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SUPPORTING STUDENTS WITH DYSLEXIA IN LEARNING TO PROGRAM – WHERE TO START? A SYSTEMATIC LITERATURE REVIEW

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Abstract

Computing Science students with dyslexia can face additional challenges when learning to program. Such challenges are likely to impact student motivation and success, which is antithetical to developing an accessible and inclusive curriculum. This paper identifies gaps in existing research through a systematic literature review and highlights where students with dyslexia could benefit from tailored support by completing a thematic analysis comparing the challenges faced by students with dyslexia and challenges for novice programmers. This constitutes the first step in research to explore differences in learning to programme for students with dyslexia. The paper concludes by considering how this analysis can inform future pedagogical research to support students with dyslexia in learning to program.

Keywords: education, accessibility, dyslexia, programming

1 INTRODUCTION

Dyslexia is traditionally characterised by difficulties with reading, spelling, memory retention and phonological impairments, all classed as neurological disabilities. The role that dyslexia plays in impeding learning development in a school context is well recognised. As argued by Taylor et al., the majority of this research focuses on learning with dyslexia in a secondary education context [42]. However, there is limited research regarding students in higher education and how dyslexia impacts learning in this context. While there has been a variety of studies discussing and investigating the challenges many students face when learning to program, for example struggling with basic structure concepts, understanding syntax, and applying abstract concepts ([44], [33], [36]), there is limited research exploring the additional challenges faced by dyslexia.

Castro et al. note that students with dyslexia struggle to learn common textual programming languages, more so than students without dyslexia [7]. Research has shown that students with dyslexia who are learning to program struggle more with key concepts such as Object Orientated programming and understanding syntax [25]. Consequently, given the need to ensure an inclusive curriculum, we must move beyond the usual accommodations of additional time and consider how we can target support for students with dyslexia in learning to program.

2 RELATED WORK

Researchers have found that students with dyslexia are more likely to study science subjects [20]. Stienen-Durand and George found that students with dyslexia can be particularly creative and innovative in their thoughts and planning processes [41]. This may partially explain why Computing Science appeals to students with dyslexia because of the creative aspects and problem-solving skills involved in the subject. However, despite the appeal of computing and programming to students with dyslexia, research shows such students struggle to achieve their full potential [24]. The challenges faced by students with dyslexia can vary depending on the individual [15]. Some challenges they may face include misspelling variable names and difficulties with syntax terms, short-term memory, and organisational skills [31]. This may partly be due to the textual nature of programming languages as dyslexia reduces the ability to process information, therefore affecting students with dyslexia's reading and processing abilities [3].

Additionally, McChesney and Bond found that programmers with dyslexia struggled with comprehension when the code was overcrowded [25]. Overcrowding occurs when there is not enough white space between words and the code is placed together tightly making it difficult for individuals to separate them. It was also noted that those with dyslexia have a more "sluggish attention...with deficits in spatial positions". Students appeared to understand more when reading short and succinct code [25]. This may well be because of short-term memory challenges associated with dyslexia ([41],[3]). There is some evidence that students with dyslexia underperform when compared with other novice programmers [38].

However, research in this area is limited. Novice programmers can still struggle, particularly with Object Oriented programming, learning syntax and understanding abstract concepts ([33], [40], [6]). While there is research discussing the challenges that students generally face learning to program and the problems dyslexic students face in learning in general, the research is limited regarding challenges dyslexic students face when learning to program.

This paper aims to add to the existing work in this area by completing a systematic literature review to identify and compare common challenges for students with dyslexia learning to program when compared with their peers. This highlights where students with dyslexia may benefit from additional tailored support when learning to program and can be used to guide further research. The research questions explored in this paper are as follows:

RQ-1: What are the commonly identified challenges in learning to program, learning to program with dyslexia, and general learning for those with dyslexia in higher education?

RQ-2: What are the differences, and the similarities of challenges faced by students learning to program who have dyslexia, compared to the challenges faced by students without dyslexia?

To address these research questions, we start by completing a systematic literature review to identify common challenges which impact novice programmers and novice programmers with dyslexia. We then report on a thematic analysis and compare the similarities and differences.

3 METHODOLOGY

This systematic literature review follows guidance by Alexander [2] and includes identifying critical questions (RQ1 and RQ2 defined above), defining a search approach including search terms, establishing selection criteria, consolidating and summarising results and interpreting and presenting outcomes [2]. The sources used to conduct the review included the IEEEXplore Digital Library, ERIC, The ACM Digital Library, Science Direct, Taylor and Frances Online and Google Scholar. Furthermore, an academic librarian's expertise was used to validate databases and ensure search terms used were appropriate and exhaustive.

The remainder of this section is split into three categories; challenges in learning to program, challenges faced generally for students with dyslexia, and challenges in learning to program for students with dyslexia. Within each of these categories, the search criteria and an overview of the qualifying research is provided. In Section 3.4 an overview of the method used to consolidate and summarise results is presented.

3.1 Challenges in Learning to Program

To compare the challenges students with dyslexia face when learning to program in higher education, it was important to research the challenges that all students face when learning to program.

3.1.1 Search Terms: The search terms used were "students learning to program", "challenges students face when learning to program" and "programming challenges". The term student was selected as within a UK context student typically refers to higher education. This focused results more on higher education as this was the scope of the research, any results referring to earlier education were disregarded. 'Challenges' was selected as many of the key works in this area use this terminology instead of difficulties e.g. see research by Butler and Morgan [6].

3.1.2 Inclusion and Exclusion Criteria. The papers that were included met the following criteria. They had to focus on the specific challenges students face when learning to program to have a standard set of challenges to compare and evaluate between students and students with dyslexia when learning to program. Furthermore, the focus of this research does not cover developing tools to mitigate the challenges.

The papers that were excluded from the criteria are as follows. Any that focused on analysing new tools to help students learn to program were out of scope. Additionally, papers that had a focus on technical elements of programming languages and their potential impact on learning, as these papers focused too much on how different individual programming languages affect learning. Papers that focused on early years education emphasised issues young children face when learning computing were also disregarded as they were out of scope. Finally,any that focused on e-learning and hybrid teaching as well as AI programming challenges were excluded. These papers did not discuss the challenges students faced when learning to program but the challenges of e-learning, hybrid teaching and AI. Any papers already identified from an alternate source were also excluded.

After the search criteria, inclusion criteria and exclusion criteria had been applied, the title, abstract and keywords were then reviewed to perform a final check that the identified research fell within the scope of the research. Any unsuitable papers were then discarded.

From the above criteria, 200 were found in the ACM digital database and of those 12 were found suitable. Within Google Scholar 85 were found and 6 were suitable, from Science Direct 7,583 were found and 2 met the inclusion criteria, many of the papers had been found in previous searches and were repeats. Using IEEEXplore returned 12,901 papers, with 5 papers meeting the suitable inclusion criteria. Many were excluded due to the papers already being found in previous databases. Consequently, a total of the 23 papers and books met the above inclusion criteria and were then included in the analysis.

3.2 Dyslexia Learning Challenges

To gain a deeper understanding of the challenges that face students with dyslexia, research about the general challenges of learning with dyslexia was reviewed.

3.2.1 Dyslexia Learning Challenges Search Terms. The search terms used were “dyslexia and learning” and “dyslexia in higher education”. These terms were chosen to focus on the learning challenges and coping strategies that students with dyslexia use in higher education. This search term returned many results; however, many were deemed out of scope for the review as determined by a review of the title and abstract, e.g. such papers were focused on medical diagnosis.

3.2.2 Dyslexia Learning Challenges Inclusion and Exclusion Criteria. The papers that were discarded in this category were any that focused on the teaching pedagogies rather than the challenges students face. Additionally, papers that focused on other learning difficulties such as dyscalculia and dyspraxia were excluded as well as those with a clinical or medical focus such as diagnosis and interventions.

The papers included focused on students with dyslexia and the challenges and issues they face when learning. After the search criteria, inclusion criteria and exclusion criteria had been applied, the title, abstract and keywords were then reviewed to perform a final check that the identified research fell within the scope of the research. Any unsuitable papers were then discarded. A total of 12 papers met the above criteria and were included in the analysis. 200 papers were found in the Google Scholar database and 5 of these were deemed acceptable. From Taylor and Francis there were 5000 results returned of those 5 met the inclusion criteria. Further to using databases for information on general challenges facing students with dyslexia papers and information from the British Dyslexia Association, Dyslexia Scotland and International Dyslexia were used to gather information.

3.3 Dyslexia Challenges in Learning to Program

3.3.1 The search terms used were “dyslexia and programming”, “dyslexia and computing science”, “computing science and learning difficulties”, “dyslexia and science”, and “dyslexia and maths”. The terms "dyslexia and programming" were used as these are the keywords and subject matter of this research. However, this returned few results and consequently was expanded to include "dyslexia and computing science". This returned many of the same results as "dyslexia and programming" and so "computing science and learning difficulties" was applied. This is because dyslexia is a learning difficulty [3] and sometimes is included in papers with other learning difficulties. This term returned a small number of results; however, some were repeated from the previous searches. Finally, "dyslexia and maths" and "dyslexia and science" were used as search terms, as these subjects can include programming. Thus, these search terms were used in case any papers explored dyslexia and programming but were not titled as such. These search terms returned a limited number of results, again mostly repeating from other search terms, and were included in case anything had been overlooked from the original search terms.

3.3.2 Inclusion and Exclusion Criteria. The papers that were discarded included any which met the following criteria. If they had a focus on clinical, medical diagnosis or the physiology of dyslexia. These were excluded because the focus of this paper is the challenges of dyslexia and not the medical hypothesis. Additionally, any that lacked computing focus or analysed the use of technology to diagnose/test for dyslexia were excluded. For example, machine learning is applied to eye-tracking data to assess individuals whilst reading.

The inclusion criteria covered any papers that investigated the challenges students with dyslexia face when programming and those focused on teaching students with dyslexia to program. After the search criteria, inclusion criteria and exclusion criteria had been applied, the title, abstract and keywords were then reviewed to perform a final check that the identified research fell within the scope of the research. Any unsuitable papers were then discarded.

From the IEEExplore database, 163 papers were found, with 3 meeting the inclusion criteria. There was a total of 29 papers found in Google Scholar of these 3 were suitable with some being repeats from the previous database. Additionally, from Science Direct 7,431 papers were found however the majority of them had a medical focus, from this database 2 were found suitable. The ACM Digital library returned 200 papers and 6 of them met the inclusion criteria. Most papers found were unsuitable. A total of 11 papers were determined as appropriate for inclusion in the analysis for this category, including the seminal work by Powell et al. This supports the argument that further research in this area would be beneficial.

3.4 Analysis Methodology

Having identified the appropriate literature, the next step was to analyse the papers in each category to identify common challenges for students throughout the literature. To do so, a thematic analysis approach as defined in Clarke and Braun was applied [8]. The following steps were applied to each category of research: read the paper in full, become familiar with the research, codify the data to identify challenges, agree codification between researchers and identify themes and finally review, analyse and report the themes. The themes from each set of papers were compared to establish any commonalities and differences which may exist. The results of this analysis are reported in the next section.

4 RESULTS

To address research question 1, the thematic analysis method outlined in Section 3.4 was applied to each of the categories, learning to program, general learning with dyslexia, and learning to program with dyslexia. Having identified the codes and then extracted themes within the research across each of these categories, the literature was then analysed once more to apply themes and identify their frequency. The challenge themes and their corresponding frequencies are outlined in Tables 1,2 and 3 respectively. The analysis within each category is addressed in turn below.

4.1 Learning to Program Themes

A total of 23 papers were included in the analysis for this category. The most frequent theme across this research (as seen in Table 1) was difficulty with understanding and applying basic concepts.

This is seen in research by Putnam et al. which provided students with a code tracing exercise and identified that students struggled with this due to a lack of comprehension of basic concepts [32]. Research by Fleury explored elements which caused difficulty for novice programmers by providing multiple similar programs and asking students to evaluate which would correctly execute. The research found that students struggled with understanding parameters and variable allocation. Other instances which aligned with this theme include Corney et al. [10], Grover et al. [18] and Qian et al. [33].

The second most frequent theme was the students' ability to design programs to solve a task. This can be seen in Robins et al. who presented an analysis of research comparing how novice programmers and expert programmers approach designing software [36]. Robins et al. identified that novice programmers design code line by line, not considering the larger picture. In contrast, experts design code in larger chunks. Also, as Medeiros et al. states in a literature review on teaching and learning programming in higher education, students who have adequate problem-solving skills often struggle with turning their pseudo code into a functioning computer program ([36],[32],[23]). This may be partly due to students relying too much on previous work to aid them in solving a new task which instead limits thinking as argued by Boulay [5].

The third most frequent theme was focused on understanding abstract concepts, as was explored by Lahtinen et al. where students and teachers were surveyed on what they believed was the best way to learn programming and what aspects of programming students struggle with. The programming concepts students struggled with specifically across this theme include recursion, pointers and references and abstract data types ([44],[19],[26]).

The remaining challenge themes are very closely matched in the frequencies. These themes were as follows; following program structure, object-oriented programming, learning syntax and learning to debug code.

Milne and Rowe discuss the challenges of understanding the structure of a program. This paper surveyed the views of students and tutors on the topics students struggle to learn when programming. Using this questionnaire, they created two tables displaying the survey results. From this survey, programming structure was perceived to have a higher difficulty level than the other challenges, as also evidenced in papers [16], [23], [33] and [36].

Holland et al. identified several misconceptions students experience with Object Oriented programming concepts such as polymorphism, classes and inheritance. The authors then implemented an intervention to mitigate these challenges by flipping the order of delivery. Instead of providing a lecture discussing the concepts then providing code examples, the authors switched the order and provided concrete examples first then asked students to replicate the structures with a different problem [21]. However, this provided no notable improvement on student understanding of these topics. Object oriented programming was also evidenced as a struggle in these papers [11], [33], and [4].

Dorn et al [12] discussed how students struggle with learning syntax, evidenced in their paper by carrying out a similar survey template to Milne and Rowe. The paper by Olipas used a phenomenological approach to determining the challenges faced by students learning to program. One of the main results found was students learning to debug their code [28] this was also reflected in [36] and [11].

Table 1: Learning to Program Themes

Theme	Theme Frequency
Learning Syntax	11
Design programs to solve tasks	13
Learning to debug code	9
Learning Object Oriented Programming	10
Difficulty with the basic concepts	15
Difficulty following program structure	11
Difficulty with understanding abstract concepts	12

4.2 Learning with Dyslexia Themes

A total of 12 papers were included in this category. The most frequent theme in this category concerned short-term memory challenges [30]. This means that such students can find it difficult to memorise new information. This is supported by [3] which lists one of the signs of dyslexia as short-term memory problems, [20]. Memory issues can lead to further problems, as discussed by Jordan et al. [22].

The second most frequently reported theme was a tie between reading and spelling problems as was discussed by Wolf [43]. The author's book discusses and investigates the main challenges of dyslexia. The author established that slower reading speeds and processing abilities were common in people with dyslexia. This was also supported by [34] and [13].

The third most frequently reported theme is also a tie between two themes: reading data in sequence and phonological challenges. The phonological challenges that dyslexic individuals face is reading aloud and processing new word sounds as evidenced by Griffiths [17]. This is also discussed in [34], [22], and [3]. The least common theme was the processing time it takes dyslexic individuals to read and understand texts as discussed by Pfeifer et al. [29] This was also discussed in [39] and [22]. Pfeifer et al. investigated what students felt were the main learning challenges faced when in higher education.

Table 2: Dyslexia Challenges in Learning Themes

Challenge	Theme Frequency

Short term Memory Challenges	6
Spelling challenges	5
Reading Challenges	5
Processing time	3
Reading data in sequence	4
Phonological challenges	4

4.3 Learning to Program with Dyslexia Themes

A total of 11 papers were included in this category, the themes are provided in Table 3. The most frequent theme in this category is difficulty remembering and processing new information. Mahajan et al. explored how the effect of dyslexia made learning new programming concepts a challenge, they investigated the challenges students with dyslexia faced as part of their research into new teaching methodologies. This theme also arose in works by Saraee et al. [38] and Castro et al. [7].

The second most frequently reported theme was learning the syntax of programming languages as this was discussed in a paper by Powell et al..[31] In this seminal paper Powell et al. interviewed seven people with dyslexia who went on to careers in computing science. From the interviews, Powell et al. extrapolated some of the challenges such individuals faced when learning to program. This theme is also discussed in [24] and [38].

Table 3: Students with Dyslexia Programming Challenge

Challenge	Theme Frequency
Learning Syntax	6
Forget names and factual information	4
Difficulty remembering new information and processing information	8
Struggle with processing sequential data	5
Difficulty with word crowding	5
Struggle to communicate knowledge	2
Struggle with systematic testing	2
Struggle to break problems down	2

The third most frequently reported theme was a tie between difficulties with word crowding and processing data in sequential order. In a paper by McChesney and Bond that used eye-tracking software to track how students with dyslexia read code, researchers found that students with dyslexia find it challenging to read and understand code that does not have enough white space between words.[25] This is also addressed in [15], [24], and [7]. Powell et al. mentions that students with dyslexia find it challenging to process data in a sequential order [31]. This can make following code examples a struggle, this was also reflected in [24].

The remaining themes are closely matched in frequency. As Stienen-Durand and George states, students with dyslexia can have trouble with remembering variable names and factual information [41], this paper researched the challenges students with dyslexia face and the pedagogical methodologies to assist the students with dyslexia. This could be related to memory problems as discussed in [31] and [9]. Stienen-Durand and George also state that dyslexic students struggle with communicating their previous knowledge, breaking problems down into manageable parts and tracing errors in the code. This is also reflected in [31], [24] and [29].

4.4 Comparing and Contrasting Themes

Having now identified the common themes in each category to address RQ1, the next stage was to identify similarities and differences between the challenges students and dyslexic students face. Based on the thematic analysis detailed above, the themes were reviewed by the researchers to determine possible connections or equivalences between the general themes and the dyslexia themes. The resulting comparison combined with the analysis below attempts to address RQ2.

From the thematic analysis there were nine differences that dyslexic students struggled with compared to students. The difference identified are forgetting names and factual information, difficulty with word crowding, difficulty remembering new info and processing information, struggle with sequential data, struggle to communicate knowledge and struggle with organisational skills. In contrast the challenges that students and dyslexic students appear to share are understanding new terminology, difficulties with syntax, systematic testing, and problem solving. These are discussed in more detail below.

4.4.1 New Terminology. Difficulty understanding and reading new terminology may be linked with the challenges of learning Object Orientated concepts because Object Orientated as a subject itself can cause many difficulties for those without dyslexia as was discussed in the previous research informatics ([33],[36]). In addition, there is the challenge of struggling to understand new terminology ([3], [34]). Therefore, the combination of a difficult subject and the dyslexic brain having to process new information means it takes more time for the dyslexic student to learn the subject. This is where additional help such as extra notes and overlearning (where learners must continue to revisit material, they have already mastered it) can overcome the challenges dyslexic students face when learning Object Orientated concepts.

4.4.2 Difficulty with Syntax. Difficulty with syntax, as well as the struggle to learn syntax, are similar, as discussed in the paper by Zamzuri et al. regarding students' challenges when learning to program [44]. It was found that learning syntax is one of the main challenges when it comes to programming ([33],[40]). As stated by Robling et al., novices learning to program often struggle when syntax errors occur, as they are unable to understand the feedback errors. Regarding the challenges faced by dyslexic students, it is not impossible to say that they suffer from the same struggles as their peers while also having short term memory issues that contribute to extra problems with learning and absorbing the information as was discovered in this research ([25], [7]). Consequently, the challenges that those with dyslexia face in reading and processing information in general disadvantage them when attempting to program as they must remember the order the syntax is in, the spelling and what key syntax words mean.

4.4.3 Testing and Debugging. There are also similarities between 'struggles with systematic testing' and 'difficulty debugging own code'. Both seem to have issues with debugging and correcting errors in code ([44], [33], [1]) although the reasoning may differ as for those with dyslexia it may be a reading or overcrowding issue ([41],[25]).

Research suggests that students without dyslexia struggle with systematic testing due to not being able to trace the problem through the code, not because of a problem-solving issue [6]. In contrast for students with dyslexia the challenge arises in reading their code, McChesney and Bond identified that when reading code students with dyslexia can skip parts unintentionally [25]. This provides an extra challenge as it could be difficult to tell if the student is struggling with a problem-solving issue or they are simply struggling to read the code.

4.4.4 Problem solving and Identifying Key Tasks. There are similarities between the 'struggle to break the problem down' and the 'struggle to design programs to solve tasks'. However, the reasoning differs again, as those with dyslexia struggle to read the assignment brief itself as they struggle to interpret and infer information from the text [41]. Additionally, with the problem of reading and processing the information comes the challenge that dyslexic students struggle with breaking assignment briefs into meaningful parts. This means it can be hard for the students to get a start on the design element and cause delays in completing work.

4.5 Summary

The previous section highlighting similarities and differences has helped to answer RQ2. We have identified four key similarities that students with dyslexia and students generally encounter when learning to program according to the literature. This could mean that students with dyslexia may find these activities especially challenging and thus could benefit from targeted support. Also identified were nine differences between students with dyslexia and students generally. Therefore, as there are additional challenges dyslexic students can encounter when learning to program, more research is needed to understand how to aid them. Additionally, even when the challenges are similar and within the same category the reason behind them may differ, thus introducing some nuance into how support could be designed to create an inclusive learning environment.

It is important to highlight some possible limitations of the work. In particular, the initial codes for thematic analysis were identified by one researcher, with validation from the remaining researcher. This research would benefit from multiple researchers creating and comparing codes to fully validate the coding.

5 CONCLUSIONS

In this paper, research was conducted to analyse scientific papers on the challenges that dyslexic students face when learning to program. Our research questions were *RQ-1 commonly identified challenges in learning to program with dyslexia?* and *RQ2: What are the differences and similarities with challenges faced by individuals learning to program who do not have dyslexia?* To address these, a systematic literature search was completed, and papers were analysed using thematic analysis.

The data attained from the thematic analysis revealed a list of ten commonly identified challenges for dyslexic students and seven commonly identified challenges for students learning to program. This allowed us to address RQ1 and provided the required insight to establish any differences and similarities with students. Evaluating the data provided information on the comparable challenges that both students with dyslexia and students encounter when learning to program for example both struggle with learning Object Oriented programming [38][16] and learning the syntax ([31],[23]). However, the analysis also revealed that students with dyslexia may encounter several additional challenges when learning to program. For example, struggling to remember factual information such as variable names and difficulty with word crowding ([25], [7]).

Further research is required to validate the similarities and differences, particularly hearing from students with and without dyslexia and what they believe to be specific challenges. This could provide valuable insights into the reasons for the additional challenges dyslexic students encounter when learning to program. In addition, further research could also explore assistive strategies to address the specific challenges highlighted by this research for dyslexic students learning to program.

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