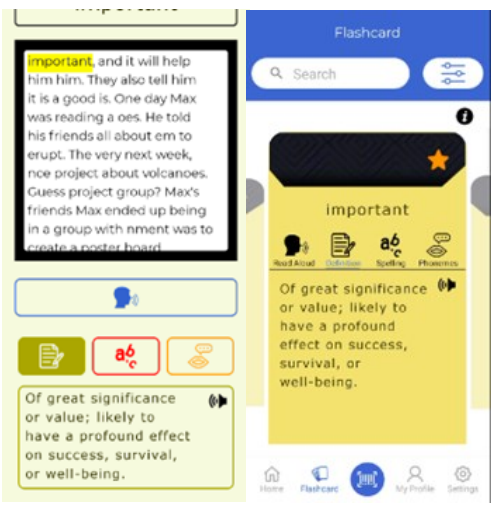

Figure 3: Definition learning feature in the word scanning and flashcard mode respectively

be extracted and identified. Supplementary learning features of pronunciation, definition, spelling and phonemic breakdowns, are provided to help the user identify and learn the word (Figure 3). The flashcard module integrates the practice of flashcard use in dyslexia intervention to reinforce word learning through repetition. Users are able to access previously scanned words, or input their own words for learning and revision (see Figure 4).

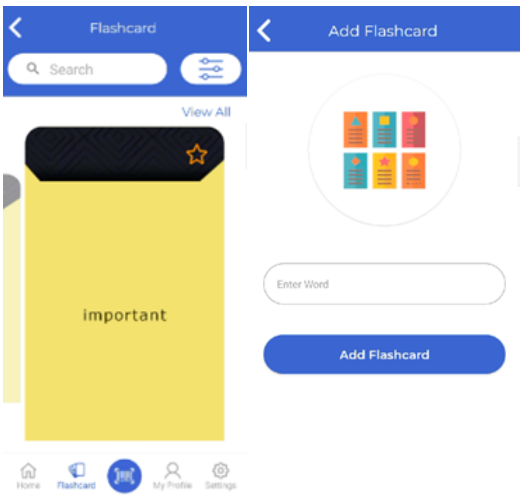

Figure 4: Sample flashcard and the 'Add Flashcard' feature

Lexicaid also allows for the customisation of audio output and font display to optimise the reading and learning experience for children with specific learning disabilities or dyslexia (Yow et al., 2019) (see Figure 5).

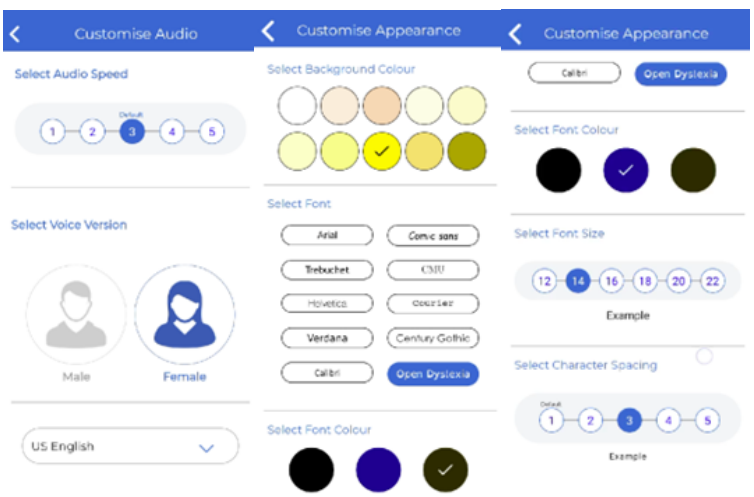

Figure 5: Audio and text customisation features

Mobile Phone Set Up

A Realme 6 Android Phone, running on Android OS 10, was used in the study as it met all the technical requirements for operating Lexicaid effectively. Each participant was also given a phone, a set of headphones and a charging unit. Lexicaid was pre-installed on all mobile phones. To ensure that the mobile phone would be used solely for the purpose of the study, all non-essential applications were deleted or removed from the home screen. Access to mobile functions and settings were disabled and restricted via a

password set by the research team. Parents were informed to reach out to the research team for support or technical assistance with the phone during the study period.

Lexicaid Feedback Questionnaire (LFQ)

To better understand participants' experience of Lexicaid use, a self-report feedback questionnaire was adapted from Form 4-1-3 of the Matching Person and Technology Assessment (MPT) (Scherer & Craddock, 2002) and conducted via Qualtrics (see Appendix D). The MPT assessment process consists of many different forms to determine the various personal and social factors that may impact the use of assistive, educational, workplace or health-care technologies. Form 4-1-3 is a follow-up assessment that explores an user's disposition and attitudes towards AT to identify any difficulties that the user may have experienced. Additional open-ended questions, such as which features were preferred or disliked, for what activities Lexicaid was most often used, areas of improvement or suggestions for further iterations, were included.

PROCEDURE

Letters of invitation were disseminated to parents to indicate their interest in having their child participate in the study. Upon responding to the letter of invitation, participants were first randomly assigned to either an experimental or control group. Participants in either groups were blind to the condition that they were in to minimize any expectancy effects of using the app (Rosenthal, 1987). As such, there were two separate sets of participant information sheets and consent forms that were then disseminated to the participants' parents in the respective conditions. Parental consent was then obtained, and participant demographics such as birthdate and socioeconomic status (SES) were collected.

Besides being used at home, Lexicaid was initially expected to be used during school hours or during intervention sessions as well. However, given the ever-changing Covid-19 restrictions, there was uncertainty as to whether or not students would be engaged in remote or in-person learning. A home-based study was thus deemed more suitable and less likely to be disrupted. Measures were converted to online mediums using Microsoft Powerpoint or the online survey platform, Qualtrics, and most pre- and post-tests were thus conducted online over Zoom. However, to accommodate the school's requests and students' schedules, the WIAT-IV had to be administered in-person instead for eight participants.

Pre- and post-tests were conducted for all participants before and after a six-week study period. Students were assessed on their reading motivation, self-perception, and on measures of reading and language as part of each test. Given the number of tests, and to reduce the likelihood of participant fatigue, pre and post-tests were conducted over two days. The MRP-R, SPPLD and the TFQ were conducted on the first day, while WIAT-IV tests were conducted on the second day. The TFQ was only conducted during pre-testing.

At the end of the study, students in the experimental group were asked to complete the LFQ. Parents of students in the experimental group, who had the chance to observe their child's use of Lexicaid were also asked to provide their feedback on Lexicaid via the LFQ.

Each student in the experimental group was given a mobile phone with Lexicaid pre-installed, and a step-by-step instruction guide on how to set up the user account. The experimental group was instructed to use Lexicaid during the study period for reading activities or when doing homework for at least two and a half hours a week. The control group continued learning and reading as per their normal study routine without external assistance provided by the researchers during the same study period. All students (in both experimental and control conditions) were expected to complete at least two and a half hours of reading and learning activities a week. At the end of each week, participants or their parents were required to submit a log online to provide an overview of the child's reading activity and Lexicaid use, if applicable (See Appendix E1/2). All mobile phones were collected back at the end of the study. Pre- and post-tests of the 13 participants in the control group (M_{age}=10.76 years, SD= 1.37; 8 males) and 18 in the experimental group (M_{age}= 11.28 years, SD=1.21; 13 males) were scored and analysed in this study. The study has been approved by the SUTD Institutional Review Board (IRB #20 -336)

RESULTS

Quantitative data were analysed using R version 4.0.5. The Shapiro-Wilk tests showed that the data were not normally distributed, as such non-parametric tests, i.e., Mann-Whitney U test, Kenward-Roger approximation and Wilcoxon signed rank test, were used to analyse the data. Mann-Whitney U test revealed that there were no significant differences in age between the experimental and control groups (Md_{Exp}=11.56 years, $Md_{Control}$=11.24 years, U=86.5, p=.226). Similarly, the Chi-square test showed no significant difference in socioeconomic status (SES) ($\chi 2(3)=4.65$, p=.20). Therefore, data across age and SES were collapsed in subsequent analyses.

Tech-Familiarity Questionnaire

Mann-Whitney U test on the pre-scores showed no significant differences between participants from the control and experimental condition groups in the types of technology available for use at home (M_{dExp}=19, $M_{dControl}$=20 U=107, p=.708) or in school (M_{dExp}=10, $M_{dControl}$=12, U=71, p=.968), the frequency of technology use at home (M_{dExp}=36, $M_{dControl}$=34, U=116, p=.984) or the frequency of technology use in school (M_{dExp}=13, $M_{dControl}$=15, U=74.5, p=.682).

WIAT-IV Measures

Type III Wald F tests (also called the Wald Chi-Squared Test) with Kenward-Roger degrees of freedom were conducted to analyse the effects of Time (pre- vs post-test) and Condition (experimental vs control) on WIAT scores. Preliminary analysis showed that the medium of administration did not have a significant effect on the students' performance (F[1,29]= 1.43, p=.187). As such this factor was not considered in subsequent analyses. There was also no significant main effect of Time (F[1,29]= 1.62, p=.201) or Condition (F[1,29]= 1.78, p=.177) on the overall WIAT-IV scores as well as the individual subtests following the use of Lexicaid (see Appendix F).

MRP-R

Similarly, the Type III Wald F test with Kenward-Roger degrees of freedom was used to analyze the scores of the MRP-R questionnaire. A significant Time x Condition effect (F[1, 29]= 16.1, p<.001) was found in the Value of Reading Section, where students from the experimental group had a significantly higher value of reading post-study than students from the control group (see Figure 6).

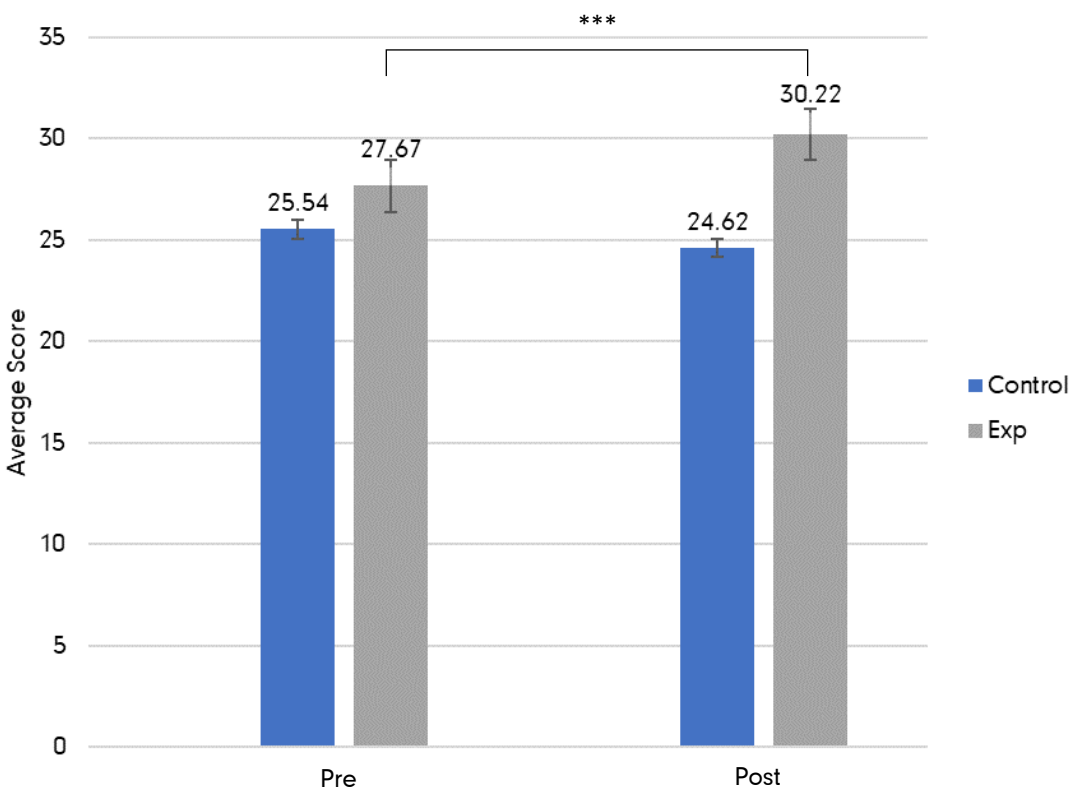

*Figure 6: Value of Reading Section by Condition. *** p < .001*

SPPLD

Of the 10 domains, the pre- and post-study scores of four domains: Writing Competence, Reading Competence, Spelling Competence, and General Intellectual Ability, were similarly examined using the Type III Wald F tests with Kenward-Roger degrees of freedom. The remaining domains, such as Athletic Competence, Social Acceptance, Physical Acceptance, Behavioural Conduct and Global Self-Worth, were not examined as past studies have shown that students' reading difficulties or poor performance at school did not have an effect on their self-perceptions of their social profile, athletic abilities and self-image (Burden, 2008; Frederickson & Jacobs, 2001).

Writing Competence. There was a marginal time effect, $F(1, 29)= 3.43$, $p=.072$, where both groups saw an increase in scores post-study. Importantly, there was a significant interaction effect of Time x Condition, $F(1, 29)= 18.2$, $p<.001$. Post-hoc Wilcoxon Tests showed a significant increase from the pre– to post-study scores of the experimental group ($p=.0028$) but no significant increase in scores for the control group ($p=.634$). Thus, students from the experimental group felt more competent in writing following the use of Lexicaid compared to those in the control group (see Figure 7).

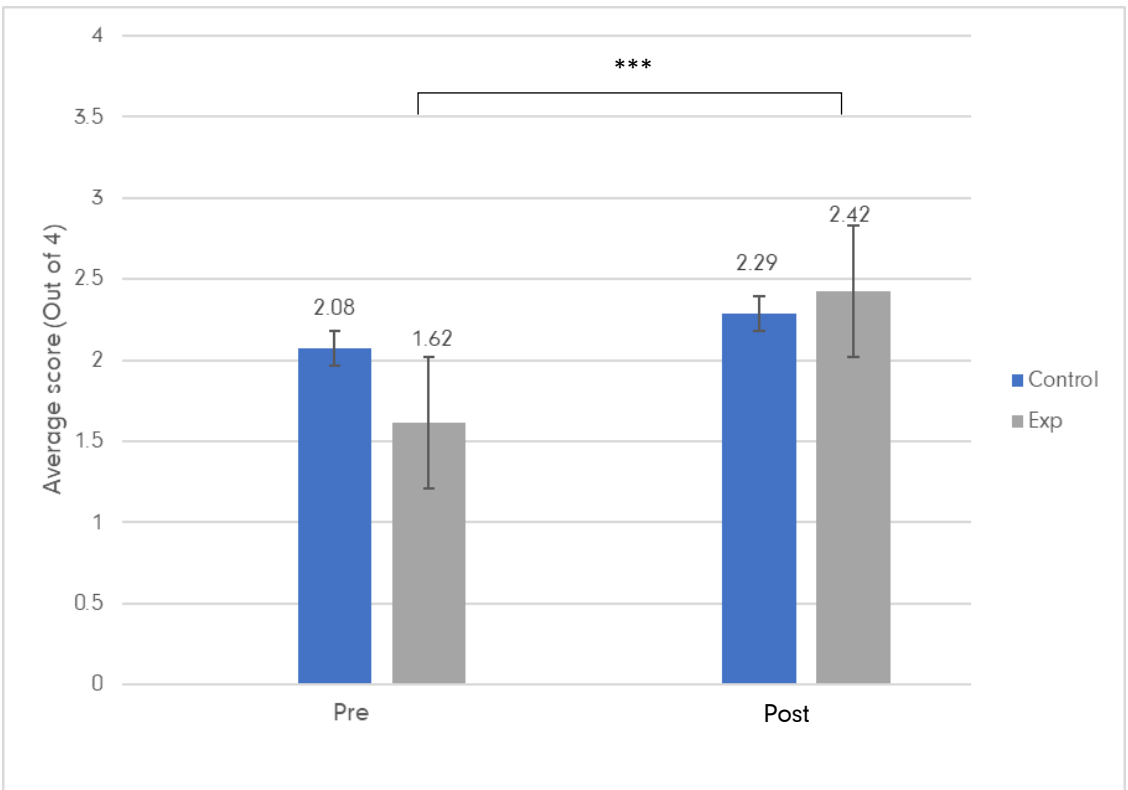

*Figure 7: Writing Competence Domain by Condition. *** p < .01*

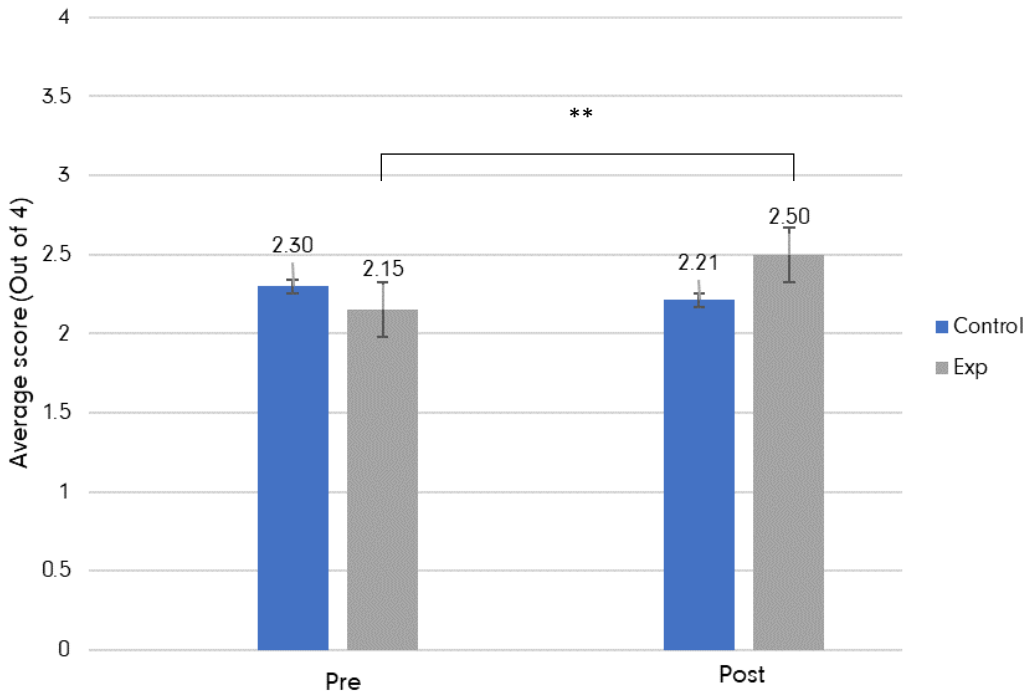

*Figure 8: Reading Competence Domain by Condition. ** p < .01*

Reading Competence. Similarly, analysis of the scores from this domain presented a significant Time x Condition effect, $F(1, 23)= 9.02$, $p=.0046$. Students from the experimental group felt more competent in reading following the use of Lexicaid compared to those in the control group (see Figure 8).

Spelling Competence. Although, results showed students in the experimental condition felt more competent in their spelling abilities post- than pre-study ($M_{pre}=2.23$, $M_{post}=2.38$), the increase was not statistically significant, $p=.650$.

General Intellectual Ability. Students from the experimental group reported more confidence in their General Intellectual Ability post-study compared to the students from the control group ($M_{control}=2.3$, $M_{exp}=2.4$; see Figure 9). However, this increase was only marginally significant, $p=.083$. There was also a marginal Time x Condition effect, $F(1, 23)= 3.82$, $p=.078$.

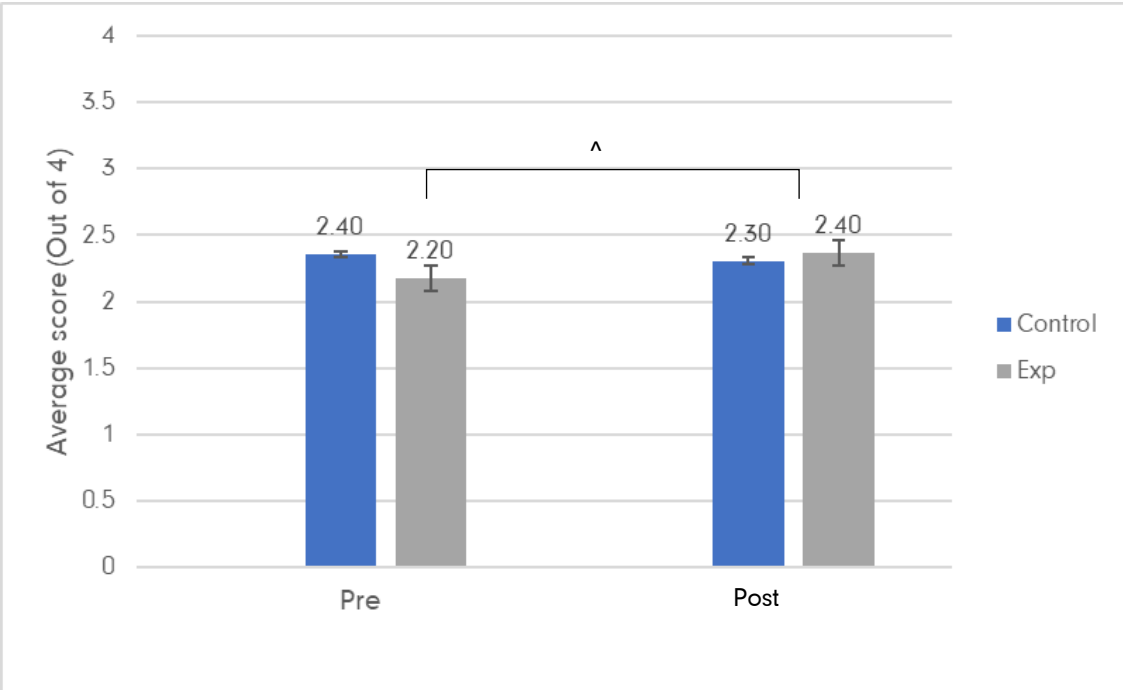

Figure 9: General Intellectual Ability Domain by Condition. ^ p < .10

DISCUSSION

Our study showed that our mobile app, Lexicaid, was effective in improving dyslexic students' self-perceptions of their reading and writing competency as well as the value of reading. Thus, the app, which included various features such as text-to-speech scanning, flashcard function, and customizable audio output and font display, displayed potential to improve dyslexic students' self-image and may in turn motivate struggling students to become more independent in their school learning. However, the app alone was not enough to efficiently improve the students' text-decoding and comprehension abilities to improve their WIAT scores during post-test. There are several possible explanations to our findings.

There has been an explosive growth of mobile apps developed to help people with dyslexia in recent times, but a majority of the apps have oversimplified the issues faced by dyslexic students and neglected to address that it is not a "one solution fits all" issue (Dawson et al., 2016; Jamshidifarsani, 2019; Vaughn et al., 2003). An app review study by Lerga, Candrlic and Jakupovic (2021) highlighted that intervention apps that have shown consistent effectiveness in the students' progress were developed together with the inputs of therapists, teachers, and parents. During the conceptualisation of these apps, common

requirements included a multisensory design with adaptive features that can be personalised by the users to address the variety of issues faced by students with dyslexia (Alghabban, et al., 2017; Zakopoulou, et al., 2017).

Our app, Lexicaid, was developed in conjunction with inputs from dyslexia experts to better facilitate independent reading and learning in dyslexic students. It incorporated multisensory designs with two key functions: (i) word scanning and (ii) flashcards, which are highly customisable. With the word scanning and flashcard features, together with the text-to-speech capabilities in Lexicaid, students could utilise the app independently while reading. The flashcard module in Lexicaid also gives students the opportunity to instantly create flashcards of difficult words they encounter while reading. Each flashcard comes with four text-to-speech options: Read Aloud, Definition, Spelling and Phonemes, which gives students a choice of how they would like to utilise the card to better suit their learning style. The freedom of choice could have made the students less anxious when attempting to read any passages using Lexicaid.

Students with dyslexia have limited ability to decode words. Studies have shown that speaking words aloud would be helpful when students are reading, as they would be able to hear (and thus recognise) the words they could not decode (Borhan et al., 2018). Text-to-speech technology has been shown to act as an aid to students with reading difficulties, compensating for the students' inability to decode words efficiently (Fälth & Svensson, 2015; Silvestri, Holmes, & Rahemtulla, 2021). By allowing students to listen to written words, the read-aloud function not only prevents misidentification of words, but also mitigates slow word reading, and the inability to connect words in a sentence for comprehension (Berkeley & Lindstrom, 2011). In a meta-analysis conducted by Wood, Moxely, Tighe, & Wagner (2018), there were a significant number of studies that showed that the use of text-to-speech tools had a significant positive impact on reading comprehension abilities. The Read Aloud function, in Lexicaid, which utilizes the Text-to-Speech technology would, therefore, allow students to easily decode the word through the audio feedback before matching it to the written word. In addition, the Spelling and Phoneme functions in Lexicaid can serve as a useful tool to enhance their decoding and spelling skills. By breaking down the word into letters or phonetic sections, the app provides a visual reference point for dyslexic students to review the word they had difficulties decoding. Apps utilising similar features, such as Grapholearn, have reported improvements in students' speed and accuracy of reading compared to their peers in the control groups (Kyle et al., 2013; Leloup et al., 2021; Mehringer et al., 2020).

Nevertheless, there are studies that found a lack of improvement in academic scores of students with dyslexia from using the text-to-speech technology (Kim, McKenna & Park, 2017; Meyer & Bourke, 2014; Young et al., 2019). In line with the results from this study, Stetter and Hughes (2010) found that text-to-speech technology did not impact adolescent students' academic scores, but students reported that they valued the increased independence that the text-to-speech software conferred on them. Silvestri,

Holmes and Rahemtulla (2021), reported that students with different cognitive competencies could have contributed to the varying effects of text-to-speech software. They found that while dyslexic students with severe decoding disability but above average listening comprehension skills benefitted most from the text-to-speech function, students with moderate decoding abilities did not see any significant improvements in their scores.

Researchers suggest that there could be many non-cognitive processing reasons behind this absence of effect of text-to-speech technology on academic outcomes. Dyslexic students tend to have poorer self-perception and motivation towards reading due to the challenges they face with the metacognitive aspect of studying (Silvestri, Holmes and Rahemtulla, 2021). As they are unable to identify their learning styles and make the necessary connections (e.g., meaning and word pronunciation), they feel frustrated and are unable to progress (Fumes & Norman, 2018; Wood et al., 2018). The flashcard method has shown to mitigate these issues by introducing different types of learning through a repetitive revision process.

Physical flashcards, like the Orton–Gillingham Flashcards, help improve students' orthographic fluency through repeated exposure to the phonology of words and/or pictures to help students identify the meaning through contextual clues (Stevens et al., 2021; Lim & Oei, 2015). Similarly, by incorporating the Flashcard feature in Lexicaid, it enables students to store words instantly on the app for repetitive learning and to revisit words that they are unsure about or not confident in reading. This in turn could enhance students' self-perception of their orthographic fluency. Thus, these added features could have contributed to the post-test improvements of the students' self-perception of reading and writing as well as value of reading. However, despite the positive impacts of flashcards on a student's attitudes towards reading, this did not necessarily translate into academic related results (Nelson et al., 2003; Ritchey & Goeke, 2006; Tran et al., 2011).

Nevertheless, it is possible that students could benefit more from a longer intervention program than the present brief intervention study. Some studies noted that there was no direct impact on the children's education scores when examining the efficacy of apps, such as LexiPal (Risqi, 2015), EasyLexia (Skiada et al., 2014), and DysEggxia (Rello et al., 2014), over a shorter duration (6-8 weeks). Instead, researchers saw an increase in motivation to use the apps and attempt to complete the reading and writing tasks (Gooch et al., 2016; Rello et al., 2014; Risqi, 2015; Saputra, 2015; Skiada et al., 2014). On the other hand, there are studies that showed an improvement in both the academic and perceptions of self-image when the apps were tested over a longer period (6 months – 1 year) and had teachers integrate them into their lesson plans (Hall et al., 2015; Lim & Oei, 2015; Lindeblad, et al., 2016; Zakopoulou, et al., 2017). Thus, the short duration of our study as well as the inability to integrate the app into regular class lesson plans due to COVID restrictions could have limited the impact of the app on the academic outcomes of the dyslexic student who participated in the study.

LIMITATIONS

It is important to note that systematic reviews and meta-analyses have found the average effect size for overall treatment efficacy to be modest. Many intervention studies are further limited by their sample size due to challenges in recruiting a large number of participants. (Galuschka et al., 2014; Toffalini et al., 2021). A larger sample size will thus be needed to better assess the efficacy of Lexicaid. A home-based study also meant that it was more challenging to ensure that students fully adhered to the study requirements and expected duration of Lexicaid use. Additionally, due to Covid-19 restrictions and school requirements, the method of WIAT-IV administration had to be done differently for some students, which might have affected the WIAT-IV outcomes across participants. Finally, an extended intervention programme could provide students with the opportunity to acclimatise to using both the reading strategies taught in class and Lexicaid to improve their reading and writing abilities.

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Appendix A

Technology Familiarity Questionnaire

1. Are any of these devices available for you to use at home?

(Please select one response in each row.)

Device	Yes, and I use it a lot	Yes, and I use it some-times	Yes, but I do not use it	No
Desktop computer	☐	☐	☐	☐
Portable laptop or notebook	☐	☐	☐	☐
Tablet computer (E.g., iPad, Blackberry, PlayBook)	☐	☐	☐	☐
Internet connection	☐	☐	☐	☐
Video games console (E.g., Sony PlayStation, Xbox)	☐	☐	☐	☐
Cell phone (without Internet access)	☐	☐	☐	☐
Cell phone (with Internet access – i.e., smartphone)	☐	☐	☐	☐
E-book reader (E.g., Amazon Kindle)	☐	☐	☐	☐
Specialised reading devices or tools (E.g., C-Pen)	☐	☐	☐	☐

2. Are any of these devices available for you to use at school?

(Please select one response in each row.)

Device	Yes, and I use it a lot	Yes, and I use it some-times	Yes, but I do not use it	No
Desktop computer	☐	☐	☐	☐
Portable laptop or notebook	☐	☐	☐	☐
Tablet computer (E.g., iPad, Blackberry, PlayBook)	☐	☐	☐	☐
E-book reader (E.g., Amazon Kindle)	☐	☐	☐	☐
Specialised reading devices or tools (E.g., C-Pen)	☐	☐	☐	☐
Interactive Whiteboard (E.g., SmartBoard)	☐	☐	☐	☐

3. How old were you when you first used a digital device?
(Please think of different kinds of digital devices such as for example desktop computers, portable laptops, notebooks, smartphones, tablet computers, cell phones without Internet access, game consoles, or Internet-connected television.)

(Please select one response.)

3 years old or younger	☐
4 – 6 years old	☐
7 – 9 years old	☐
10 – 12 years old	☐
13 years old or older	☐
I have never used a digital device until today	☐

***If the student selects "I have never used a digital device until today", the questionnaire will terminate as the proceeding questions will not be relevant to the student.*

4. How old were you when you first accessed the Internet?

(Please select one response.)

3 years old or younger	☐
4 – 6 years old	☐
7 – 9 years old	☐
10 – 12 years old	☐
13 years old or older	☐
I have never accessed the Internet	☐

***This is a filter question. If a student responds "6", I have never accessed the Internet, IC005, IC006, IC007 are not applicable, and students will proceed with IC150.*

5. During a typical <u>weekday</u>, for how long do you use the Internet <u>at school</u>?

(Please select one response.)

No time	☐
1 – 30 minutes per day	☐
31 – 60 minutes per day	☐
Between 1 hour and 2 hours per day	☐
Between 2 hours and 4 hours per day	☐
Between 4 hours and 6 hours per day	☐
More than 6 hours per day	☐

Only if students answered "1"-"5" in Q1-4.

6. During a typical <u>weekday</u>, for how long do you use the Internet <u>outside of school</u>?

(Please select one response.)

No time	☐
1 – 30 minutes per day	☐
31 – 60 minutes per day	☐
Between 1 hour and 2 hours per day	☐
Between 2 hours and 4 hours per day	☐
Between 4 hours and 6 hours per day	☐
More than 6 hours per day	☐

7. On a typical <u>weekend</u> day, for how long do you use the Internet <u>outside of school</u>?

(Please select one response.)

No time	☐
1 – 30 minutes per day	☐
31 – 60 minutes per day	☐
Between 1 hour and 2 hours per day	☐
Between 2 hours and 4 hours per day	☐
Between 4 hours and 6 hours per day	☐
More than 6 hours per day	☐

8. In a typical school week, how much time do you spend using digital devices during classroom lessons?

(Please select one response in each row.)

Subject	No time	1 – 30 minutes a week	31 – 60 minutes a week	More than 60 minutes a week	I do not study this subject
English	☐	☐	☐	☐	☐
Mathematics	☐	☐	☐	☐	☐
Science	☐	☐	☐	☐	☐
Mother Tongue	☐	☐	☐	☐	☐

9. In a typical school week, how much time do you spend using digital devices outside of classroom lessons (regardless of whether at home or in school) for the following subjects?

(Please select one response in each row.)

Subject	No time	1 – 30 minutes a week	31 – 60 minutes a week	More than 60 minutes a week	I do not study this subject
English	☐	☐	☐	☐	☐
Mathematics	☐	☐	☐	☐	☐
Science	☐	☐	☐	☐	☐
Mother Tongue	☐	☐	☐	☐	☐

10. How often do you use digital devices for the following activities outside of school?

(Please select one response in each row.)

Activity	Never or hardly ever	Once or twice a month	Once or twice a week	Almost every day	Every day
Playing online games	☐	☐	☐	☐	☐
Using email	☐	☐	☐	☐	☐
Communicating online or on social media (E.g., MSN, WhatsApp, Telegram)	☐	☐	☐	☐	☐
Participating in social media (E.g., Facebook, Instagram)	☐	☐	☐	☐	☐
Browsing the Internet for fun (such as watching videos) (E.g., YouTube)	☐	☐	☐	☐	☐
Reading on the Internet (E.g., books, comics, news)	☐	☐	☐	☐	☐
Searching for information on the Internet (E.g., facts, locations, date of events)	☐	☐	☐	☐	☐
Using apps on a mobile device	☐	☐	☐	☐	☐
Browsing the Internet for schoolwork (E.g., for preparing an essay or presentation)	☐	☐	☐	☐	☐
Doing homework on a computer	☐	☐	☐	☐	☐
Doing homework on a mobile device	☐	☐	☐	☐	☐

Using learning apps or learning websites on a computer	☐	☐	☐	☐	☐
Using learning apps or learning websites on a mobile device	☐	☐	☐	☐	☐
Using learning apps or learning websites for reading on a computer	☐	☐	☐	☐	☐
Using learning apps or learning websites for reading on a mobile device	☐	☐	☐	☐	☐
Using specialised devices or tools for reading	☐	☐	☐	☐	☐

11. How often do you use digital devices for the following activities <u>at school</u>?

(Please select one response in each row.)

Activity	**Never or hardly ever**	**Once or twice a month**	**Once or twice a week**	**Almost every day**	**Every day**
Communicating online at school	☐	☐	☐	☐	☐
Using email at school					
Browsing the Internet for schoolwork	☐	☐	☐	☐	☐
Practicing and drilling, such as for language learning or mathematics	☐	☐	☐	☐	☐
Doing homework on a school computer or mobile device	☐	☐	☐	☐	☐
Using school computers or mobile devices for group work and communication with other students	☐	☐	☐	☐	☐
Using learning apps or learning websites	☐	☐	☐	☐	☐
Using learning apps or learning websites for reading	☐	☐	☐	☐	☐
Using specialised devices or tools for reading	☐	☐	☐	☐	☐

Appendix B

Domains of the SPPLD and Description (Renick & Harter, 2012)

Domain	Description
General Intellectual Ability	The extent which individuals perceive themselves to be smart or good learners in school.
Reading Competence	The extent to which individuals feel at ease or adequate when completing reading, writing, spelling and math activities.
Writing Competence	The extent to which individuals feel at ease or adequate when completing writing activities.
Spelling Competence	The extent to which individuals feel at ease or adequate when completing spelling activities.
Math Competence	The extent to which individuals feel at ease or adequate when completing math activities.
Athletic Competence	The extent to which individuals feel competent at athletic activities.
Social Acceptance	The extent to which individuals perceive their self-attributes that contribute to social success (e.g., knowing how to make friends, getting other people to like you).
Physical Acceptance	The extent to which individuals are happy with or like the way they look.
Behavioural Conduct	The extent to which individuals are happy with or like the way they behave.
Global Self-Worth	The extent to which individuals like themselves as a person.

Appendix C

WIAT-IV Order of Administration, Selected Subtests and Description (Malloy et al., 2013)

Administration Order	WIAT-IV Subtest	Subtest Description
1	Spelling	Measures written spelling ability from dictation. Students either wrote down letter sounds or words that were dictated in the context of a sentence.
2	Word Reading	To measure letter and letter-sound knowledge and single word reading. Students either identified letters and matched letters to sounds. They also read aloud a list of regular and irregular words.
3	Reading Comprehension	Measures reading comprehension skills at the level of the word, sentence, and passage. Students either read a sentence or a narrative/expository passage and answered a series of questions.
4	Orthographic Fluency	Measures the orthographic lexicon or sight vocabulary. Students read aloud as many irregular words as possible in two timed trials.
5	Pseudoword Decoding	Measures phonic decoding skills. Students read a list of pseudowords aloud.
6	Decoding Fluency	Measures phonic decoding fluency. Students read aloud as many pseudowords as possible in two timed trials.

Appendix D

Lexicaid Feedback Questionnaire

Perceptions and Feedback Following Mobile Application Use (Child)

We would like to better understand your perception and feedback on the mobile application after using it. Please respond to all the questions in each section honestly. Remember there is no right or wrong response.

Section 1 – Student Motivation

There are four statements that describe your perception of your motivation following the use of the mobile application. Please respond by circling only one number for each statement below.

Following the mobile application use, do you assess that your:

	In no degree	In a very small degree	In a small degree	In a fairly high degree	In a very high degree
a. Motivation for schoolwork has increased?	1	2	3	4	5
b. Motivation for assimilating text has increased?	1	2	3	4	5
c. Motivation for communicating text has increased?	1	2	3	4	5
d. Motivation for traditional reading has increased?	1	2	3	4	5

Section 2 – Student Learning

There are seven statements that describe your perception of your learning following the use of the mobile application. Please respond by circling only one number for each statement below.

Following the mobile application use, do you assess that you:

	In no degree	In a very small degree	In a small degree	In a fairly high degree	In a very high degree
a. Have improved traditional reading skills?	1	2	3	4	5
b. Have improved the ability to assimilate spoken text?	1	2	3	4	5
c. Have increased the amount of text assimilated?	1	2	3	4	5
d. Have improved the ability to comprehend texts?	1	2	3	4	5
e. Are more autonomous while interacting with texts?	1	2	3	4	5
f. Are more autonomous in school work in general?	1	2	3	4	5
g. Can compensate for lack of reading skills by listening to spoken text?	1	2	3	4	5

Section 3 – Mobile Application as an Assistive Tool for Students with Dyslexia and/or Reading Difficulties (RD)

There are five statements that determine how you perceive the use of the mobile application as being a useful Assistive Tool for students with dyslexia and/or RD. Please respond by circling only one number for each statement below.

Do you assess the mobile application usage to:

	In no degree	**In a very small degree**	**In a small degree**	**In a fairly high degree**	**In a very high degree**
a. Enhance students' [with Dyslexia and/or RD] learning opportunities?	1	2	3	4	5
b. Enhance students' [with Dyslexia and/or RD] reading development?	1	2	3	4	5
c. Enhance students' [with Dyslexia and/or RD] text comprehension ability?	1	2	3	4	5
d. Improve students' [with Dyslexia and/or RD] ability to write text?	1	2	3	4	5
e. Be useful for your independent learning at home?	1	2	3	4	5

Section 4 – Frequency of Mobile Application Use

We would like to know how frequently you use the mobile application. Please respond by ticking only one box for each question.

a. During a typical weekday, for how long do you use the mobile app at school?

No time	☐
1 – 30 minutes per day	☐
31 – 60 minutes per day	☐
Between 1 hour and 2 hours per day	☐
Between 2 hours and 4 hours per day	☐
Between 4 hours and 6 hours per day	☐
More than 6 hours per day	☐

b. During a typical weekday, for how long do you use the mobile app outside of school?

No time	☐
1 – 30 minutes per day	☐
31 – 60 minutes per day	☐
Between 1 hour and 2 hours per day	☐
Between 2 hours and 4 hours per day	☐
Between 4 hours and 6 hours per day	☐
More than 6 hours per day	☐

c. During a typical <u>weekend</u>, for how long do you use the mobile app <u>outside of school</u>?

No time	☐
1 – 30 minutes per day	☐
31 – 60 minutes per day	☐
Between 1 hour and 2 hours per day	☐
Between 2 hours and 4 hours per day	☐
Between 4 hours and 6 hours per day	☐
More than 6 hours per day	☐

Section 5 – Feedback on Mobile Phone Use

We would like to better understand your use of the mobile application, and your thoughts about it. Please respond by circling <u>only one answer</u> for each row below. Do tell us how you really feel. Remember, there is no right or wrong answer.

	Question	Not at all (0%)	Some-times (25%)	Half the time (50%)	Often (75%)	All the time (100%)	Not Applic able
a.	This mobile app is benefiting me and improving my quality of life.	1	2	3	4	5	NA
b.	I know how to use the mobile app and its various features	1	2	3	4	5	NA
c.	I feel more secure (safe, sure of myself) when using this mobile app.	1	2	3	4	5	NA
d.	This mobile app fits well with my accustomed routine.	1	2	3	4	5	NA
e.	I have the capabilities and stamina to use this mobile app without discomfort, stress and fatigue.	1	2	3	4	5	NA
f.	The supports, assistance and accommodations exist for successful use of this mobile app.	1	2	3	4	5	NA
g.	This mobile app physically fits in all desired environments (purse, pocket, desk, car, etc.).	1	2	3	4	5	NA
h.	I feel comfortable (and *not* self-conscious) using this mobile app around family.	1	2	3	4	5	NA
i.	I feel comfortable (and *not* self-conscious) using this mobile app around friends.	1	2	3	4	5	NA
j.	I feel comfortable (and *not* self-conscious) using this mobile app at school or work.	1	2	3	4	5	NA
k.	I feel comfortable (and *not* self-conscious) using this mobile app around the community.)	1	2	3	4	5	NA

Comments:

Section 6 – Additional Feedback on the Mobile Application

The following questions are to gain better understanding about your feedback on the mobile application. Do indicate your responses in the lines below. There are no right or wrong answers.

a. **What do you like most about the mobile application?**

b. **What do you like the least about the mobile application?**

c. **Which feature did you use the most?**

d. **What did you normally use the mobile application for?**

e. **Where did you normally use the mobile application?**

f. **When did you normally use the mobile application?**

g. **Are there any features that you think you need but are missing in the mobile application? Describe.**

h. **What do you think the mobile application should improve on?**

Appendix E1

Weekly Log Sheet for Control Group

Over the next 4 weeks, your child will continue learning and reading as per his/her normal study routine. Your child will be expected to complete a minimum of 2.5 hours of reading-related activity or homework per week (7 days).

For Questions 3 & 4, please fill in the estimated duration (specify in minutes or hours) spent on weekly reading-related activities or homework in the form below.

Thank you very much!

1. Name of Child:

2. Please select the appropriate week:

- Week 1 (6 Feb 2021 - 12 Feb 2021)
- Week 2 (13 Feb 2021 - 19 Feb 2021)
- Week 3 (20 Feb 2021 - 26 Feb 2021)
- Week 4 (27 Feb 2021 - 5 March 2021)
- Week 5 (6 Mar 2021 - 12 Mar 2021)
- Week 6 (13 Mar 2021 - 19 Mar 2021)

3. Please indicate the duration (specify in minutes or hours) spent on reading-related activities this week (e.g., books, comics, news, webtoons, web pages, online articles etc.):

4. Please indicate the duration (specify in minutes or hours) spent on homework, schoolwork or revision this week:

Additional Comments (if any):

Appendix E2

Weekly Log Sheet for Experimental Group

Over the next 4 weeks, your child will continue learning and reading using the mobile app Lexicaid as per his/her normal study routine. Your child will be expected to complete a minimum of 2.5 hours of reading-related activity or homework per week (7 days).

For Question 3 - Use of the app would include the child having the app available by his/her side as a learning aid.

For Questions 4-6, please fill in the estimated duration (specify in minutes or hours) spent on weekly reading-related activities, homework or using the app in the form below.

For Question 6 - Active use of the app will include actively scanning words, accessing the flashcards or learning features.

Thank you very much!

1. Name of Child:

2. Please select the appropriate week:

- Week 1 (6 Feb 2021 - 12 Feb 2021)
- Week 2 (13 Feb 2021 - 19 Feb 2021)
- Week 3 (20 Feb 2021 - 26 Feb 2021)
- Week 4 (27 Feb 2021 - 5 Mar 2021)
- Week 5 (6 Mar 2021 - 12 Mar 2021)
- Week 6 (13 Mar 2021 - 19 Mar 2021)

3. My child has been using the app for at least 2.5 hours to complete reading-related activities, homework, schoolwork or revision:

- Yes
- No

4. Please indicate the duration (specify in minutes or hours) spent on reading-related activities this week (e.g., books, comics, news, webtoons, web pages, online articles etc.):

5. Please indicate the duration (specify in minutes or hours) spent on homework, schoolwork or revision this week:

6. Please indicate the estimated duration (specify in minutes or hours) spent using the app's learning features or active use of the app:

Additional Comments (if any):

Weekly Log: Mean Duration Spent on Reading Activities per Student

	Experimental		Control	
***Mean* time, Hrs**	Reported Reading & Homework Activities	Recorded App Usage	Reported Reading & Homework Activities	Recorded App Usage
Week 1	7.64	2.76	7.76	NA
Week 2	8.89	2.95	9.70	NA
Week 3	7.94	2.65	8.08	NA
Week 4	8.50	3.83	8.02	NA
Week 5	9.52	3.63	11.4	NA
Week 6	10.87	3.98	9.07	NA

Appendix F

Participant Distribution and Mean Age

	WIAT-IV (Online)		WIAT-IV (In-Person)	
	Control	Experimental	Control	Experimental
No. of Participants	10	13	3	5
***Mean* Age in years (*SD*)**	10.60 (1.54)	11.39 (1.24)	11.28 (0.17)	10.98 (1.34)
Gender, *n* (%)				
Female	4 (40.0)	3 (23.1)	1 (33.3)	2 (40.0)
Male	6 (60.0)	10 (76.9)	2 (66.7)	3 (60.0)

Mean Standard WIAT-IV Scores of Participants

	Experimental, *M* (SD)		Control, *M* (SD)	
	Pre	Post	Pre	Post
Total Achievement	81.0(17.2)	83.7 (22.9)	87.0 (25.9)	86.7 (21.1)
Spelling	79.1 (16.9)	84.1 (16.8)	82.2 (15.9)	82.5 (14.5)
Word Reading	78.3 (18.3)	86.3 (22.6)	87.7 (11.3)	88.15 (13.3)
Reading Comprehension	81.9 (13.0)	86.9 (15.9)	89.6 (16.6)	86.92 (13.9)
Orthographic Fluency	81.6 (15.5)	82.8 (14.9)	85.2 (10.1)	85.6 (8.45)
Pseudoword Decoding	83.4 (14.5)	80.9 (14.1)	88.6 (11.2)	88.4 (14.5)
Decoding Fluency	83.4 (17.45)	84.3 (13.3)	88.9 (8.89)	88.5 (8.12)