Learning Styles and Dyslexia Types

Understanding Their Relationship and its Benefits in Adaptive E-learning Systems

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Abstract—Learning is a fundamental element of people's everyday lives. Learning experiences can take the form of our interactions with others, through attending an educational establishment, etc. Not everyone learns in the same way, and even people who are considered to have a similar standard of abilities or proficiency will exhibit different learning styles. This does not necessarily mean that some students are better than others; it means that students are different from one another. Adaptive e-learning system should be capable of adapting the content to the user learning style, abilities and knowledge level. In this paper, we investigate the benefits of incorporating learning styles and dyslexia type in adaptive e-learning systems. Adaptively aspects based on dyslexia type and learning styles enrich each other, enabling systems to provide learners with materials which fit their needs more accurately. Besides, consideration of learning styles and dyslexia type can contribute to more accurate student modelling. In this paper, the relationship between learning styles, in particular the Felder–Silverman learning style model (FSLSM), and dyslexia type, is investigated. These relationships will lead to a more reliable student model.

1 Introduction

Research reveals that the learning styles of dyslexic students are different to those of non-dyslexics [1]. Furthermore, learning experiences that are aligned with a student's preferred learning style are more likely to be effective and will increase the self-esteem of dyslexic students.

Exley [2] found that when lessons were aligned with students' preferred learning styles, the students' level of performance and attainment increased. Morgan and Klein [3] outlined how dyslexic learners exhibit very different learning approaches to non-

dyslexics and, therefore, require different learning experiences that focus on more practical and relevant skills. All adults need to have the ability to complete the administrative tasks that are associated with everyday life, such as completing application forms. However, each learner has distinct needs that are dictated by their strengths and weaknesses. Teachers need to develop methods by which learners can identify and understand their learning style and, subsequently, adapt it to their needs. This understanding will allow learners to improve the effectiveness of their learning and identify suitable methods of achieving their objectives.

Dyslexic adults often encounter feelings of frustration in the classroom setting because the lessons they are taught are not aligned with their preferred learning style. Although remedial help is sometimes available in the learning setting, this is not always effective because it is not explicitly adjusted so that it aligns with the learning style of the individual student. In one study, Morgan and Klein [3] described a case involving a learner named Michael. While Michael did receive assistance at school to help him to advance his skills, this assistance took the form of conventional teaching methods and was, therefore, unsuccessful. Research by Scott [4], proved that multisensory teaching is beneficial for dyslexic students [4]. Furthermore, learning interventions that concentrate on addressing students' weaknesses are not as effective as those that focus on their strengths.

In light of the above, what constitutes an effective learning intervention in terms of content and mode of delivery differs from dyslexic and non-dyslexic and from dyslexic to dyslexic. It is, therefore, crucial that differences in learning style are taken into consideration in adaptive educational programs, and that the learner has an opportunity to influence how such a program is delivered. Allowing students some degree of control over the style of learning and the material presented enhances the likelihood that the information presented will be relevant to them and is in a form that they can understand. In addition to facilitating and enhancing the learning process, this will also increase dyslexic students' motivation to learn, something that is often lacking in members of this student population.

In this paper, section (2) introduces the background concepts of dyslexia and its effects on students, and the learning styles models. Section (3) will propose the two dyslexia models, it will establish the relationships between dyslexia type and learning style. In Section (4), the researchers discuss the relationships between dyslexia type and learning style based on collaborative student modelling approach.

2 Background

2.1 A basic overview of dyslexia

The word 'dyslexia' is derived from the Greek language, with "dys" meaning difficulty and "lexia" meaning language [5]. The definition of dyslexia that will be applied within this paper is that provided by the British Dyslexia Association (BDA) [6].

Dyslexia is a specific learning difficulty that mainly affects the development of literacy and language related skills. It is likely to be present at birth and to be life-long in its effects. It is characterized by difficulties with phonological processing, rapid naming, working memory, processing speed, and the automatic development of skills that may not match up to an individual's other cognitive abilities. It tends to be resistant to conventional teaching methods, but its effect can be mitigated by appropriately specific intervention, including the application of information technology and supportive counselling.

According to research by Tinklin, Riddell, and Wilson [7], twice as many students disclosed that there were dyslexics in 1999/2000 than those who specified they were dyslexics in 1995/1996. This is not necessarily an indication that dyslexia is on the rise, but is likely to be more indicative that more students are being actively encouraged to disclose their dyslexia than ever before, and that some of the stigma associated with the condition has been removed in more recent years. Further statistics that were published by the Higher Education Statistics Agency (HESA) [8], revealed that the majority of students who revealed that they had learning disabilities were male. This is unsurprising given the fact that research has proven that males are more likely to have dyslexia than females and that the majority of disabled students declared over that period were men [7]. While dyslexia does have the potential to impede learning, it is by no means an indication of intellectual and creative capability. Notable sufferers of dyslexia include Albert Einstein, Leonardo da Vinci, Walt Disney, Thomas Edison, Isaac Newton, Steve Jobs and Pablo Picasso. Every one of these remarkable men were described as lazy and unskilled in their school days as a result of their learning differences; however, they all went on to make a significant contribution to society despite their disadvantage [9]. Indeed, research has revealed that dyslexia by no means renders an individual incompetent. On the contrary, individuals who have dyslexia have been proven to possess advanced intuition, creativity, perception, visualization, and originality [9].

Today, teachers have a much better understanding of dyslexia and of the teaching interventions that can be employed to help students who suffer from this condition. However, such students continue to encounter many challenges in their quest to access learning experiences that are aligned with their needs and capabilities. One reason for this is that many educational systems are not equipped for students who have dyslexia. This is true in the UK, despite the fact that the UK is widely regarded as having one of the most comprehensive legislative support networks for dyslexic people among all European countries, as evidenced by a number of formal enactments including the Disability Discrimination Act 1995 (DDA) [10], the Disability Equality Duty 2006 (DED) [10], and the Special Educational Needs and Disability Act 2002 (SENDA) [11]. If dyslexic students are offered learning experiences that are comparative to those available to their peers and, therefore, the guidelines of the various legislative frameworks are adhered to, they have every potential to achieve academic and career success.

Research by Woodfine, Nunes, and Wright [12] revealed that learning experiences that involve real-time text-based activities, such as those associated with the use of online chat and conference facilities could put students who have dyslexia at a distinct disadvantage to their peers. The issues that people with dyslexia experience when

interacting with e-learning systems extends beyond accessibility and design issues alone, and incorporates many other factors. However, while some of these issues are readily acknowledged, there is a lack of existing research in the field, and academics lack a solid understanding of the problems that students who suffer from dyslexia experience when attempting to interact in collaborative learning environments. It is potentially because of this gap in understanding that many of the technologies that have been introduced into contemporary classrooms with the intention of facilitating the learning experiences of students with dyslexia have fallen short.

Dyslexia is a very complicated and multifaceted condition that affects sufferers in many different ways. Rarely, two people with dyslexia will typically encounter the same symptoms. This basic fact is at the core of this current research. As the nature and impact of a student's dyslexia symptoms will vary from individual to individual, it is very difficult to develop a standard learning system that is capable of meeting the needs of all dyslexia sufferers. As such, to provide effective learning interventions, educators need to develop learning experiences for the dyslexic students they teach on a case-by-case basis. In light of the disadvantages associated with such an approach and the current lack of formal research into the use of e-learning systems with students who suffer from dyslexia, this study aimed to explore dyslexic students' interactions with e-learning systems in depth with the intention of forwarding recommendations for future technological applications.

As outlined above, dyslexia manifests itself in many different ways, and it is, therefore, exceptionally difficult to categorize dyslexia. However, some broad subtypes of dyslexia have been identified [13]. One of the fundamental reasons as to why e-learning applications may not be as effective for dyslexic students as they are for standard learners, can be attributed to the fact that technology developers have not put in their minds the different types of dyslexia. At present, the technologies that are available are very generic and do not offer any means of differentiating learning experiences according to the needs of the user. As such, there is a need for developers to create more flexible and adaptable systems that can adjust to the type of dyslexia that a student has. As dyslexic students may differ in terms of the symptoms that they exhibit, it is useful to consider dyslexia in terms of the three broad categories defined by Ingram [14]: *(1) visio-spatial difficulties (2) speech sound difficulties and (3) correlating difficulties.*

2.2 Research on learning styles

Web-based educational systems can represent very effective methods of delivering learning experiences to students because they can be widely distributed and can be readily accessed, regardless of location or time. However, the current offerings are usually relatively standard without any differentiation; as such, they are not necessarily pedagogically beneficial if each individual student's level of knowledge and preferred learning style is unknown. Existing research into learning styles indicates that incorporating an understanding of a student's learning style in the instruction provided enhances the success of learning experiences [23]. As such, creating learning materials that can be adapted to a student's preferred learning style represents a powerful means

of personalizing education that delivers optimal results. Such a personalization has the potential to help students to develop a more comprehensive understanding of the topics under consideration and to reduce the time it takes to teach them new concepts and skills. If teaching methods take into consideration the fact that every learner has distinct learning preferences or a set learning style [24], an enhanced set of resources can be developed that appeals to that learning style. This resource can, therefore, help the learner to develop a more readily develop a comprehensive understanding of a subject.

Multiple studies have demonstrated that a learner's performance improves when teaching experiences are explicitly aligned with his or her learning style [17; 1; 18]. For example, in one study, Brooks and Weeks [1] compared different approaches to teaching spelling. Their research concluded that learning experiences that were aligned with a student's cognitive style more effectively enhanced his or her spelling skills.

Having reviewed the multiple models that have been used to identify students' learning styles, in both electronic and paper form, a model was selected for further exploration in this research. The model selected for use in this research needed to meet the following inclusion criteria:

a) Assessments are relatively quick and straightforward to complete and would not induce fatigue,
b) Were aimed at adults,
c) There was no risk that the assessments could be skewed by erroneous answers from inappropriate questions,
d) Could account for an appropriate number of learner types,
e) Are free and available online and
f) Employ a web-based model that allows students to complete the assessment at a time and place to suit them.

Significant effort was invested in ensuring that the dyslexic participants did not experience any of the difficulties reported by Disability Right Advocate (DRA) when completing assessments that involved multiple-choice exercises [19].

The Felder-Silverman Learning Model was selected for application in this research for a number of reasons. It met all of the inclusion criteria outlined above, it has been successfully used to test dyslexic students [20], and it has been employed in a digital context and validated with adult university students. Zywno [21] published a study that examined the validity and reliability of the Felder-Silverman Learning Model and assessed how students interacted and used the model. Moreover, Graf, Lin and Kinshuk [22] investigated how different learning styles interact with one another, in particular the Felder-Silverman learning style model, and how they influenced one of the dyslexia deficits: working memory capacity.

2.3 Index of learning styles

The Felder-Silverman learning style dimensions are neither original nor comprehensive. For example, the first-dimension sensing / intuition is one of four dimensions of a well-known model based on Jung's theory of psychological types [23]. The fourth dimension active/reflective processing is a component of a learning style

model developed by Kolb [24]. The other dimensions of these two models and dimensions of other models [25] also play important roles in determining how a student receives and processes information.

Felder and Silverman [26] described how learners utilize different mechanisms to send, receive and process information; as such, they have different learning approaches. They developed the Felder-Silverman learning style model [26], which rates students' learning styles according to a scale that consists of four dimensions. They determined a learner's learning style through the use of a questionnaire that was developed in 1991 by Richard Felder and Barbara Soloman [27]. This questionnaire is made up of 44 questions that are designed to categorize a learning style across four dimensions. Of the various learning models that are available, the Felder-Silverman Model is the only model that references the sensing/intuitive dimensions of learning.

Graf et al. [28] and Latham et al. [29] successfully simplified the FSLSM model. Their experiments revealed that 17 questions could effectively predict a user's overall learning style in at least 75% of cases. Furthermore, the top three questions predicted the result in 84% of cases. Their findings were incorporated in the current research, and their proposed subset of the most effective ILS predictor questions formed the basis of the learning styles assessment model contained within this research.

As we have already established, dyslexic individuals exhibit a diverse range of symptoms (section 2.1). As such, it is important to conduct a formal investigation into the support strategies that can be employed to assist dyslexic learners. This leads to the development of two central research models: dyslexia symptoms and classification, and dyslexia and learning style model. These models act as the foundation upon understanding the relationships between dyslexia type and learning style.

3 Dyslexia Models

3.1 The Dyslexia Symptoms and Classification Model (DSCM)

As described in Section (2.1), many different types and classifications of dyslexia have been proposed in existing literature and, as such, dyslexia itself can be divided into many different categories. Each theory defines dyslexia symptoms very differently, describes the key signs and symptoms in different ways, and proposes different means of facilitating effective learning experiences for dyslexic learners. The lack of consensus on dyslexia categories entails that it can be very difficult to classify dyslexia into different types. The model proposed in this section is based on Ingram's [14] classification because this has been commonly employed in existing literature and is generally acknowledged to represent an effective method of categorization. In 1964, Ingram described how dyslexics exhibit different symptoms. On the basis of his observations, he recommended dividing dyslexia into three categories: visuo-spatial difficulties, speech-sound difficulties, and correlating difficulties. However, while he highlighted appropriate categories, he did not describe the symptoms associated with each classification; as such, this represents a challenge for this research, which seeks to develop the basis of personalized learning experiences in accordance with dyslexia

type. To overcome this issue, the author has identified the dyslexia symptoms associated with each of three dyslexia classifications that Ingram proposed [14]. These are as follows:

1. *Visuo-spatial difficulties (vs)* symptoms are: Reading, writing, memory and mathematics.
2. *Speech sound difficulties (ss)* symptoms are: Reading, writing, memory and speaking.
3. *Correlating difficulties (c)* symptoms is: Writing.

In order to develop an enhanced understanding of the dyslexia classifications and their accompanying symptoms, a Venn diagram was developed using the following mathematical operation:

Let U be the universal set for all individual dyslexia symptoms, U is defined as {reading, writing, memory, mathematics, speaking}

Let be vs= {reading, writing, memory, mathematics},

ss= {reading, writing, memory, speaking}, and

c= {writing}

Writing is the most common of the dyslexia symptoms among Ingram's [14] three classifications. Writing difficulties sit at the intersection of the three classifications.

$vs \cap ss \cap c$ = {writing}

If the student's dyslexia symptoms manifest themselves as reading or writing difficulties, he/she is considered to exhibit a severe form of dyslexia, and this sits at the intersection of visuo-spatial and speech sound difficulties.

$vs \cap ss$ = {reading, writing, memory}

vs^c = {speaking}

ss^c = {mathematics}

The resulting Venn diagram is presented in Fig 1. This depicts the relationships between the dyslexia classification and the accompanying symptoms.
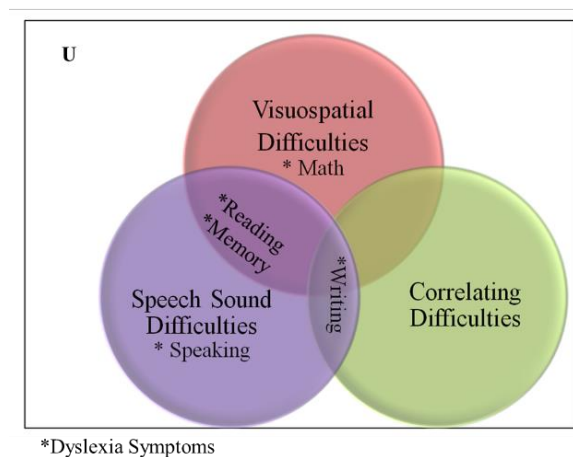

Fig. 1. The relationships between dyslexia classification and symptoms (Venn diagram)

In Section (2.1) a literature review was conducted to identify the symptoms that subject experts agree are commonly associated with dyslexia, and to examine these in depth. It was apparent that the authors of the respective studies were unable to agree as to the validity of some dyslexia symptoms. As such, any dyslexia symptoms that remain a subject of major dispute were explicitly rejected from this model and, instead, a consensus-based model of dyslexia symptoms and classification was generated. This model will form the foundation of the internal expert user model of dyslexia symptoms within the any adaptive e-learning system targeting dyslexic learners. It will operate as a checklist that will be employed to identify whether students have dyslexia and will also be utilized at a later date to identify the extent to which learning style can be observed in terms of the dyslexia symptoms that students share. A graphical representation of the system model is presented in Fig 2.
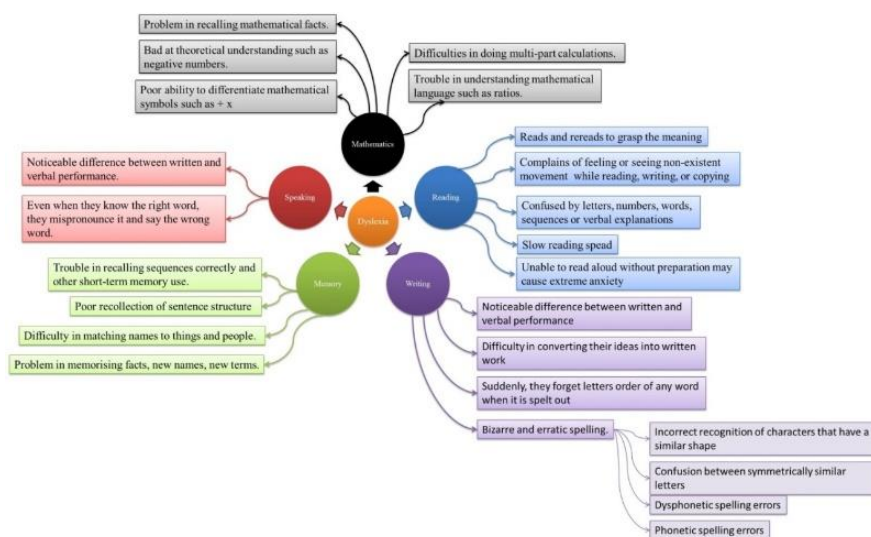

Fig. 2. The Dyslexia Symptoms and Classification Model (DSCM)

There are a number of significant factors that should be taken into consideration when interpreting the consensus model outlined in Fig 3. These are as follows:

- A large number of researchers have examined and described the features that dyslexic subjects commonly exhibit. The works described in the literature review represents only a small proportion of the existing knowledge that is available on the behavioural characteristics that are associated with dyslexia.
- The proposed model is based on a loose notion that 'typical' dyslexia symptoms exist. Given the very complicated nature of dyslexia, it is very unlikely that an individual with dyslexia will exhibit all the symptoms described. In addition, the symptoms themselves will significantly vary from subject to subject in terms of how they manifest themselves and their severity.

- In the event that consensus between theorists could not be established in terms of a given symptom, these symptoms were excluded from the model; for example, poor organisational skills [30].

3.2   Dyslexia and Learning Styles Model (DLSM)

There are several benefits associated with investigating the correlation between learning styles and dyslexia type (described in detail in Section 3.7). These include acquiring the knowledge required to adapt learning experiences to learning styles, and using the data about learning styles to improve the effectiveness of the process by which experiences are adapted to dyslexia type. Furthermore, information about learning styles and dyslexia type provides more holistic adaptivity in terms of taking into consideration both students' learning styles and their dyslexia type in adaptive educational hypermedia systems.

The interaction between the Felder-Silverman learning style model (FSLSM) and dyslexia type was investigated to further exemplify the relationship between learning styles and dyslexia type. The next subsection presents a comprehensive literature review of existing studies that contain useful insights that enhance understanding of the relationship between the four dimensions of FSLSM and dyslexia type. Following a review of existing works in this area, experiments that employed real data are presented. These involved the learners completing an Index of Learning Styles (ILS) questionnaire, the results of which provided useful information about the respondent's learning styles. The participants were also asked to perform a basic task that was designed to elicit information about their dyslexia type. The results of the analyses are examined in depth and compared with the results of the literature review in (Section 4). A key focus of this discussion is on the ways in which an understanding of the identified relationship can facilitate adaptive educational hypermedia systems.

3.3   The relationship between FSLSM and dyslexia types

The relationship between learning styles and dyslexia type was investigated in depth via a comprehensive literature review in order to generate useful insights that could be employed to improve the adaption process of learning styles. An analysis of the existing studies in this domain was employed to identify the relationships between dyslexia type and the dimensions of FSLSM. The following subsections will present an overview of these studies. The discussion will start by providing a comprehensive overview that will facilitate an understanding of the relationships between dyslexia types and learning styles. Following this, notable studies will be examined to investigate the extent to which there is evidence of a relationship between each learning style dimension and dyslexia type.

3.4   Understanding the relationships between learning styles and dyslexia

A study by Simmons and Singleton [31] compared the reading comprehension of a group of dyslexic university students with their non-dyslexic peers, and established that dyslexic students exhibited significant impairment in terms of their ability to construct inferences while processing complex text. No significant differences between the two groups were observed when the participants were asked literal questions about information that was explicitly stated in the text. However, significant differences were found when inferential questions were asked that required the students to combine one or more units of information or to use their existing knowledge to interpret an ambiguous statement. Dyslexic students did not perform as well as non-dyslexic students on tasks that involved answering inferential questions, and the researchers attributed this to the fact that dyslexic students have a working memory deficiency [31]. Their findings were supported by later research by Calvo [32], in which the results of reading-span task revealed that working memory plays an important role in the text-integration process and, as such, is critical to elaborative inference. Essentially, inferential ability plays an important role in bridging the gap between the required semantics [32].

Beacham, Szumko and Alty [20] examined the effect that different presentation modes had on the outcome of online courses that were provided to dyslexic students. Within this study, key information about the participants' learning styles was elicited through the use of the ILS questionnaire. According to Simmons and Singleton [31], dyslexics have impaired working memory capacity. The results of these studies support the hypothesis that learners who have lower working memory tend to have a poorer reading ability. Mortimore [33] suggested that the achievements of students with dyslexia are enhanced when they are presented with multi-sensory learning experiences that use a variety of channels to reinforce learning. Mortimore's research supported an earlier study by Beacham and Alty [34] that concluded that the learning performance of dyslexic learners can be directly impacted by the different combinations of media through which the learning experiences are presented.

Earlier research by West [35] suggested that there is a relationship between visuospatial strategies or strengths and dyslexia. However, this hypothetical relationship has yet to be proven through empirical research and, as such, it remains somewhat subjective [33]. Exley [2] conducted research in which seven dyslexic students were assessed. She found that five of these students preferred a visual learning approach and suggested that her findings were of significance. In a small-scale study, Mortimore [33] completed cognitive styles analysis [36] of 30 students, 15 with dyslexia and 15 without, with the intention of identifying the extent to which dyslexic students favor visual processing over verbal approaches. This study also suggested that there is a relationship between visual style labels and dyslexia.

3.5   Linking FSLSM dimensions and dyslexia types

As described above, it can be more effective and straightforward for students and their teachers to classify dyslexia according to symptoms as opposed to classifications

or types. According to the DSCM, there are three types of dyslexia. Each type has different associated difficulties including reading, writing, speaking, mathematics, and memory. The next sections will map each dyslexia symptom against the dimensions proposed by Felder and Silverman [26].

Reading: A student who has dyslexia reading difficulties tend to think primarily with images and feeling not sounds or words (visual). They struggle to grasp the meaning of words or symbols. Their struggling in translating words puts them at a disadvantage in timed tests: since they may have to read questions several times before beginning to answer them, they frequently run out of time. Their perceiving of the world involves observing, gathering data through the senses (sensory). Learners with reading dyslexia remember much of what they hear and more of what they hear and then say (sensory). They get a lot out of discussion more than reading. Actually, this reflects that the most applicable assistive technologies for them are related to sounds such as "Text to Speech Readers" and "Reading Pens".

Writing: A study by Brooks and Weeks [37] concluded that students who have writing dyslexia learn more effectively if instruction is adapted to their visual and semantic strengths. Exley [2] concluded that dyslexic students who have writing problems tend to attempt to vocalize elements of the word (verbal) while also creating a visual image of it (visual). In his study, he examined the effectiveness with which seven dyslexic students were taught how to spell new words. He found these students learned new works through visual strength providing this ability is combined with auditory channels. The students who participated in the study required a strong visual image of the word that was written in bold on an A3 sheet of paper or on a large whiteboard to utilize the visual channel. Alternatively, they spoke elements of the word aloud while generating a visual image of it (visual/verbal).

Speaking: Learners with speaking dyslexia typically speak with a stutter or in disjointed sentences when under stress, mispronounce long words, or transpose phrases, words and syllables when speaking. As such, these individuals generally avoid situations in which they are required to discuss or explain things to others (reflectively). Reflective learners work better in isolation or in discrete partnerships as opposed to collaborating with larger numbers of people [26]. They find delivering a presentation or public speech particularly stressful. Turner and Hope [38] advised students who have speaking dyslexia to summarize their thoughts and ideas in the form of a picture or diagram (visual) form to increase their confidence and overcome their fears.

Mathematics: Chinn and Ashcroft [39] explains that difficulties in mathematics for students with dyslexia may be due directional confusion, sequencing problems, poor short - term and working memory, speed of working, cognitive style, anxiety, stress and self-image. Joffe [40], in her study of students with dyslexia's mathematics performance, found that calculation tended to be the major area of weakness, and this she attributed to the students with dyslexia difficulty with verbal labelling and short-term memory. She found that spatial skills (sensory), needed for understanding shape, size and relative size and quantity. The mathematical skills for the students with dyslexia are improved when they try to link the mathematical terminologies with (visual) reminder according to study by [2]. Mathematical functions should be

illustrated by flow charts and graphs to simplify complex processes or algorithms (visual/sequentially).

Memory: Students with dyslexia have excellent long-term memory for experiences, locations, or faces. However, they have poor memory for sequences or information that has not been experienced. They reasons mainly with images (visual) and with step-by-step progression diagram (sequentially). It facilitates processing and transfers information to the long-term memory. It is fair to argue that learners with severe deficiencies in working memory would have problems in reading, and according to Beacham, Szumko, and Alty [20] would likely prefer visual learning (visual). Wey and Waugh [41] argue that learners with low working memory capacity benefit from visual material and therefore prefer a more (visual) learning style.

3.6 Constructing Dyslexia and Learning Styles Model (DLSM)

According to Cassidy [42], an individual's learning style can be interpreted as the way in which he or she perceives, interacts with, and responds to the learning environment. Furthermore, learning styles can be perceived as the forms, methods or strategies that a student prefers to select, process, and work with information. As such, learning style can be broadly viewed as a student's learning preferences. As we have already discussed, the Dyslexia and Learning Styles Model (DLSM) is based on the Felder-Silverman's Index of Learning Styles (ILS) [26] and combines learning styles across four dimensions (active/reflective, sensory/intuitive, visual/verbal, and global/sequential) to define the learning styles of dyslexic students (See Fig. 3).
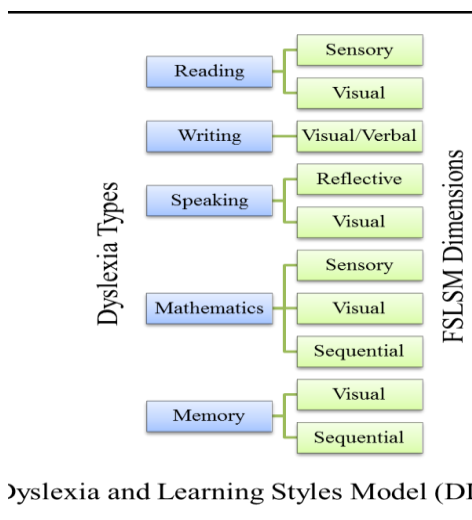

Fig. 3. Dyslexia and Learning Styles Model (DLSM)

An analysis of the DLSM revealed that, of the learning styles that are recognized, the visual learning style appears to be the most dominant in dyslexic learners and is

employed by learners of all dyslexia types. Beacham, Szumko and Alty's [20] study agreed with this reasoning, proving that 97% of dyslexic learners are visual learners while the remaining 3% are also positioned in the mild-verbal range. They also discussed how such learning style preference was to be expected since dyslexic people have been proven to exhibit strong talents in the areas of creativity and visual thinking. This finding echoed the earlier conclusions drawn by Wey and Waugh [41]. Both studies revealed that learners who have low working memory benefit from visual material and, therefore, prefer a more visual learning style. To develop a personalized learning experience that is aligned with a dyslexic learner's preferences in terms of learning style, dyslexia type and knowledge level, the author of the current study proposed a new ontological approach to learning experiences that was based on learning style and dyslexia type [43]. The DLSM model was employed to design this system and provided significant input to the formulation of the personalized learning materials. Rule-based techniques that employed simple IF-THEN logic rules were utilized in the proposed model to deliver personalized learning materials [43]. An example of this can be observed in Table 1.

Table 1. Example logic rule to match the dyslexia type with suitable learning style

Example rule to match the dyslexia type with suitable learning style:
IF dyslexia type is "memory" THEN learning style is "visual" OR "sequential";

These logic rules will help the developers when developing personalized materials and presenting learning experiences that match dyslexia type with learning style.

3.7 Benefits of understanding the relationship between FSLSM and dyslexia types

The relationship between FSLSM and dyslexia type that is identified can be employed to generate additional information about the students. This information can enhance the student modelling process. This will, in turn, lead to the development of a more reliable and richer student model that effectively and accurately offers optimized holistic adaptivity. Specifically, the relationship between learning styles and dyslexia types can offer two types of adaptive educational hypermedia systems. The first type of systems are those that are capable of detecting dyslexia types or learning styles in isolation but not in combination. In the case of these systems, the relationship yields additional information about additional characteristics of the user that may be of relevance. As such, a system that can only detect dyslexia types can utilize the identified relationships to acquire further information about the learning styles of each user. This additional information can be subsequently employed to develop a more comprehensive student model and to provide more holistic adaptivity by taking both dyslexia types and learning styles into consideration. In addition, this relationship can be informative for systems that are only able to detect learning styles through providing information about

dyslexia types. This, again, enhances the student model and increases the extent to which the system offers holistic adaptivity.

The second type of systems that can benefit from the relationship between learning styles and dyslexia types are systems that incorporate both learning styles and dyslexia types. If the student model includes information about only learning styles or only dyslexia types, it can be extended by including information about the other. In this case, while the student model already includes both learning styles and dyslexia types, explicitly identifying the interaction between learning styles and dyslexia types can result in the construction of a more reliable student model.

As discussed above, explicitly identifying the relationship between learning styles and dyslexia types can generate key information that can be employed to improve the adaption process. In addition to accelerating the process by which learning experiences are adapted to student learning styles, it can also improve the reliability of the student model. Incorporating larger amounts of data in the adaption processes leads to a more accurate and dependable results and, therefore, improves student modelling.

4 The Analysis of the Relationship Between FSLSM and Dyslexia Type

The outputs of the literature review presented in Section (3.4) revealed that there is a relationship between learning styles and dyslexia type. The study described in this section was designed to assess the extent to which there is a direct relationship between the four dimensions of the FSLSM and dyslexia type as a means of verifying the relationship identified in the literature review, which was subsequently used to develop the DLSM (see Section 3.6). To this end, an experimental study involving 34 students with dyslexia (11 dyslexic and 23 possible dyslexics) was conducted. In order to identify the students' learning styles and dyslexia type, a collaborative student modelling approach was employed via which the students were required to complete the ILS questionnaire (see Section 2.3). The dyslexia type test employed in the current research was designed and constructed using the free online evaluation that was published by Davis Dyslexia Association International[1] as a reference. This study and the subsequent results are presented in the following two subsections.

4.1 Study

For the purposes of the in-depth analysis, the learning style values were divided into three groups: active, balanced, and reflective preference. These groups were based on the recommendations presented by Felder and colleagues [26; 44] and in line with the need to reduce questions as a means of increasing reliability (see Section 2.3). Therefore, values greater or equal to +4 indicate a preference for one pole, those smaller or equal to -4 indicate a preference for the other pole, and values between +3 and -3

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[1]http://www.testdyslexia.com/

indicate a balanced learning style. In order to analyze the relationship between learning style and dyslexia type, only those cases in which the learning style was strong or moderate were taken into account. The same approach was employed within the dyslexia assessment test, i.e., only the cases in which the student demonstrated severe or moderate dyslexia type were taken into consideration.

4.2 Discussion

The purpose of this study was to identify if there were any further indications to support the literature review findings; i.e., that there is a relationship between the four dimensions of FSLSM and dyslexia type. The results obtained within this aspect of the research were promising and further supported the claims made in the literature that there is a relationship between the visual/verbal dimension in particular. The distribution of learning style across the dyslexic learners involved in this research is presented in Fig. 4.
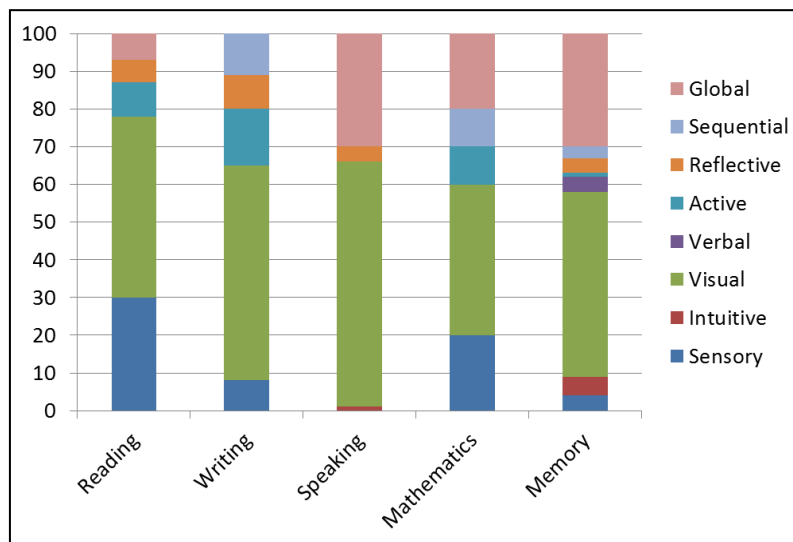

Fig. 4. Dyslexic learners' learning style data distribution

In terms of the reading dyslexia type, the findings of the literature review presented in Section (3.5) revealed that people who have reading dyslexia tend to primarily mentally process information in terms of images and feelings, not sounds or words. The results of the study conducted within this research support the view that there is a strong correlation between visual preference and learners with reading difficulties. This was expected, since a large number of studies, as summarized by Beacham, Szumko and Alty [20], have found that 97% of dyslexic learners are visual learners and the remaining 3% are located in the mild-verbal range. The results of the current study also

found that there is a correlation between dyslexia reading difficulties and sensory learning style.

The results of the current study also revealed that learners who have a writing dyslexia type tend to be visual learners. This in line with the findings of the previous research reviewed in the literature review described in Section (3.5). However, according to the relationships between the four dimensions of the FSLSM and dyslexia type described in the literature, learners with writing dyslexia type also prefer a verbal learning style, and this statement was not supported by the results of the current study, which found that none of the learners that had a writing dyslexia type were verbal learners.

According to the DLSM (Section 3.6), learners who have a speaking dyslexia type tend to exhibit a visual and reflective learning style. This assumption was supported by the findings of the current study. Moreover, this study demonstrated that 30% of learners who have speaking dyslexia tend to be global learners. This finding is new and, as far as the author is aware, has not been discussed in previous research in this domain.

In terms of memory dyslexia type, this study found that there was a correlation between memory dyslexia type and visual learning style. However, there was no evidence to support the view that learners with memory dyslexia type prefer sequential learning style. In fact, on the contrary, the results of this study revealed that such students tended to prefer a global learning style.

The results obtained during this study indicated that students with mathematics dyslexia prefer a visual learning style. This is in agreement with the findings of existing research in this area. However, there was insufficient evidence to support the claims made in the literature that learners with mathematics dyslexia prefer a sequential and sensory learning style.

5   Conclusion

This paper discussed the relationship between learning styles and dyslexia type as well as the benefits of considering learning styles and dyslexia type in adaptive e-learning system. Accommodating learners' needs and providing them with adaptive courses and learning experiences is an important issue for adaptive e-learning system. The general aim of incorporating learning styles and dyslexia type in such systems is to provide more holistic and accurate adaptivity. Adaptivity based on dyslexia type affects the course in a more general way than adaptivity based on learning styles. Both kinds of adaptivity enrich each other and combining them leads to courses that provide more adaptivity, considering dyslexia type as well as learning styles of a learner.

Adaptivity can only be provided if the needs of learners are known by the system. To improve student modelling, relationships between learning styles and dyslexia type were investigated and identified. In current investigations, Felder–Silverman learning style model (FSLSM) is mapped with dyslexia type to form the Dyslexia and Learning Style Model. After deriving relationships between the FSLSM and dyslexia type from literature, an experiment with 34 students was performed. The results showed a strong relationship for the visual dimension and dyslexia type.

The interaction between dyslexia type and learning styles can be used to improve the student model of an adaptive e-learning system and therefore to provide more holistic and accurate adaptivity. A system that is able to detect either only learning styles or only dyslexia type can use the relationship to get some information about the other, not detected feature. According to this additional information, the system can provide more adaptivity. For systems that already consider both, learning styles and dyslexia type, the relationship can be used to improve automatic student modelling and build a more robust student model.

In this paper, the existence of a relationship between learning styles and dyslexia type is shown. Future work will deal with using the additional information gathered from the relationship and demonstrate the benefits by the use of real data. We also plan to build a learning style student model using the additional information about dyslexia type in order to improve the automatic student modelling approach. Furthermore, we plan to extend them research to include additional dyslexia type such as lack of organisation in dyslexia.

6 Acknowledgement

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