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A Research Review: How Technology Helps to Improve the Learning Process of Learners with Dyslexia

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ABSTRACT

Dyslexia is a language disorder that leads to difficulty with words and it is the most common type of learning disability. This article presents a systematic review on the current state of assistive technologies used in improving the learning process of learners with dyslexia. A total of 25 journals articles and international conference papers published between 2000 and 2014 were included in the review. The research articles were collected from 12 databases and analyzed based on the qualitative cyclical process. A majority of the studies focused on children and adolescents. Four main themes on the types of technologies used in aiding the learning process of learners with dyslexia are derived and discussed. These include text-to-speech, eye-tracking, virtual learning environments, and games. The text-to-speech technology is the most common type of technology used by learners with dyslexia. In terms of the roles played by the assistive technologies, another four emerging themes are identified, which cover the roles of aiding reading, writing, memory, and mathematics. The review also discovers that a majority of these studies focus on the use of technologies for improving the reading ability of learners with dyslexia.

Keywords: Assistive technology; Dyslexia; Research review; Learning

INTRODUCTION

Learning disabilities are commonly accepted as "neurological disorders that can cause difficulty in acquiring certain academic and social skills" (National Center for Learning Disabilities, 2014). It is reported that over one billion people in the world have some forms of learning disabilities and about 150 million of them are school-aged students (Laabidi et al., 2014). According to National Center for Learning Disabilities (2014), there are four main types of learning disabilities, which are Dyslexia, Dyscalculia, Dysgraphia and Dyspraxia. Among these four, Dyslexia is one of the most common

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learning disabilities (Saviour et al., 2009). Learners with dyslexia often face difficulties to perform accurate word recognition, decoding, reading, spelling, speaking and writing (Lapkin, 2014).

Dyslexia is a language learning disorder that leads to difficulties in reading, spelling and phonological (Oakland et al., 1998). It is a neurological disorder and often linked to genetic condition (Chan, Foss, & Poisner, 2009). As reported by Rahmani (2011), it is estimated that four percent of the world population is affected by severe dyslexia and another six percent have mild to moderate dyslexia.

The use of information and communication technologies (ICTs) assisted learning has increased significantly, and those with learning disabilities form a portion of this population. More than a decade ago, it is estimated that in developing countries, less than ten percent of children with learning disabilities do not receive any education (Florian, 2003). Florian (2003) further asserts that even in developed countries, policies that call for greater involvement of special needs students in education seem to conflict with other educational policies that emphasis on high achievement. However, in a report by Nolan et al. (2004), the number of students with disabilities accessing Higher Education Institutions (HEIs), including professional courses has increased significantly from year to year. The rapid advancement of technologies most probably explains this change as more and more assistive technologies are introduced to widen the opportunities for students with learning disabilities to overcome the obstacles that they encounter in the traditional education systems.

Assistive technology is the technology used by people with disability that builds on individuals' strengths, compensates for their disabilities and improves their performance (Lewis, 1998). The use of assistive technology enables learners with dyslexia to complete their tasks independently and efficiently, and may subsequently, improve their academic achievement. There are specific adjustment software or devices for manipulating the computer in order to enable users to access the content on screen, command the computer and process the data (Laabidi et al., 2014). As mentioned by Laabidi et al. (2014), the specific adjustment software or devices are screen reading software, screen magnification software, braille display, alternate input devices, special keyboard, keyboard enhancements and accelerators, and alternative pointing devices.

Many articles have been published on the development of technologies to assist people with learning disabilities and there are also several recent existing reviews of the literature on this development (Desideri et al., 2013; Laabidi et al., 2014; Starcic & Bagon, 2014). However, the existing reviews emphasize on assistive technologies for various types of disabilities or special needs. Indeed, there is still a lack of major reviews that focus specifically on those with dyslexia despite the fact that dyslexia is the most common type of learning disability (Saviour et al., 2009). This review focuses on the current state of research and development on how technologies aid the learning process of learners with dyslexia.

METHODOLOGY

The databases used for data collection include ACM Digital Library, Google Scholar, IEEE Xplore Digital Library, Springer, Elsevier, Emerald Insight, Wiley Online Library, National Academy of Sciences (NAS), Taylor & Francis Group, informa healthcare, EdITLib, and The Higher Education Academy Journals.

A list of search terms was used in the search process. These include “assistive tools”, “assistive technology”, “types of assistive technology”, “learning process of dyslexic students”, “dyslexia”, “learners with dyslexia”, “people with dyslexia” and “person with dyslexia”. The search terms were combined by mean of Boolean logical operator ‘AND’ in order to decrease the scope and reduce the number of non-pertinent results. Three steps were involved in the search process. First, the titles of the retrieved papers were reviewed. The articles with unrelated focuses such as those emphasizing on physical disabilities were excluded. Then, the abstracts of all selected papers were read. The criterion for inclusion before moving on to next step is that the articles must include specific emphasis on assistive technology and dyslexia. Finally, the selected articles were read in full and analyzed.

A total of 25 journal articles and international conference papers published between 2000 and 2014 were included in the review. Table 1 shows the databases and the selected articles from the respective databases.

FINDINGS AND DISCUSSION

This section presents the review findings of the 25 selected papers. It provides an overview of the review via a matrix. This is followed by highlighting the themes that were derived from the review. Two main themes, technologies involved and the roles of these technologies, were identified.

Matrix of current research

Eleven out of the 25 reviewed papers mention the age range of the participants of their studies and it was found that the majority of them focused on children and adolescents. The review also reveals that existing assistive technologies function to improve the learning process of learners with dyslexia, particularly their reading and writing as well as improving their memory and mathematical skills.

Crystallized intelligence or the ability to use learned knowledge and experience is important in language development. Crystallized intelligence grows through during adulthood and remains relatively stable until old age (Schroeders, Schipolowski, & Wilhelm, 2014). Hence, children and adolescents with dyslexia require additional tools (assistive technologies) to improve their crystallized intelligence for language development purposes and this may possibly explain the focus of most papers on children and adolescents. Table 2 shows the matrix of findings.

Table 1: The list of papers and the respective databases

No.	Database	Paper	Total paper
1.	ACM Digital Library	Abdullah, Hisham, & Parumo (2009); Rello & Baeza-Yates (2014); Rello, et al. (2014)	3
2.	EdITLib	Dziorny (2007)	1
3.	Elsevier	Kalyvioti & Mikropoulos (2012); Malekian & Askari (2013); Rello, Kanvinde, & Baeza-Yates (2012)	3
4.	Emerald Insight	Mpia Ndombo, Ojo, & Osunmakinde (2013)	1
5.	Google Scholar	Arendal & Brandt (2005); Nelson & Parker (2004); Schiavo & Buson (2014)	3
6.	IEEE Xplore Digital Library	Ahmad, Jinon, & Rosmani (2013); Khakhar & Madhvanath (2010); Tzouveli et al. (2008)	3
7.	informa healthcare	Draffan, Evans, & Blenkhorn (2007)	1
8.	National Academy of Sciences (NAS)	Hornickel et al. (2012)	1
9.	Springer	Al-Edaily, Al-Wabil, & Al-Ohali (2013); Diraa et al. (2009); Freda et al. (2008); Moe & Wright (2013); Rekha et al. (2013);	5
10.	Taylor & Francis Group	Chiang & Liu (2011)	1
11.	The Higher Education Academy Journals	Draffan (2001)	1
12.	Wiley Online Library	Ecalle et al. (2008); Habib et al. (2012)	2

Types of technologies

The review reveals that a wide variety of assistive technologies are available to support learners with dyslexia based on their needs. Four main types of technologies that help to improve the learning process of learners with dyslexia were dervied, namely, text-to-speech technologies, eye tracking technologies, virtual learning environments and games.

Text-to-speech technologies

Text-to-speech technology is the most common assistive technology used by learners with dyslexia. Schiavo & Buson (2014) discussed the opportunities of using interactive e-Books for improving the reading skills of learners with dyslexia. Interactive e-Books allow the readers to record their voice while reading. In addition, the interactive e-Books permit the reader to listen and practise the recognition of basic units of speech within different words that aims to improve the reader's phonemic awareness as well as his or her ability to memorize and practise word recognition.

Rekha et al. (2013) developed Read-Aid, an assistive reading tool to improve reading pattern among children with dyslexia. The Read-Aid Tool consists of two simple tabs: a start tab for setting the view (font settings and number of words to display), and a read tab to read the targeted text. The intervention of Read-Aid Tool

Table 2. Matrix of 25 papers

Study / Target Population	Methodology	Participants / Age	Technology involved	Purposes
Abdullah, Hisham, & Parumo (2009) Children with dyslexia in Malaysia	Developmental work	_	MyLexics -Dual coding theory (visual and verbal) -Scaffolding teaching strategy	Reading and writing -helps children with dyslexia read and write in Malay language (alphabets, syllables and words)
Ahmad, Jinon, & Rosmani (2013) Children with dyslexia	Developmental research	Special education primary school teachers (for the evaluation of MathLexic)	MathLexic (interactive multimedia application) -number recognition -number sequence - mathematical symbols -mathematical operations	Mathematical learning -improve understanding -improve mathematical skills
Al-Edaily, Al-Wabil, & Al-Ohali (2013)	Experimental research	14 female children (7 with dyslexia and 7 without dyslexia) 10 to 12 years old	Dyslexia Explorer -screening system that uses eye tracking technologies	Analyze visual patterns of reading Aggregate measures of eye gaze intensity and patterns
Arendal & Brandt (2005)	Pilot study	18 adults with dyslexia	@lphatec -computer assisted reading and writing	Reading and spelling -improve reading skills and spelling of coherent words significantly
Chiang & Liu (2011)	Qualitative research	15 volunteer male students from 10 high	Assistive reading software -Kurzweil 3000	Reading and spelling -pronunciation

Students with learning disabilities (dyslexia)	-semi structured individual interviews	schools located in Taipei		-comprehension
Diraa, Engelen, Ghesquiere, & Neyens (2009) Students with dyslexia	Experimental research	32 participants (17 students for Kurzweil 3000 and 15 students for Sprint) 19 to 38 years old	Special purpose software -Kurzweil 3000 -Sprint	Reading -improve reading speed -detect mistakes
Draffan (2001) Learners with dyslexia	Exploratory research	_	Large, talking calculators	Mathematical learning
Draffan, Evans, & Blenkhorn (2007) 1000 candidate participants selected from the customer records of Microlink PC(UK) Ltd.	Quantitative and qualitative study	475 accepted telephone interviews and 455 were identified to have dyslexia	General purpose hardware Special purpose hardware General purpose software Special purpose software	Improve the learning process in general
Dziorny (2007) Students with dyslexia	Qualitative study	_	Digital Game-based Learning (DGL)	-help students to develop a framework for conceptual understanding -assist problem solving -improve students' motivation and interest
Ecalle, Magnan, Bouchafa, & Gombert (2008)	Experimental research	30 children with dyslexia (26 for experiment 1 and 4 for experiment 2)	Computer game incorporating an audio-visual phoneme discrimination task with ortho-phono-logical units	Improve literacy skill

Freda, Pagliara, Ferraro, Zanfardino, & Peppino (2008) Students with dyslexia	Developmental work	_	LaTex -parser (enables LaTex to associate each mathematical object with its matching spoken mathematical language	Mathematical Learning -read technical and scientific documents -understand the spatial structure of formulas and matrices -write paper with technical and scientific content in electronic form
Habib, Berget, Sandnes, Sanderson, Kahn, Fagernes, & Olcay (2012)	Exploratory research Qualitative data -semi structured interviews Quantitative data -questionnaire	12 adults with dyslexia involved in semi-structured interviews and 24 adults (12 with dyslexia and 12 without dyslexia) involved in questionnairesurvey 19 to 36 years old	Virtual learning environments (VLEs) -VLE Fronter -eye-tracking device -talking word processer	Writing -save time (spell-checker and grammar checker highlight mistakes) -identify and correct errors
Hornickel, Zecker, Bradlow, & Kraus (2012)	Experimental research	38 normal hearing children with dyslexia (16 female and 22 male) – divided into an experimental group (using FM systems) and a control group 8 to 14 years old	Assistive listening devices (classroom FM systems)	Reading -improve auditory attention (auditory brainstem responses to speech became more consistent) and phonological awareness
Kalyvioti & Mikropoulos (2012) Undergraduate students of University of Ioannina, Greece	Developmental research	Control group: 7 students without dyslexia (3 male and 4 female) Experimental group: 7 students with dyslexia (4 male and 3 female)	VIRDA-MS (Virtual Reality Dyslexia Assessment-Memory Screening)	Help to cope with daily memory challenges -tackling short-term memory and long-term memory

Khakhar & Madhvanath (2010) Children with dyslexia	Developmental work	_	Jollymate (emulate the Jolly Phonics system) -Lipi Toolkit -Lipi IDE	-improve reading and writing skill of children with dyslexia
Malekian & Askari (2013) Elementary school second grade male students with dyslexia in Aligudarz city	Quasi-experiment research	40 randomly selected male students with dyslexia Experimental group: 20 students Control group: 20 students	Multi-sensory game	Reading -improve word reading -reduce the difficulty of word chain -improve text understanding -reduce the problem of phonemes omission
Moe & Wright (2013) 497 of Nota's members (the user group)	Qualitative research -telephone survey	200 randomly chosen children and adolescences (the comparison group) 12 to 16 years old	Hybrid audio books	Reading -improve reading skill
Ndombo, Ojo, & Osunmakinde (2013) People with dyslexia at all age groups (children and adults)	Peer-reviewed paper	_	Intelligent integrative assistive system -RL Machine Learning (game middleware) Algorithm -HMM Machine Learning Algorithm (phonological and reading barriers) -PPM Machine Learning Algorithm (writing barriers)	Phonological -improve the skill of syllable awareness, onset-rime awareness and phoneme awareness Reading skill -improve the skill of word recognition Writing skill -reduce the number of mistakes
Nelson & Parker (2004)	Replication of O'Hare study	Web based survey: 220 respondents (68% with dyslexia)	Voice Recognition (VR) software	Writing -improve spelling and writing

		Chronological age ranging from 12 to 14 years old Reading age ranging from 9 to 10 years old		-save time from typing and handwriting
Rekha, Gollapudi, Sampath, & Indurkhya (2013)	Experimental research	15 children – 8 boys and 7 girls (12 with dyslexia and 3 without dyslexia – for comparison and evaluation purposes) 8.5 to 11.5 years old	Manual-masked technique Read-Aid Tool	Reading -improve reading speed -improve reading comprehension scores -decrease reading errors
Rello & Baeza-Yates (2014)	Experimental research -online questionnaire -semi-structured interview	Experimental group: 32 participants with dyslexia (18 female and 14 male) Control group: 38 participants without dyslexia (24 female and 14 male) Usability evaluation: 12 participants with dyslexia (3 female and 9 male) 6 to 52 years old (mean = 23.15 years)	DysWebxia -CASSA (Context Aware Synonym Simplification Algorithms)	Reading -improve reading performance -provide suitable and simpler synonyms for complex words
Rello, Bayarri, Otal, & Pielot (2014) 54 potential participants with literacy difficulties	Quantitative research -questionnaire -one pre-tests and two post-tests	48 children with dyslexia (29 girls and 19 boys) 6 to 11 years old (mean = 8.79 years)	DysEggxia (game designed to support spelling acquisition)	Writing -improve spelling skills -reduce spelling errors

Rello, Kanvinde, & Baeza-Yates (2012)	Quantitative and quantitative research -semi-structured interviews, questionnaire, and think aloud technique	Target group: 22 native Spanish speakers with dyslexia Control group: 22 participants without dyslexia 13 to 37 years old (mean = 21.1 years) Control group mean age = 21.27 years	IDEAL eBook Reader -text-to-speech technology -eye-tracking devices	Reading
Schiavo & Buson (2014) Learners (readers) with dyslexia	Empirical research	_	Interactive e-books	Reading -improve in memorizing -practise word pronunciation -improve phonemic awareness
Tzouveli, Schmidt, Schneider, Symvonis, & Kollias (2008) People with dyslexia	Developmental work	_	AGENT-DYSL system -recording and analysis component -knowledge infrastructure -profiling and content presentation component	Reading -supports the use of any teaching material used in classroom education -provides the required additional reading assistance

shows children's improvement in terms of reading speed, comprehension scores, and reduction in reading errors.

Rello et al. (2012) presented IDEAL eBook Reader, an ebook reader that displays ebooks in a more accessible method based on the reader's needs. IDEAL eBook Reader enables reader to customize the parameters (font styles, color, font size, brightness contrast, and spacing) for greater comfort while reading. It also provides DysWebxia default setting which sets all the parameters specifically for learners with dyslexia. Besides that, IDEAL eBook Reader supports text-to-speech technology that allows readers to listen to the eBook content in the form of audio. This tool is compatible with a wide range of text-to-speech engines that support multiple languages. In addition, the text being read out loud is highlighted so that readers can always follow the reading.

An assistive reading software, Kurzweil 3000 was used as an intervention tool to improve reading speed, spelling, pronunciation and comprehension (Chiang & Liu, 2011; Diraa et al., 2009). This Kurzweil 3000 software can access both printed and electronic documents. Besides Kurzweil 3000, Diraa et al. (2009) also employed Sprint, another assistive reading software in their study. Sprint adds speech and language technology to a computer and reads the available text on the computer out loud. Sprint is very useful in detecting mistakes because it is able to read aloud when text is entered to the computer.

Khakhar & Madhvanath (2010) elaborated on Jollymate, a self-learning device for children with dyslexia. Jollymate emulates the Jolly Phonics system in teaching letter sounds and letter formation. In this case, Lipi IDE tool from the Lipi Toolkit project is used to recognize handwritten characters and detect mistakes when a character is written incorrectly. Additionally, Ecalle et al. (2009) used a computerized 'talking book' program that reads aloud words and these words appear on a window of the screen.

Eye-tracking Technologies

Eye-tracking technology is an indirect way to improve the learning process of learners with dyslexia. Al-Edaily et al. (2013) designed a screening system for dyslexia using an eye tracking technology called "Dyslexia Explorer". Dyslexia Explorer aims to help specialists in analyzing the visual patterns of reading and aggregating the measures of eye gaze intensity and patterns. Firstly, Dyslexia Explorer captures the eye movement when the learner is reading some scripts. Then, a Fixation Filtering Algorithm is used by the system to filter the gaze readings to fixations and saccades. Finally, the system analyzes the duration of fixations and spatial distribution. Hence, eye tracking technology enables specialists to identify reading problems and phonological difficulties, particularly for the purpose of designing effective remedial programs for learners with dyslexia.

In the study by Habib et al. (2012), an eye tracking device is used to record the participants' eye movement during their interaction with a virtual learning system and the interview session. It facilitates the researchers' observation process. In another experimental study by Rello et al. (2012), an eye tracker (Tobii T50) was used for recordings when the participant read in silence the passages. The eye tracking data was then analyzed using Tobii Studio and the R 2.14.1 statistical software. Lastly, the mean of the duration of fixations and number of fixations were determined. All in all, eye tracking technology has indirectly contributed to the learning process of learners with dyslexia.

Virtual Learning Environments

Habib et al. (2012) defined a virtual learning environment as a software system designed to support teaching and learning.

In their study on the effect of the increased use of virtual learning environments on the learning experience of learners with dyslexia, it was found that such virtual learning environments improved their writing skills and writing activities. In addition, the word processor used in the virtual learning environment increases writing efficiency because it provides spellchecker and grammar checker that highlight mistakes that users would have not otherwise noticed.

Kalyvioti & Mikropoulos (2012) designed and developed VIRDA-MS (Virtual Reality Dyslexia Assessment-Memory Screening) virtual environments to improve the memory performance of adults with dyslexia by using the Superscape 5.10 software package. In this study, three memory systems were examined, namely short-term memory, working memory and long-term memory. The "Direct Visual Sequence Recall" task was employed in the short-term memory test; "Direct and Reversed Visual Sequences Recall" task in the working memory test and "Visual Stimuli Synthesis" task in the long-term memory test. The results of the study indicates that learners with dyslexia and learners without dyslexia performed similarly well in the test and subtests for short-term memory, working memory, and long-term memory.

Games

Rello et al. (2014) presented DysEggxia, a game designed to improve the spelling skills of children with dyslexia. The writing errors found in the texts written by children with dyslexia were used to create training exercises prior to integrating these exercises in DysEggxia. DysEggxia contains 5000 exercises with different levels of difficulty for children with dyslexia. These exercises can be categorized into six types of errors that frequently appear in the analyzed text. Malekian & Askari (2013) have done a survey on the effect of multi-sensory games among male students with dyslexia. The purpose of using multi-sensory games is to assist reading and spelling among children with dyslexia because they are unable to learn letters and words from common instructions at schools and require special instruction to attract their attention. The results of the survey indicate that multi-sensory games are effective in reducing the problem of reading as well as understanding words and text.

Besides, the study by Ecalle et al. (2009) shows that literacy skills of children with dyslexia can be improved by undergoing training using a computer game that incorporates an audio-visual phoneme discrimination task with phonological units presented simultaneously with orthographic units. The computerized 'talking book' program (animated multimedia talking book) used in the study allows children to read texts on the computer screen with speech feedback. Game-based assistive technology is also being used in higher education to assist learners with dyslexia. Dziorny (2007) discusses the effect of Digital Game-based Learning (DGL) for learners with dyslexia in higher education. In DGL, learners with dyslexia can create their own framework to enhance their understanding. In addition, DGL allows learners with dyslexia to solve problems and explore new materials by using their own creativity instead of relying on written or verbal communications. Furthermore, DGL presents interesting and motivational learning platforms for learners with dyslexia, hence inspiring them to work through the difficulties in their learning process.

Roles of assistive technologies

This section discusses the four main themes that revolve around the roles of the assistive technologies, which include providing aid for reading, writing, memory, and mathematical learning.

Reading

Fifteen out of twenty-five studies (Abdullah et al., 2009; Al-Edaily et al., 2013; Arendal & Brandt, 2005; Chiang & Liu, 2011; Diraa et al., 2009; Hornickel, 2012; Khakhar & Madhvanath, 2010; Malekian & Askari, 2013; Moe & Wright, 2013; Ndombo et al., 2013; Rekha et al., 2013; Rello & Baeza-Yates, 2014; Rello et al., 2012; Schiavo & Buson, 2014; Tzouveli et al., 2008) indicate that the use of assistive technologies to improve reading among learners with dyslexia. It is noticeable that reading can be improved either directly or indirectly.

The most commonly used assistive technologies to improve reading directly are the text-to-speech technologies. Text-to-speech technologies enable learners with dyslexia to listen and practise repetitively on the targeted words or texts. Hence, it can improve their word pronunciation, reading speed and decrease reading errors. Apart from that, text-to-speech technologies can improve the phonological awareness, phonemic awareness and reduce the problem of phonemes omission. The assistive technologies employed in improving reading skills indirectly are the eye tracking technologies. Eye tracker is used to capture the eye movement during the reading session of learners with dyslexia. The collected data are analyzed and the duration of fixations is determined. Conclusively, it is prevalent that eye tracking technologies allow specialists to figure out the different patterns of reading problems among learners with dyslexia and find a suitable solution for each category of patterns.

Writing

As discovered in this review, writing is another important purpose for the use of assistive technologies. The technologies employed in improving the writing skills of learners with dyslexia include voice recognition software (Nelson & Parker 2004), computer games (Rello et al., 2014) and virtual learning environments (Habib et al., 2012). While text-to-speech technologies translate written text to spoken speech, the voice recognition software translates spoken speech or words into written text on screen for learners with dyslexia (Nelson & Parker, 2004). With such assistance, it improves their spelling and writing as well as efficiency because typing is not required with such voice recognition software. Furthermore, spellchecker helps to identify and correct errors, hence reduces the number of mistakes made by learners with dyslexia.

Memory

Information and Communications Technologies (ICT) and Virtual Reality (VR) technology offer safe and controlled environments that provides high level of interactivity, immediate feedback, and contribute to the improvement of visual processing skills and short-term memory (Phipps et al., 2002). Kalyvioti & Mikropoulos (2012) developed virtual reality environments to improve the memory performance of adults with dyslexia. Three memory systems (short-term memory, working memory and long-term memory) were examined in the study. The study reveals that both learners with dyslexia and learners without dyslexia showed similar memory performance with the aid of the virtual reality learning environments.

Mathematical learning

Children with dyslexia face problems in seeing words, writing numbers in inverted form, and solving arithmetic calculations. There are four studies that discussed the assistive technologies used in improving the mathematical skills of learners with dyslexia. Ahmad et al. (2013), for example, designed MathLexic, an interactive multimedia application to improve the mathematical learning among learners with dyslexia. MathLexic provides exercises to improve the performance of children with dyslexia in various aspects such as number recognition, number sequence, mathematical symbols and mathematical operations.

Freda et al. (2008) and Draffan (2001) conducted studies on the reading and writing of mathematical representations with the support of speech synthesizers. Nowadays, word processors with integrated speech synthesizer are widely used by those with reading and writing disabilities. However, word processors are not utilized in the mathematical field because the screen reader that supports the speech synthesizer is not able to interpret non-text elements such as images, symbols and graphics. With the aim of overcoming such limitation, Freda et al. (2008) developed a software that enables learners with dyslexia to read technical and scientific documents and understand the spatial structure of formulas and matrixes. LaTex is a textual markup language that is being used as a transitional language. In the software developed by Freda et at. (2008), LaTex is integrated with a parser to associate each mathematical object with its matching spoken mathematical language to produce speech in natural language.

CONCLUSION

In general, this study provides a synthesized view on the current state of assistive technology used in improving learning process of learners with dyslexia and keep readers up to date on the suitable types of technologies used for learners with dyslexia. Specifically, the study reveals four main themes on the types of assistive technologies used in aiding the learning process of learners with dyslexia, namely, text-to-speech technologies, eye-tracking technologies, virtual learning environments, and games. In addition, another four main themes were derived based on the roles of these assistive technologies which include aiding reading, writing, memory, and mathematical learning. The review also discovers that a majority of the papers reviewed set their focus on younger learners with dyslexia. Hence, future studies may place emphasis on older learners with dyslexia as dyslexia does not go away over time (Foundations Tutoring, 2013). Future development may also focus on building assistive technology devices with open hardware. Hunley (2015) mentions that the basic tenets of open hardware are openness and usability that enable the creation of more customized and personalized assistive technology devices. Open hardware allows the features of assistive technology devices to be added or removed as the learners' needs change with age and ability, thus extending the life of their devices (Hunley, 2015). All in all, this review has provided valuable insight on the current trends pertaining to the use of assistive technology in helping the dyslexics to gain better learning experiences.

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