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Developing an educational app for students with autism

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This paper describes the design, development, and pilot test of an App, and explains how research based strategies and pedagogical approaches can be embedded within an App based format. The aims and scope of the research were to; (a) synthesize research findings on reading comprehension difficulties for students with autism spectrum disorder (ASD) identifying evidence-based strategies that underpin improvements; (b) determine the features associated with the design of 'quality' educational apps; (c) create a reading comprehension app for students with ASD and; (d) test in applied settings. The study utilized extensive literature searches to determine key considerations for design and development of the App and then piloted the completed product through employing an AB case study design with two participants. Pre and post testing measured discrete vocabulary skills including expressive and receptive vocabulary, reading comprehension, phonological development, and reading behaviors. The results of the design process and pilot test provide recommendations for developers and educators when considering the critical pedagogical content and functionality of Apps for supporting reading comprehension skills for students with Autism.

KEYWORDS

autism (ASD), iPads, comprehension, reading strategies, software design and development

Introduction

Research concerning students with autism (ASD), and the use of mobile digital technologies in education is relatively recent and therefore there is limited evidence of the effectiveness of this technology for learning (Knight et al., 2013). Research concerning iPads and applications (apps) for students with ASD has typically focused on the development of discrete skills such as communication and social and adaptive behaviors over academic skills (Ennis-Cole, 2015). Furthermore, research has yet to determine if apps for iPads can support the development of the 'critical' academic skills that underpin literacies: reading and reading comprehension (Kagohara et al., 2012, 2013). Literature concerning the reading difficulties of students diagnosed with ASD describes evidence-based strategies known to underpin the development of reading comprehension skills (Whalon et al., 2009; El Zein et al., 2014). These evidence-based strategies are typically delivered face-to-face through teacher or peer mediated instruction. However, children diagnosed with ASD specifically those in mainstream classrooms who could be considered as 'high functioning' have difficulties understanding social and emotional cues which impair face-to-face communication (Ricketts et al., 2013). The use of digital formats may mitigate the difficulties often encountered by students with ASD in face-to-face communication.

This paper discusses the principles underpinning the purposeful selection of embedded content and design for an app to support the development of reading comprehension skills for students with ASD in Australian mainstream classroom contexts. The content and design elements described in this paper examine the theories associated with cognition and ASD to explain reading comprehension difficulties for students with ASD and evidence-based strategies successful in mitigating difficulties in reading comprehension for students with ASD to create a quality educational app.

The researcher designed and developed a reading comprehension app that was tested in applied settings $n = 2$ in a AB case study design with children diagnosed with ASD. The first phase of the research consisted of the development of the instrument (app). This phase considered: the theories that relate to ASD and way they could impact on reading comprehension; research concerning the effectiveness of face-to-face strategies that mitigate reading comprehension difficulties in students with ASD; recommendations for the necessary content and features of 'good' educational apps; and the synthesis of the previous three stages into the development of the app. The final phase involved testing the app in applied settings.

Literature review

The literature presented here represents the three domains under consideration for the app development process. Each domain draws on a specific area of research that is connected to the design and development of the app. Findings taken from each of these domains underpin the choice of specific content and functions and the way they support pedagogical strategies and approaches in the digital format of the app.

Theories related to autism and reading comprehension

Initially, it was necessary to review the theories associated with ASD and the way they impair learning across the autism spectrum (Nation et al., 2006; Lindgren et al., 2009). These theories concern autistic perception and social and emotional understandings as they became part of specific design and content decisions in the development process. For example, to understand a text, readers must be able to integrate clauses and sentences to form semantic representations. Many students with ASD display difficulties integrating syntactic and semantic information to create meaning (O'Connor and Klein, 2004). Gersten et al. (2001) argue that for many students with reading difficulties, problems occur in the domain of their strategic processing and their metacognitive competencies. These weaknesses and difficulties with self-monitoring will impact on a student's capacity to understand the purpose of a text. The theories discussed below provide explanations of comprehension difficulties in students with ASD, founded on the language or information processing problems associated with the disorder (Nation et al., 2006; Gately, 2008; Norbury and Nation, 2011). Researchers have also drawn similar parallels with the comprehension issues in typical populations concerned with the relationship between oral language deficits, intelligence, and poor comprehension.

Individuals with ASD often demonstrate an impaired or limited capacity in understanding others' states of mind, intentions and emotion. Researchers attribute this to an inability to appropriately develop 'Theory of Mind' (ToM; Baron-Cohen et al., 1985). Furthermore, core social and language deficits associated with the disorder have been implicated in a child's capacity to acquire ToM (Frith, 1989; Meltzoff, 1999). Difficulties with understanding the feelings and intentions of others as seen with ToM impair comprehension and understanding, particularly in face-to-face interactions (Ricketts et al., 2013). It is not known to what extent this extends to textual information, however, it would be reasonable to extend this theory to cover understanding inferences within text. This would be compounded by attempts to remediate difficulties with reading comprehension using face-to-face teaching methods. However, it is important to recognize that reading comprehension difficulties are not universal in students with ASD due to the heterogeneity of a diagnosis (Saldana et al., 2009; Williamson et al., 2012).

Ozonoff et al. (1991) propose that cognitive difficulties with flexibility, planning, organization, and self-monitoring are within Executive Function (EF) in individuals with ASD. Thus, if EF is compromised and applied to reading, this could manifest as problems in understanding the goal or purpose of the text. This in turn would result in an inability to read for understanding. Difficulties with the organization of information would mean that integrating and making connections between paragraphs in text and understanding themes, ideas, and concepts would also be problematic (Carnahan et al., 2011).

Other research has proposed that comprehension problems in children with ASD result from deficits within complex cognitive processes (Randi et al., 2010), as proposed by Weak Central Coherence Theory (WCCT; Happe, 1999; Happe and Frith, 2006). The WCCT could explain the kind of comprehension difficulties demonstrated by some students with ASD in understanding main ideas in text, and summarizing and sequencing critical elements of a story (Happe and Frith, 2006; Williamson et al., 2012). It proposed by WCCT that differences in autistic perception within cognitive function show a bias in perception of detailed (local) over full scope (global) information (Mottron and Bellville, 1993; Rinehart et al., 2000). This is also referred to as 'stimulus over selectivity' (Lovaas et al., 1979). An example to illustrate this concept is seen below (see Figure 1).

In Figure 1, attention is drawn first toward the smaller letters incongruent with the overall representation. This bias in attention supports the theory that visual perception in individuals with

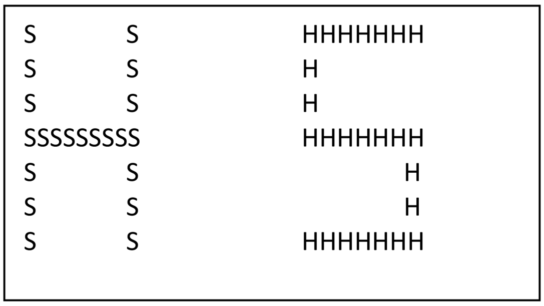

FIGURE 1
Example of visual perception task.

autism can favor detail rather than overall visual representations (Frith, 1989; Happe, 1999; Nation, 1999; Happe and Frith, 2006). Happe and Frith (2006) explain that strengths in processing local detail could be described more as a processing bias, which may explain why those aspects of behavior relating to excessive attention to detail result in difficulties in integrating text at a macro level. Difficulties in integrating information and a bias toward details may also provide explanations for disparities in research between component reading skills such as word recognition, fluency, and comprehension (Nation et al., 2006).

Teaching practitioners, speech and language specialists, and some individuals with ASD assert that there are strengths in visual processing over auditory perception in some individuals diagnosed with autism (Kunda and Goel, 2008; Kunda and Goel, 2011). Thus, visual aids in the form of activity schedules, images, and pictures are regularly used as a teaching method to support learning skills for individuals with ASD (Knight et al., 2014). Research in neuropsychological studies have also indicate deficits in the auditory processing profiles of some children with ASD, which supports the perception of strengths or bias across the visual processing domain (Roth et al., 2012).

These theories provide varied explanations of the difficulties associated with reading comprehension and ASD. As a result, they underpin decisions regarding the selection and presentation of specific content and pedagogical strategies for the app development and design process, explained in more detail later.

Autism, language, and reading comprehension

Literature concerning the reading ability of children with ASD has generally correlated problems in reading comprehension with the language and communication deficits associated with the disorder (Smith-Gabig, 2010). The association between poor oral language skills and problems in reading comprehension has already been established in typically developing children (Bishop and Snowling, 2004; Nation et al., 2004; Cain and Oakhill, 2006). Despite the language and communication deficits related to the disorder, many studies have noted that children with ASD, particularly those considered 'high-functioning', may still develop phonological awareness or an understanding of the structure of words at age appropriate or above levels (Mayes and Calhoun, 2003; Saldana et al., 2009).

Norbury and Nation (2011) investigated the role of structural language skills and the relationship between oral language comprehension, word reading ability, and students with ASD. They examined the hypothesis that poor structural language could predict problems in reading comprehension and word reading ability for students with ASD. This study recruited 27 adolescents with ASD but with different language phenotypes, and a cohort of similar age students without ASD as the control contrast group. This research was framed in reference to the simple view of reading proposed by Gough and Tunmer (1986). The simple view of reading identifies two core skills in the reading process, the decoding of the words and the comprehension of those words in text. This focus on decoding and comprehension is widely accepted as one method of categorizing the range of difficulties many children encounter with reading (Woolley, 2010). In this instance, the simple view of reading was incorporated with the model proposed by Bishop and Snowling (2004) which suggested more specifically that it is children's phonological and non-phonological skills such as expressive and receptive vocabulary that support their comprehension and decoding. Although the Norbury and Nation (2011) results showed considerable variation across students with the ASD phenotype, the data indicated that deficits in oral language were related to comprehension problems for students with ASD and for students without ASD, who showed comprehension and language impairments. It is important to note, however, that Norbury and Nation (2011) maintained that these results did not account for all variations in reading comprehension deficits for children with ASD. They suggested that cognitive processing difficulties associated with students with ASD may be an issue. The claim is that students with ASD are more likely to process local, literal, and immediate information over global and more abstract information, as hypothesized in the "Weak Central Coherence Theory" or the "Executive Function Theory" (ie., Pennington et al., 1997; Happe, 1999; Jolliffe and Baron-Cohen, 2000).

Reading instruction for individuals with autism

Research studies into interventions supporting reading comprehension in ASD are commonly small in scale (Whalon et al., 2009; El Zein et al., 2014). A recent synthesis on reading intervention studies involving students with ASD from kindergarten to Year 12 (El Zein et al., 2014) identified 12 published studies that met their inclusion criteria. These were studies conducted between 1980 and 2012, peer reviewed, and included single-subject, single-group, experimental, and quasi-experimental designs all utilizing a dependent measure of reading comprehension. Four studies implemented strategy instruction

(Whalon and Hanline, 2008; Åsberg and Sandberg, 2010; van Riper, 2010; Stringfield et al., 2011), and three utilized explicit instruction, for example question generation, making predictions and the use of graphic organizers (Flores and Ganz, 2007; Ganz and Flores, 2009; Knight, 2010). A further three studies examined student grouping practices (Kamps et al., 1989, 1994, 1995), and another two investigated referents within text through anaphoric cueing instruction (O'Connor and Klein, 2004; Campbell, 2010). Anaphoric cueing instruction involves the resolution of the ambiguity in the use of pronouns such as he, she, someone, and everyone. These interventions covered the range of strategies that are typically applied to remediate and support reading comprehension for all students.

Not included in this synthesis was a 'grounded theory' study that investigated the ways in which students with ASD comprehend text and the factors that influence comprehension for these individuals (Williamson et al., 2012). Based on the understanding that students with ASD have a 'different' way of interacting with and focusing on text, based on the theoretical frameworks of WCCT, EF, and ToM, Williamson et al. (2012) provided the participants with explicit daily reading instruction. For example, this explicit instruction included the remedial strategies of 'think-alouds' where the reader vocalized the strategies they were using as they read the text. The 'think-aloud' strategy was video modeled, so that the students had both a visual and an auditory model to review. Bell and Bonetti (2006) referred to the use of a video to display and reinforce the strategy as visualizing and verbalizing. They claimed that this duel processing helped students to gain more insight into their own thinking process and use of strategies. Williamson et al. (2012) also asked the participants a range of questions to determine if they were accessing background knowledge associated with the text. Participants were asked to talk aloud to represent their thoughts verbally as they read the texts, to write about the read text, and to draw pictures as mental representations. With a total of 13 participants, three different profiles emerged in the way meaning is made from text. Williamson et al. (2012), described these profiles as "text bound comprehenders, strategic comprehenders, and imaginative comprehenders" (p. 464). Text bound comprehenders were those described as having difficulties in accessing relevant background knowledge to support the development of text-based comprehension. Despite these differing profiles, Williamson et al. (2012), made the point that teaching comprehension strategies to students with ASD needs to be planned and reinforced through systematic practice.

Technology and instructional design

Although many behavioral techniques employed by teachers and carers have assisted the learning and communication of children with ASD, these can be time intensive and expensive. Research into the use of computers and children with autism (Heimann et al., 1995; Moore and Calvert, 2000) has reported higher levels of attention, motivation, and engagement and assistance in the development of problem-solving strategies. A review of studies involving evidence-based reading instruction and ASD (Whalon et al., 2009) discusses four studies that have addressed code-focused reading skills utilizing computer-assisted instruction. However, none of these studies targeted comprehension above a word focused level (Heimann et al., 1995; Tjus et al., 1998; Basil and Reyes, 2003; Coleman-Martin et al., 2005). All four studies reported gains across a variety of code-reading skills that included word spelling, word recognition, sentence reading, and sentence imitation. Whalon et al. (2009) described the results of these studies as promising and suggest it is likely that computer-assisted instruction may be a viable method of learning instruction. They also indicated that there was a lack of available evidence to promote the use of computer-assisted instruction as a sole mode of support, suggesting this mode of learning be used as an augmentative measure.

Many researchers still highlight the lack of evidence regarding the learning outcomes of using mobile devices and apps in the fields of general and special education (Knight et al., 2013; King et al., 2014; van der Meer et al., 2015; Churchill, 2017; Skaraki, 2021). For example, Stephenson and Limbrick (2013) reviewed 36 research studies involving touch screen mobile devices by participants with developmental disabilities. This review concluded that few studies have focused on the development of academic skills with new mobile technology, and that in these instances the evidence provided was mostly suggestive. King et al. (2014) explored the way in which children and young adults with ASD use iPads in the classroom stating, "the field would benefit from further research to address the question of whether [the] use of apps improves learning" (p. 167). Ennis-Cole (2015) explained that computerized tools can scaffold and support learning in the areas of communication, social skill development and behavior but at this time s/he does not consider them as an intervention for ASD.

What is a 'good' educational app?

Su and Draper-Rodriguez (2012) presented a framework developed from research into computer learning games to assist teachers in evaluating the suitability of educational apps. Ten features considered important were: (1) scaffolding; (2) collaborative interaction patterns to increase engagement; (3) highly digitized speech and colorful graphic images; (4) interactive tasks requiring an active response; (5) clear instructions; (6) opportunities to practice tasks; (7) consistent intervals of time for each learning task; (8) encouragement, reinforcement, and modeling; (9) feedback for correct and incorrect responses; and (10) age appropriateness of both content and how it is presented. Su and Draper-Rodriguez (2012) also recommend that future iPad developers should aim to: incorporate a suitable blend of learning, practice, and game elements; create student pathways to learning goals that were free from distraction; and design software features that can replicate the pedagogy of the classroom teacher. In the evaluation of a range of educational apps for children in early learning environments, Falloon (2013) identified similar features to Su and Draper-Rodriguez's (2012) framework. Falloon noted that design features of educational apps should "promote thoughtful engagement and productive learning" (p. 519). Nikolopoulou (2007) also recommended that "software be integrated into the classroom with appropriate pedagogic approaches" (p. 178). When examining a selection of apps claiming relevance for students receiving some level of special education, researchers agreed that best practice should determine app selection and be matched to Individual Education Plan goals (Newton and Dell, 2011; More and Travers, 2012).

One of the most comprehensive studies on the educational features of apps concluded with the creation of a rubric (Walker, 2014). The research was designed to establish appropriate content and rating descriptors for use by teachers and educators. Walker's rubric contains seven domain criteria developed using the Delphi method in consultation and collaboration with more than 90 educators and subject matter experts (SMEs) from several countries. These SMEs, through an iterative process, provided feedback on criteria they believed important for evaluative purposes. The feedback contributed to constructing the rubric domains and subsequent rating descriptors. The Delphi method uses an iterative research approach to achieve a consensus among experts (Finch et al., 2014). Each domain of the rubric was rated by participants based on content validity (Lawshe, 1975). Consequently, Walker's seven domain criteria as agreed upon by the participating SMEs are:

1. Curriculum connection, and how well the targeted skill or concept is directly taught through the app.
2. Authenticity, where targeted skills are practiced in an authentic format/problem-based learning environment.
3. Feedback that is specific, resulting in improved performance and data that is available electronically to the student and/or teacher.
4. Differentiation, where the app offers complete flexibility to alter settings to meet student needs.
5. User Friendliness, where students can launch and navigate within the app independently.
6. Motivation, how highly students are motivated to use the app.
7. Student Performance, where students show outstanding improvements in performance as a result of using the app.

The domain criteria listed above assist educators in selecting and evaluating high quality educational apps. To the author's knowledge, these have not been used as design and development criteria for creating educational apps. The recommendations by Su and Draper-Rodriguez (2012), Walker (2014) and Nikolopoulou (2007) were incorporated into the design and development of an app to support reading comprehension in students diagnosed with ASD. The comprehension strategies embedded within the app were selected from the literature. These included: anaphoric cuing (O'Connor and Klein, 2004; Campbell, 2010), sequencing ideas or events, character feelings and emotions, making predictions (Earles-Vollrath et al., 2008; Whalon and Hanline, 2008; Whalon and Hart, 2010), and picture building (Bell and Bonetti, 2006; van Meter et al., 2006). These strategies require the reader to engage with literal meanings, inferential understandings, and sequencing tasks and require the reader to link different pieces of information within the text to choose an appropriate response (Flores and Ganz, 2007; Whalon and Hart, 2010; Flores et al., 2013). These content and design elements were synthesized in order to design and create the app.

Materials and methods

App development

The app was created from a children's story published in 1914 (Burgess, 1914). The story was available within the public domain negating any issues with copyright. The app '*Blinded*' was created from the text of *'Blinded'* and was purposefully chosen by the researcher as it was a chapter story and not a short text. The original text and the purposefully created digital version described here consist of more than 15,000 words of text and embedded reading comprehension strategies. Chapter format was chosen because the structure and length of a chapter story and provides the student with multiple opportunities to practice higher order comprehension skills and create a 'schema' of characters and events. The importance of this was discussed by O'Connor and Klein (2004) who explained that the development of 'schema' associated within a story allows the reader to reflect on what has already happened and predict what is likely to happen next. This also allows the reader to explore the characters and the plot which is important for establishing context and developing understandings when accessing and integrating information through text. Students with ASD have difficulties in interpreting people's feelings, emotions, and actions (Klin et al., 2000; Lord et al., 2000). The opportunity for students with ASD to explore, reflect, and review the personalities, emotions, behaviors and actions of the characters in a safe setting of a digital story was important for the selection of the narrative used in the present research study.

'Blinded' was first published in the United States and it was evident the language and context were not familiar for contemporary Australian student readers. There were several animal characters indigenous only to an American context. Accordingly, the story and some of the characters were modified to create a context that was culturally relevant, interesting, and motivating for the reader (Nikolopoulou, 2007). To ensure that the vocabulary and the complexity of the text and sentences were age appropriate for the intended participants of the research (Su and Draper-Rodriguez, 2012), the modified text was subsequently analyzed using Fry's Readability Scale (Fry, 1968). This analysis

revealed that parts of the text were suitable for a reading age of around 8–11 years, with much of the text suitable for a reader in middle primary school. The app was developed to be a tool for self-directed learning (Ganz and Flores, 2009; Flores et al., 2013), and therefore it was important to consider how the software could be designed to scaffold this process through pedagogical approaches similar to those of a teacher (Su and Draper-Rodriguez, 2012; Falloon, 2013; Callaghan and Reich, 2018). The design needed to provide the reader with an opportunity to learn how to use and navigate their way through the app independently (Walker, 2014). Readers can personalize their learning by choosing their own avatars similar to a digital game (see Figure 2). The reader cannot unlock any of the story chapters until the instructional 'walkthrough' has been completed (see Figure 3).

After completing an instructional 'walkthrough' (explaining how to use the app) the reader receives a 'key' to unlock the first chapter of the story. Each chapter is locked until the user completes the set strategies and cannot skip ahead and lose the thread of the story. A passage of text is released with a 'strategy' icon at the bottom of the page (see Figure 4). The student reads and/or listens to the text and is unable to proceed further into the text until the strategy is completed with the correct response. If the first response to the strategy is incorrect, a hint or clue in the form of a prompt is provided. The prompt highlights parts of the preceding text that supports a correct answer (see Figure 5). If the second response is also incorrect, then the software shows the student the correct answer (see Figure 6). This is, in part, mirroring the same way in which a teacher would provide prompts and scaffolding with direct instruction techniques in face-to-face teaching instruction (Whalon and Hanline, 2008; Armstrong and Hughes, 2012). Therefore, the student is receiving direct and immediate feedback to correct any incorrect responses (Su and Draper-Rodriguez, 2012; Walker, 2014).

Teachers or parents can monitor the reader's level of correct and incorrect responses through an electronic spread sheet produced by the reporting function (Walker, 2014). This spreadsheet information can be used as a diagnostic tool as it reports directly on student performance, error rates, and hints. This form of monitoring shows which particular task or area of reading comprehension the reader may be having difficulty with, so a more individualized program could be designed for the student. Teachers or parents can choose the option of 'in app reporting' by adding their email address into the app's settings. The student-generated content is automatically saved and emailed to the address upon completion of some or all of the chapters. This reporting function saves the picture builder activities which can be used later for activities like story sequencing to consolidate learning.

Considering research on scaffolded learning and the effectiveness of providing prompts (Whalon and Hanline, 2008), the app has focus on interactive tasks that require active responses (Su and Draper-Rodriguez, 2012). Embedded within each chapter are multiple strategies to support reading

FIGURE 2
Add user screen in app with choice of six avatars.

FIGURE 3
Screen shot of Chapter view in app showing Walkthrough and Chapter 1 completed.

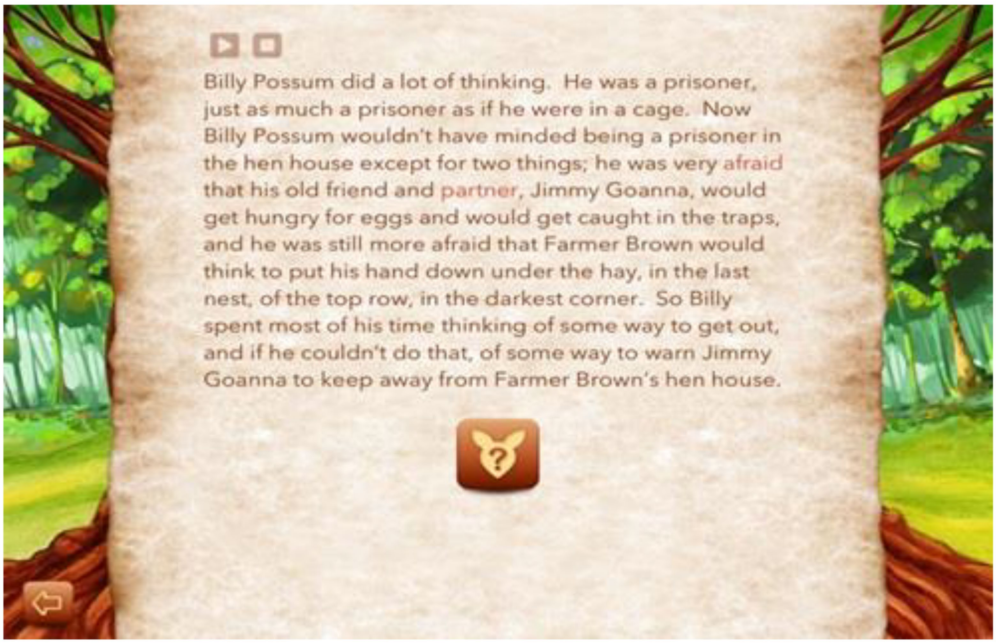

FIGURE 4
Screen shot in app of question strategy icon.

comprehension. These strategies include the dictionary function (see Figure 7), to support vocabulary development. Each definition provided by the dictionary function was written in plain language and in the context of the story. It was considered important not to use a linked dictionary function that would present multiple definitions of a word and create confusion.

FIGURE 5
Screen shot in app after incorrect response and highlighted text to scaffold second response.

FIGURE 6
Screen shot in app of correct response and release of following text.

Comprehension tasks were also presented in 'cloze' format consistent with the research conducted by O'Connor and Klein (2004) and Bellon et al. (2000).

Cloze is a teaching instruction strategy for reading comprehension where sentences are presented missing key words. The reader must insert or select the word that best fits

FIGURE 7
Screen shot in app of text with dictionary function displayed.

that sentence, while still maintaining the 'schema' or comprehension of the whole passage (Duke and Pearson, 2002; O'Connor and Klein, 2004). It is important to acknowledge the way in which the comprehension strategies are embedded in the story do not take the student 'out' of working within the text to answer questions. This is to reduce distraction and maintains the student's focus on learning (Nikolopoulou, 2007; More and Travers, 2012; Falloon, 2013). Both the dictionary function and the cloze activities are presented within the text so the learning task is accessed in the same way as reading a traditional text. This preserves the 'authenticity' of the learning task (Su and Draper-Rodriguez, 2012; Walker, 2014).

Equipping the text to account for learning strengths was also a consideration (Walker, 2014). Some individuals with ASD may demonstrate a visual bias, for others auditory information may be preferential (Roth et al., 2012). The incorporation of an audio option into the text in a standard accented human voice (Churchill, 2011; Falloon, 2013) was chosen to support an individual's cognitive bias (Kunda and Goel, 2011). The audio option has the advantage of supporting readers who are less fluent readers. It links the text with the paralinguistic aspects of pragmatic language, such as prosody or pitch, tone, and modulation (Grynszpan et al., 2008). Linking the text to the spoken word supports the reader's processing of the words and assists the reader in mirroring the style and pace of the spoken voice they are listening to when reading along with the text (Grynszpan et al., 2008). The audio option can be turned on or off at any point throughout the story.

The use of rich, strong, contrasting colors within the app is in contrast to many apps that use cartoon or one-dimensional characters. Color discrimination can be reduced in individuals with ASD, mostly in an ability to discern light and saturation (Hurlbert et al., 2011). Glenberg and Langston (1992) have explained that 'good' illustrations are able to assist less experienced readers in providing information that is not directly or explicitly written into text. The app enables readers to create rich graphic representations of the text through a 'picture builder' option (Su and Draper-Rodriguez, 2012). The graphic representations are authentically drawn and consist of several painted scenes and characters taken from the text (see Figure 8). The readers build their picture by dragging the elements at the top of the page and positioning them where they choose to place them based on their individual interpretation of the story (van Meter et al., 2006).

The 'picture builder' provides the reader with opportunities to construct their own visual understandings (see Figure 8) while working within the text. The reader is able to select specific story elements at different stages within the text, to construct new visual and mental representations of the text and integrate these images with their existing knowledge or schema (van Meter et al., 2006). When these visual images are completed, they are stored within the body of the text in the app and included in the reporting function emailed to

FIGURE 8
Screen shot in app of picture builder.

FIGURE 9
Screen shot in app of picture builder completed by student.

teachers or parents (See Figure 9). The use of visual and audio scaffolding together with the opportunity for consistent and independent practice, has been found to support the development of students' reading comprehension which, in turn, supports these comprehension processes in becoming more automatic (Woolley, 2010).

Testing in applied settings

The present research was conducted to gage the suitability of the app and the measures chosen to evaluate its key design elements and participants responses. The data provided an opportunity for adaptations and/or modifications to be made to the app and the method and procedures for evaluation. In the related field of psychosocial interventions and individuals with ASD, White et al. (2007) have advised that a preliminary study is an important and initial phase of research involving interventions and allows for the formulation and systematic examination of instruments and techniques. This may be a simple AB design as utilized by Yang et al. (2003) for enhancing social behaviors for children with autism in general education classrooms. The present study followed the same AB design (pre and post intervention) and adhered to ethical approval concerning informed consent and recruitment of participants.

Participants

Principal criteria for inclusion in the study were for students between nine and twelve years of age with a formal diagnosis of ASD and enrolled in mainstream education classes. There was an additional requirements that the participants were able to recognize and read words at or around their chronological age and this ability was confirmed by the students' regular classroom teachers prior to recruitment into the study. Exclusionary criteria for this research consisted of: a diagnosed visual or hearing impairment; other known genetic syndromes recognized to affect cognitive responses; intellectual disability; and mental illness. The aim was to be specific regarding the participants involved in the research, with the target cohort to be students diagnosed as ASD. Participants $n = 2$ recruited for the study attended the same school, and were situated within the same grade (Year) 5 and 6 class. Both participants were identified through school records as being diagnosed with high-functioning autism. Their reading levels and fluency were at age expectation as confirmed through their classroom teacher. The school principal, teacher, parent/s, and each participant provided written consent prior to the commencement of the pre-data collection phase. Both participants' names have been replaced with pseudonyms to protect their privacy. Tim was aged 12 years and six months and Sam 12 years and nine months. The researcher noted that Tim displayed signs of social impairment relative to the characteristics of autistic disorder, whereas these social characteristics were not as evident in Sam. Both participants were familiar with the use of an iPad prior to commencing the intervention. The researcher provided instructions and a demonstration on navigation of the app before supplying each participant with an iPad loaded with the intervention software.

Data collection

As part of a pre-test and post-test battery, each participant was administered the "Peabody Picture Vocabulary Test" Form B (PPVT-4; Dunn and Dunn, 2007) which measures the receptive (hearing) vocabulary of children and adults. This was followed by the "Expressive Vocabulary Test" Form B, Second Edition (EVT-2; Williams, 2007) to evaluate expressive vocabulary attainment. To rule out any phonological weaknesses which could contribute to deficits in comprehension, the "Phonological Abilities Test" (PAT; Muter et al., 1997) was administered. This test consists of four phonological awareness sub-tests, letter knowledge, and also a speech rate subtest. The students' reading comprehension levels were measured in written format using the "Tests of Reading Comprehension," 3rd edition (TORCH:3; Mossensen et al., 2003). The comprehension test chosen, 'In the Mall', is recommended for Grade (years) 5–7 levels and is classified as fictional. A comprehension test developed by the researcher was administered after the TORCH: 3. The test consisted of 24 questions that related to basic facts in the story (who, what, when, where), and nine higher level inferential questions. The participants' attitudes toward reading were measured using an adapted version of the Elementary Reading Attitude Survey (McKenna and Kear, 1990). On completion of the pre-test sessions both participants were given the app and the classroom teacher supplied with a checklist to record dates and times of engagement and any other issues such as illness that could impact upon participation. After 4 weeks, the researcher returned and collected notes the teacher and each participant. At that time, a battery of post tests were administered that varied from the pre-tests. These included the PPVT-4 and EVT-2 Forms A, and the TORCH:3 'rock pools' recommended for year 4 and classified as non-fiction. All other post-tests were the same as the pre-tests.

Results

Student one: Tim

Tim completed the app intervention in 4 weeks and explained that he really enjoyed reading the app. His positive engagement was also noted on a teacher check-list by his classroom teacher. Tim explained that he liked the story and the ability to listen to parts of the story when he wanted to, as well as do the activities as he read the different parts. In particular, he said he liked using the 'picture builder' (the function supporting visualization). He was motivated by the app and wanted to know where he could get the next story.

Results of the pre-tests indicated that Tim's receptive vocabulary (PPVT-4) was above average at a 66 percentile level. This result increased marginally on the post-test to 68%. Tim's expressive vocabulary (EVT-2) was lower than average on the pre-test at a 30 percentile level. A retest after the intervention noted that he was at 50 percentile, or age equivalence. The Phonological Abilities Test indicated that Tim had no phonological weaknesses as results were at ceiling level. Reading comprehension levels on the TORCH: 3 were recorded as average on both pre and post-intervention tests however, results on both tests indicated problems with locating and interpreting information, and understanding inferences. Scores on the app comprehension test showed a change with an initial pre-test score of 12 out of 24 (50% correct) and post-test result of 18 out of 24 (66% correct).

Student two: Sam

Sam completed the intervention in 2weeks. His teacher noted how determined he was to get through the app as quickly as possible. In week two he remarked that he would rather read his own book and stated, "I do not want to be rude or offend, but I find the app a bit childish." Sam also made these comments to the researcher when discussing his use of the app, and explained that he really enjoyed the 'picture builder' function of the app.

Results of the pre-tests showed Sam's receptive vocabulary (PPVT-4) in the upper average range at a 73 percentile level, rising slightly to 75 percentile on post-test data. Sam's expressive vocabulary results (EVT-2) were in the upper range of average at an 81 percentile level rising to 84 percentile on Post-test results which was at one standard deviation above average. The Phonological Abilities Test indicated that Sam had no phonological weaknesses as results were at ceiling level. Reading comprehension levels on the TORCH: 3 were recorded as average on both pre and post-intervention tests with results showing deficits in understanding inferences and embedded meanings. Sam's results of the app comprehension test were 16 out of 24 (66% correct) on the pre-test rising to 19 out of 24 (79% correct) on the post intervention test).

Discussion

The findings and comments from the participants involved with the study did raise some issues that needed addressing. The students' reading comprehension improvements, as measured by the students' end of intervention performance on the app comprehension test, needed to be better clarified. For instance, was this improvement on the app comprehension test caused by the students' engagement with the intervention or were the change in scores associated with an error of measurement using a non-standardized assessment tool? To address the possibility that it may be standard error of measurement associated with a test, intervention, re-test situation it is recommended add a re-test. One method to control for a standard error of measurement (Harvill, 1991) is to do a test retest of the assessment instrument before the start of the intervention within a short time span between the tests so the same test is administered under slightly different conditions. This procedure helps to identify the reliability of the test or instrument (Harvill, 1991) by establishing stable base-line data.

A second issue that arose from the study related to comments from one of the participants. This concerned his thoughts that the story was 'a little childish' and therefore not an engaging theme. Students with ASD have been noted to have a more restricted range of interest than students without the disorder (Klin et al., 2000). For example, in terms of reading and students with ASD, there is some evidence that they have more of a preference for stories which involve tangible objects, such as stories about cars and trains, in comparison to stories involving less tangible objects, such as fairy tales (Dunst et al., 2012).

Traditional thinking is that children's interests in stories change over time, with the main change from more narrative texts at primary school level, to more expository texts in secondary school (Woolley, 2010). In relation to story genres, the indications are that stories in the middle primary school have more of a focus on animals, family and sport based settings as well as fantasy and explorative stories, however, by upper primary school, students show more interest in stories that have elements of horror, adventure, science fiction, war, and mysteries (Knowles and Smith, 2005). The concern was that the text, "*blinded*" may be of more interest to students with ASD in the lower and middle primary school grades, than students with ASD in the upper primary school grades.

As a result, changes were made to criteria concerning the age range. This was amended from an initial selection age of nine years to a lower limit of seven years of age to ensure that the app story, from a reading interest perspective for the participants (Knowles and Smith, 2005), would be more age-appropriate, and at an instructional level for the majority of participants (Duke and Pearson, 2002; Woolley, 2010; Su and Draper-Rodriguez, 2012).

The task of translating pedagogical processes into app design and development created some dilemmas. For example, pedagogical approaches to teaching reading comprehension can be different from those of teaching sciences. Reviewing the frameworks and recommendations for educational apps, it was noticed that this element was sometimes implicit and described in different ways. This was evident in two areas of Walker's (Walker, 2014) rubric; authenticity and feedback. Feedback in Walker's rubric was described as needing to be 'specific, resulting in improved performance and data that is available electronically to the student and/or teacher' and authenticity where targeted skills are practiced in an authentic format/problem-based learning environment. Although feedback should be relevant to the task and authentic, without a pedagogical understanding on how to provide feedback and scaffolded support for reading it would be difficult for someone without pedagogical knowledge to create. Therefore, it is not a matter of a 'one size fits all' pedagogical approach for all apps (Papadakis and Kalogiannakis, 2019). For the purpose of designing and developing educational apps, the ideal design should incorporate an evidence-based or well established pedagogical approach aligned with a range of targeted evidence-based strategies.

It is too simplistic to believe that the mode of learning, such as mobile technologies, can be the one and only critical feature that determines learning outcomes (Kalogiannakis and Papadakis, 2017; Papadakis and Kalogiannakis, 2019). In the same way, it should not be expected that embedding learning in gaming formats will be successful despite demonstrated increases in the engagement and motivation of learners. The design and development process raised several questions concerning the complexity of synthesizing specific features that were appropriate for the app and those which were not. For example, the audio function does not link to highlighted text because this may impede the comprehension process. Letters and words within continuous text offer different kinds of informational support than when isolated (Clay, 1991). Good readers need to self-monitor their reading process and integrate and process phonological, morphological, and syntactic information simultaneously. This means making meaning not only at the word level but at the sentence and then paragraph level. When text is highlighted it places the emphasis only at the word level thus interfering with the integration process that is central to comprehension. This is particularly important for students with ASD and relates to weak central coherence and executive function theories that propose difficulties with local and global perception, the organization of information, integrating and making connections between paragraphs in text, and understanding main themes, ideas and concepts (Ozonoff et al., 1991; Mottron and Bellville, 1993; Rinehart et al., 2000).

It was important to determine exactly how to make the app engaging and motivating to promote productive learning and at the same time not overly distracting to the reader (Su and Draper-Rodriguez, 2012; Falloon, 2013; Xezonaki, 2022; Zourmpakis et al., 2022). The dilemma for development was how the app could create the 'feel' of a digital game without actually being a digital game. An example of this can be taken from gaming software where this would be achieved by reaching a certain level and then 'unlocking' the next level. This feature was re-created within the app by forcing readers to complete chapters sequentially, unlocking each with a key received at the completion of each chapter. This gave the reader a sense of achieving a next level, retaining a focus on learning activities, and at the same time ensuring that the student could not skip ahead. Similarly, the student continually works within the story context like a game and is not taken out for functions such as word meanings in dictionary or cloze activities. These considerations highlight the complex balance that exists between maintaining motivation and engagement with the educational content and minimizing distractions from other elements.

The app was not graduated in difficulty like a game, as it was designed for practice and self-directed learning. Having clear instructions and ensuring the user can feel the level of difficulty is not too high will mean they are more motivated to continue through the story (Su and Draper-Rodriguez, 2012; Walker, 2014). As a result, the tasks in the beginning chapters were not complex and required literal responses as the answers could be sourced directly from the text. This is also an important consideration for students with ASD, due to difficulties understanding inferential information (Nation et al., 2006), which relates to Theory of Mind (Baron-Cohen et al., 1985; Frith, 1991). These features are discrete and not easily observable but were still important considerations when aligning the content and features of the app to the intended user group (Newton and Dell, 2011; More and Travers, 2012). Similarly, language and concepts presented in the app were adapted from the original story to closely align with the user group. Certain words and concepts were changed in the text and audio was recorded with a native accented speaker (Churchill, 2011; Falloon, 2013). These visual and audio features were important parts of localizing the app to the intended user context (Nikolopoulou, 2007). It is common practice for developers to create apps in one context and then release internationally to attract a wider sales base using direct translation. Therefore, an educational app that may be very appropriate in one context may not be as relevant for learners in another. Considerations such as users' culture, language, or social learning contexts are not always taken into account and ensuring the learning is authentic for the learner in these ways is important (Nikolopoulou, 2007; Walker, 2014).

Conclusion

The complex issues related to design and development of the instrument (app) described in this paper show the challenges that educators face in sourcing digital educational supports that are aligned with the intended user or group. The findings here have implications for developers by reiterating recommendations from other research explaining that educational apps should employ well-established instructional strategies such as scaffolding and differential reinforcement (Duker et al., 2004; Falloon, 2013; Kalogiannakis and Papadakis, 2017; Papadakis and Kalogiannakis, 2019). This is particularly relevant for apps produced for mobile digital technologies such as tablets or iPads, as they are often used outside of formal learning contexts where learning support is not readily available.

Finally, one of the main dilemmas in the development process was to establish 'what to put in' and 'what to leave out', and what was necessary for learning and what could distract from the learning process. These are important considerations that have direct implications for those who create educational apps and for those who choose them for a specific educational purpose. Closer collaboration between developers and educators in the design and development process could negate some of the difficulties associated with producing genuine educational apps. As a result, more apps could be available that meet the educational needs of targeted populations or suitable across a range of contexts. This reinforces the importance of matching the user, the technology, and the activity (Edyburn, 2003; Odom et al., 2015) which are important considerations and can inform future research design.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by University of Tasmania Ethics Approval H0012932. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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Conflict of interest

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

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