A Novel Web-Based Approach for Visualization and Inspection of Reading Difficulties on University Students

Carolina Mejia, Beatriz Florian, Ravi Vatrapu, Susan Bull, Sergio Gomez, and Ramon Fabregat

Abstract—Existing tools aim to detect university students with early diagnosis of dyslexia or reading difficulties, but there are not developed tools that let those students better understand some aspects of their difficulties. In this paper, a dashboard for visualizing and inspecting early detected reading difficulties and their characteristics, called PADA (acronym for the Spanish name *Panel de Analíticas de Aprendizaje de Dislexia en Adultos*), is presented. PADA is a web-based tool designed to facilitate the creation of descriptive visualizations required for a better understanding by students about their learner model. Through information visualization techniques, PADA shows students the knowledge in their learner models in order to help them to increase their awareness and to support reflection and self-regulation about their difficulties in reading. PADA provides different learning analytics on reading performance of students, so that they can self-identify their strengths and weaknesses and self-regulate their learning. This paper describes examples that cover a variety of visualizations (bar-charts, line-charts, and pie-charts) to show user model fragments as personal details, reading profiles, learning styles, and cognitive traits of the students. We tested PADA with 26 students (aged 21–53 years) of different academic programs and levels, dyslexic and non-dyslexic. The results show that PADA can assist students in creating awareness, and help them to understand their difficulties associated with the reading tasks, as well as facilitate reflection and self-regulation in the learning process. Implications for the design of learning analytics are discussed and directions for future work are outlined.

Index Terms—Dyslexia, university students, reading difficulties, open learner modeling, learning analytics solutions

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1 INTRODUCTION

DYSLEXIA is a common learning disability which may persist into adulthood [1], [2]. University students with this type of disability may experience difficulties during their academic careers, since reading is the basis of most, if not all, formal educational processes and has significant importance in many learning domains. Although, dyslexia in the university context has not been studied in depth, a number of research studies have borne out that, in spite of having a learning disability, dyslexic students could develop compensatory learning strategies to help them to succeed in their studies [3], [4].

In Spain, university students are not questioned about their learning disabilities when they start their academic careers; therefore, the number of specific cases of students with dyslexia is unknown. For this reason, our research work began focused on detecting Spanish-speaking university students who have a previous diagnosis of dyslexia or are affected with some reading difficulties (i.e., dyslexia symptoms). Then, we detect the learning style that these students have acquired to deal with their difficulties, i.e., their learning preferences. Finally, it became necessary to study the cognitive processes associated with reading that can be altered in these students, with the aim of determining their cognitive deficits, and identifying whether or not the student has dyslexia [5], [6].

Learning disabilities of students can be studied by defining learner models based on demographics, characteristics, preferences and cognitive traits associated with the learning disability of the student. Thus, understanding the types and severity of dyslexia and reading difficulties can be achieved. In previous studies, the definition of the learner model was made and tools were developed to capture personal details of the students, detect their reading difficulties, detect their learning style, and assess their cognitive processes [5], [6], [7].

As current step in our research work, it is essential to support and assist these students in overcoming their difficulties during their higher education and beyond. Studies on university students with learning disabilities have revealed that (1) awareness of their weaknesses, and then some of their strengths, as well as (2) ability to make decisions and self-regulate their learning, are powerful predictors for their academic success [8], [9], [10]. Therefore, first of all, it is necessary to create awareness in students of their reading difficulties, learning styles and cognitive deficits. This awareness

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facilitates learning reflection by encouraging students to make decisions and self-regulate their learning. Second, it is necessary to provide specialized feedback and advice to support such self-regulation processes of the students.

Consequently, this study is directed towards the visualization and inspection of information from the learner model to create awareness in the affected students. To do so, opening the learner model to the students is proposed. Other research studies taking this approach have shown that it is a successful strategy to promote awareness-raising, which leads to reflection on learning, and its facilitate self-regulation, thereby the learning process is supported [11], [12].

In this sense, one of the emerging visualization techniques and potential impact on enhanced learning are learning analytics [13], [14], [15]. Basically, these analytics are graphical representations of aggregated data about students, for purposes of understanding their activity and performance in a fairly intuitive format, thus achieving the optimization of learning.

According to aforementioned issues, in this paper we present a Dashboard of Learning Analytics of Dyslexia in Adults (namely PADA, acronym for the Spanish name *Panel de Analíticas de Aprendizaje de Dislexia en Adultos*). PADA is a web-based tool designed to help with the understanding and inspecting of the student model, promote awareness and facilitate reflection on reading difficulties. It has an architecture based on the Activity-based Learner-models framework proposed in [16] to have a flexible and extendable dashboard to open more fragments of the learner model if they are later required.

Our research aims to collect answers regarding whether students would find PADA useful to detect their reading difficulties and their implications for learning and cognition. An important contribution of this paper presented in a case study, examined the usefulness of PADA in terms of assisting affected students to achieve understanding, inspection, awareness, reflection and encourage self-regulation in their learning process, particularly in the reading process.

This paper is structured as follows. In the second section, we provide a short review of the work related to supporting adult students with dyslexia, the importance of opening the learner model to these students, and the approach to the emerging area of learning analytics. The third section summarizes the research proposal in terms of a review of the related work. The fourth section describes the tools of previous research works used to collect data to feed the student model. The fifth section describes PADA and its architecture and presents how learning analytics were built. In the sixth section, questions that aim to achieve research objectives addressed by the case study are discussed, as well as description of the setup of the case study conducted with 26 students. The sample consists of dyslexic and non-dyslexic students and all of them reported to be affected with some reading difficulties. Section seven presents the results and findings of the case study. Finally, in the eighth section some conclusions are drawn and discussed.

2 RELATED WORK

2.1 Support of Students with Dyslexia

Several studies have explored dyslexia in children: detecting population of children with dyslexia, assessing their cognitive processes to determine specific deficits and creating assistance programs to improve their learning efficiency to read and write [17], [18], [19]. However, as we mentioned before, research in learning disabilities has shown that the dyslexia problem can persist into adulthood. Moreover, dyslexia has not been deeply studied in university students. Therefore, we rely on the methodological approaches used with children to define the steps in this research work. Thus, three phases are followed: 1) detection of affected students, 2) assessment of cognitive processes and 3) application of assistance programs. Related work focused on university students independently in some of these phases is presented below:

- *Detection of affected students*. There are two parallel ways in which the detection could be made. One way is the detection of *reading difficulties*, i.e., the individual weaknesses of the affected students. In this sense, findings reported provided reasonable evidence in support of the self-report questionnaire as a highly predictive tool to detect or contact with students with learning disabilities [20], [21]. We highlight the work of [22] who designed a self-report questionnaire that is hand-filled by students at the University of Malaga (Spain), making it possible to detect students previously diagnosed with dyslexia or those with reading difficulties among this population. The other way is the detection of *learning styles*, i.e., the strengths (or preferences) of these affected students. Although there is little empirical evidence on the positive effects that learning styles theory has on learning performance [23], other researchers note that students with dyslexia succeed when teaching is multi-sensory and uses all channels [24], [25]. In this sense, as [24], [26] remark it can be relevant detecting the learning style of these students to identify the most effective learning strategies they could use to learn. Likewise, many students with dyslexia have acknowledged that awareness of their learning style has helped them to understand the ways in which they learn, to understand their strengths, even their weaknesses, and to develop appropriate strategies [25], [27]. There are many models to detect the learning style [24], [28], we highlight the revised version of the Felder-Silverman model [29] for a number of reasons: (1) it is aimed at university students, particularly it has been tested with dyslexic students [30], (2) it is easy to administer and takes short time, (3) it is also easy to fill-in, which helps to avoid biased responses, (4) it has tested in electronic form, and (5) it has been validated, and shown to produce reliable results.
- *Assessment of cognitive processes*. After the detection phase it is necessary to assess the cognitive processes that can be altered in those students and determining whether or not they have dyslexia [31], [32]. Therefore, several tools to identify dyslexia-related cognitive deficits were analyzed and reported in previous research work. The findings revealed that in the Spanish language, appropriate tools are not found for the assessment of these cognitive processes in adult dyslexic population, but we highlight the work

of [2] who conducted a research that consisted of the adaptation of an English assessment instrument to Spanish language of phonological and orthographic processes.

- *Application of assistance programs*. Detection of reading difficulties and learning styles, as well as identification of cognitive deficits are necessary for generating of appropriate assistance to help students to overcome these shortcomings and support the cognitive performance of them [2], [33]. Previous work related with assistance in Spanish spoken universities and support for the treatment of these difficulties and cognitive deficits in university students has not been found.

Previous studies have shown that detection, assessment and assistance supported by technologies tend to increase affected students' motivation and personalize their learning process [33], [34], [35]. Technologies also help these students progress in skills development and enhance their learning performance [33], [36]. Additionally, the benefits of using assistive technology (e.g., speech recognition systems, screen readers, and talking spell checkers) are considered in compensatory strategies for these affected students [37], [38]. Finally, technology addresses a new challenge: to promote student reflection on their learning (skills, difficulties, preferences, misconceptions, etc.) [39], [40], [41]. However, this challenge has not been studied in students with dyslexia or reading difficulties [9], [42].

2.2 Open Learner Modeling

A learner model is responsible for storing the student information. Basically, this model represents knowledge, interests, preferences, goals, background, and individual traits of the students during their learning process, allowing for personalization and adaptation towards their current needs [43]. Traditionally the information in the learner model is closed to the students. However, benefits of opening the learner model to students to encourage awareness and reflection have been argued [11], [12], [44], [45].

For this reason, an open learner model approach is proposed, in which the learner model is accessible for viewing by the students in an understandable format. Moreover, considering the fact that university students with dyslexia may not have received adequate assistance during their learning process allowing them to know and deal with their difficulties; looks like open learner modeling is an opportunity to promote autonomy in these students so that they can recognize their reading difficulties, learning styles and learn about their cognitive processes for themselves. Consequently, self-regulation is supported, so that students affected will be able to identify the appropriate focus of their efforts, to overcome their difficulties and meet their learning needs [41], [44], [45], [46].

Basically, if a student views the learner model, information is provided about his/her competencies for each topic inquired previously. A review of the literature shows that an open learner model allows access to the learner model content in a variety of forms [12]. The most common of which are skill meters, textual descriptors and tables for each topic or concept to be accessed [11], [46], to more complex structured representations of understanding such as bayesian networks [47],

hierarchical trees and concept maps [48]. Others include simulation [49] and Fuzzy Models [50]. Recent work has also used treemaps to visualize the learner model [51].

Currently, an emerging area for the visualization of the learner model have been explored: learning analytics [13], [14], [15], [52]. Its primary goal is closely tied to a series of other fields of study including business intelligence, web analytics, academic analytics, educational data mining, and action analytics [53]. In recent years, however, there has been particular concern among researchers with using learning analytics to improve teaching and learning. Particularly works in this area are based on the aggregation and analysis of students' data collections in their social contexts, for purposes of understanding and optimizing learning, teaching, and the environments in which it occurs. Learning analytics seeks to select, capture, aggregate, report, predict, use, refine, and share data during the learning processes for teachers and students [53]. The aim of learning analytics is to provide useful support for understanding and decision making during learning and teaching. Thus, learning analytics focus on the detection of key-activity and key-performance indicators which can be based on statistical and data mining techniques, so that for instance recommendations can be made for learning activities, resources, training, people, etc. that are likely to be relevant. Alternatively, the data can be processed so that they can be further extended to support other educational roles in decision-making, as remarked in [14], [15], [54]. For instance, in this study the data are extended to teachers and experts (e.g., psychologist, pedagogical expert, or counselor) to support teaching strategies and assistance for students with dyslexia or reading difficulties.

Thus, open learner modeling and learning analytics are two areas highly related to learner model visualization. Open learner modeling is more centered on personalization and learning contexts while learning analytics do more emphasis on semantic aggregation, statistical analyses, and results towards prediction and recommendation.

2.3 Approach for Learning Analytics Production

In order to open the learner model using learning analytics solutions for understanding the performance and activity in learning contexts and considering the fact such solutions can be extended to teachers and experts, we look for a framework to deliver this type of indicators from three different perspectives: students, teachers and experts.

Accordingly, in previous research done by some of the authors [16] a technical framework was defined to build *Activity-based Learner-models* in order to monitor activities of students and deliver learning analytics solutions for different perspectives on social planes. Thus, a perspective defines the set of available learning analytics functions for a role in the web-based software (e.g., student, teacher, expert, etc.) whereas a social plane determines the monitored and analyzed population related with an activity or outcome (e.g., a single student, a classroom, a group, etc.). For instance, an expert can request a particular learning analytic, such as the performance in a task, either for a single student or for the whole classroom.

The Activity-based Learner-models are based on foundations of different research areas. From the pedagogical research, *Engeström's Activity Theory* is used to model
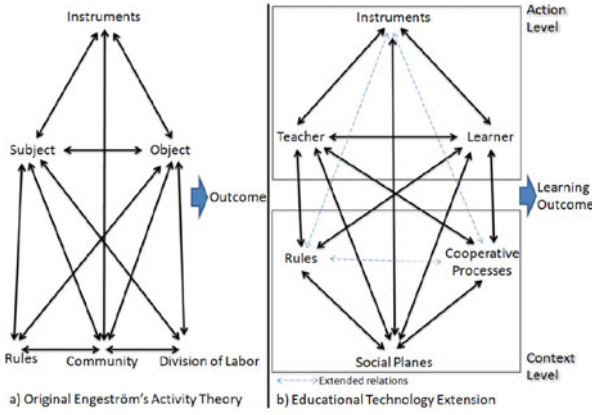
Fig. 1. Engeström's Activity Theory and educational technology extension.

activity dimensions [55]. From the computer supported collaborative learning (CSCL), Dillenbourg and Jermann's concept of *social planes* allows us to model activities taking into account social interactions [56]. From personalization and context management, the *actuator-indicator model* gives a framework to implements the software architecture by dividing its construction in four well-defined functional layers (i.e., sensor, semantic, control, and indicator) [57]. A brief summary of the evolution of these three mentioned pillars and the union of them is presented below.

- *Engeström's Activity Theory* [55] is the pedagogical base. This model describes the structural relations between the components of an activity (1. instruments, 2. a subject, 3. an object, 4. rules, 5. community, and 6. division of labor) to leads an outcome. The activity's outcomes can trigger new activities and each element can be related to individual activities. Thus, complex process can be described recursively. The three first components, called the action part, are visible. The other components are constrains in the context part. This model has been used widely to identify potential improvements of work settings for instance in [58], [59] among others. Recently in [60] its potential for personalized clinical diagnosis systems has been explored.

- Engeström's Activity Theory was introduced in educational technology by means of the concept of *social planes* [56]. Thus, the original element "community" is better expressed with the concept of "social planes". It found evidence for activating awareness and reflection through visualization of information from different social planes. The original Activity Theory had some other adaptations in this new area of research. The elements "teacher" and "learner" replace the "subject" and the "object" of the original model respectively. In addition, the element "division of labor" is understood in educational technology as "cooperative process". Finally, particular constraints of an educational software system (such as a Learning Management System or LMS) add extended relations between instruments, procedural rules (such as instructional rules), and cooperative process. Fig. 1 shows a parallel view of the original Engeström Activity Theory and the extended version for educational technology [55].

- The *Actuator-Indicator Model* allows implementation of the extended Activity Theory in educational software. For instance, in [16] the implementation of Activity-based Learner-models was related to the LMS Moodle, based on existing data in the Moodle log table and using the Moodle log function for the sensor layer. The Actuator-Indicator Model describes four technological layers to proceed from monitoring and assessment to suitable response to learners. The four layers are: 1) the sensor layer to collect data; 2) the semantic layer to aggregate the previous information with semantic meaning; 3) the control layer to process aggregated information using rules, data mining techniques or statistical analysis and also to coordinate the result delivery to display functions; and 4) the indicator layer to display the results of previous analysis in the corresponding interface.

All in all, with Activity-based Learner-models a wider communal perspective on the learning process is available for learning analytics and visualization of the learner model.

3   PROPOSAL SUMMARY

Our vision is that students with dyslexia or reading difficulties can learn at their own pace, knowing their strengths and weaknesses, and using their own strategies. To do so, the effectiveness and quality of their learning experience should be enhanced, by providing a better fit between the needs of affected students at a particular time and the learning facilities provided. However, the awareness of their reading difficulties (weaknesses) and learning styles (strengths) as well as their cognitive deficits should be encouraged in order to facilitate the learning reflection and self-regulation of it. In this sense, technologies have the potential to make a real difference for those with special learning needs, so that all students can make the most of their skills, irrespective of their disabilities. Accordingly, we highlight the construction of learner models in order to gather students' information and hence delivering of suitable personalized and adapted learning to their needs in a learning context.

By opening this learner model we provide the student with additional information (e.g., reading difficulties, learning styles and cognitive deficits) about their learning process that is not usually available to them, so that they may then decide where they need or wish to improve their skills, and carry out the corresponding learning activities autonomously to achieve this improvement. In this sense, we propose the use of learning analytics solutions to open the learner model.

Taking into account the foundations on Activity-based Learner-models presented in [16], we think that this technical framework is suitable for providing appropriate learning analytics to students with dyslexia or reading difficulties. Therefore, this study raises new challenges to describe activity-based learner-models for the effective application of learning analytics in the support of the affected students. On one hand, it is necessary to clarify how to implement this technical framework in independent educational software such as PADA (see Section 5). On the other hand, new roles need to be supported as important subjects of educational activities for assistance of dyslexia or reading difficulties; in this work the role of psychological expert emerges and requires different
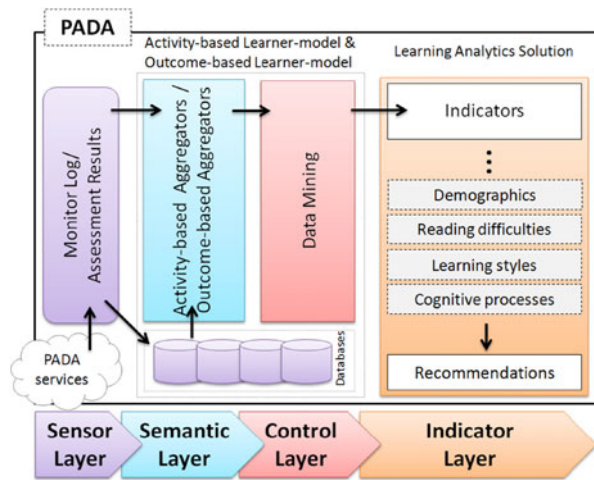
Fig. 2. The Activity-based Learner-models technical framework adapted to PADA.

communal perspectives. It is important to note that this role is not mentioned in the theories of learning orchestration. Finally, this work requires moderation of two types: *activity centered* and *outcome centered*. The prototypes of indicators implemented in [16] were only activity centered. The first type of moderation (activity centered) provides task support. This support can take many forms such as outlines, recommendations, storyboards, or key questions. It focuses on the modeling of a task, giving advice or providing coaching. The second type of moderation (outcome centered) is guiding by feedback. This type of learning support tackles the problem solving skills of students by providing them an external view on their performance. Therefore, such learning support is related to the assessment procedures that are defined for an educative process.

Fig. 2 shows the Activity-based Learner-model technical framework adapted from [16] to this work. This technical framework was extended to Outcome-based Learner-model. Thus, the monitoring and assessment can be either activity centered (e.g., Activity-based Aggregators) or outcome centered (e.g., Outcome-based Aggregators). Therefore, learning analytics can be on activities and performance of the students in terms of demographics, reading difficulties, learning styles and cognitive processes. From these learning analytics, the provision of recommendations by psychological experts could be planned. In section 5, the architecture of PADA is described and the challenges previously defined are answered.

4 STUDENT MODEL AND DATA COLLECTION

The learner model called in this research work student model comprises four submodels: 1) the *demographic submodel* considers variables related to student personal information such as their educational level, age and gender; 2) the *reading profile submodel* stores information about their reading difficulties as well as school life, personal and family history of learning difficulties, associated difficulties, and reading and writing habits; 3) the *learning styles submodel* is used to include the students' learning preferences; and 4) the *cognitive traits submodel* describes characteristics of the students that are gathered by evaluating the cognitive processes involved in reading such as phonological awareness,

orthographic processing, lexical access, processing speed, verbal working memory, and semantic processing.

Collecting data from the student model is performed separately by a set of four web-based tools (1. Demographic data forms, 2. ADDA, 3. ADEA, and 4. BEDA) which are independent of any educational software system. An overview of each one of these software tools is presented below.

- *Demographic data forms*. To capture the student's personal details, web-based forms were developed. These forms retrieve information on: age, gender, academic level and program, origin country, and if they use or not assistive technology, among other details.

- *Self-report questionnaire to detect dyslexia in adults* (ADDA, acronym for Spanish name *Autocuestionario de Detección de Dyslexia en Adultos*). Using ADDA the student's reading profile is captured. This tool was designed and built using as references the instrument proposed in [22]. Particularly, ADDA allows to: detect students at the university that inform of having dyslexia or reading difficulties, know the most common difficulties presented by them, identify reading profiles, and to provide feedback. It is a set of 100 questions to be answered by making a simple or multiple choices, by marking YES-NO or using open-ended. The questions covered a wide range of aspects organized into eight sections: history of learning difficulties (6 items); school and learning to read experience (13 items); history of family learning difficulties (4 items); current specific learning difficulties (32 items); associated difficulties (29 items); affective issues (5 items); reading habits (8 items); and writing habits (3 items). This questionnaire was administered using a web-based software. Questions were presented in text and audio format. Students used the mouse or keyboard to choose answers.

- *Self-report questionnaire to detect learning styles* (ADEA, acronym for Spanish name *Autocuestionario de Detección del Estilo de Aprendizaje*). Using ADEA the student's learning style is captured. This tool refers to the Spanish translation of the Felder-Silverman's Index of Learning Styles (ILS) [29]. The ILS was selected after reviewing numerous models in electronic and/or paper form. In particular, this model combines several learning style models in its four dimensions (i.e., processing, perception, input, and understanding), giving a more detailed description of the students. Additionally, it includes learning strategies, motivation for learning and preferences for organizing information. It is a set of 44 questions which allow inquiring the strategies that a student employs or prefers to select, process and work with information. As mentioned above, it classifies different kinds of learning styles along four dimensions: processing (active or reflective), perception (sensitive or intuitive), input (visual or verbal), and (sequential or global). This questionnaire also was administered using a web-based software. Questions were presented in text and audio format.

- *Assessment battery of dyslexia in adults* (BEDA, acronym for Spanish name *Batería de Evaluación de Dislexia en Adultos*). To capture the student's cognitive traits, we use BEDA. This tool is a novel computerized assessment battery for dyslexia and it focus on assessing cognitive processes associated with reading in Spanish. BEDA is web-based software and it is composed of 15 tasks that can be completed by students, 16-years old and older. The BEDA tasks detect and verify if a student has or not dyslexia and identify the associated cognitive processes that may be affected. BEDA consists of eight modules: six for the assessment of each cognitive process involved (i.e., 1. phonological processing, 2. orthographic processing, 3. lexical access, 4. processing speed, 5. verbal working memory, and 6. semantic processing), one for the analysis of results, and one for administration purposes. Thus, BEDA has various interfaces: the main menu, the pedagogical agent who provides the instructions, and an assessment task to assess phonological processing. A task in BEDA is composed of different items (or exercises) that students must perform. Additionally, every task has an instruction and some example items.

5 PADA: DASBOARD OF LEARNING ANALYTICS OF DYSLEXIA AND/OR READING DIFFICULTIES IN ADULTS

Once the data detection and assessment of students is saved, learning analytics of the data collected can be produced. In this paper PADA tool is proposed to produce such learning analytics. PADA is a dashboard for visualizing and inspecting fragments of information from the learner model related to reading difficulties for university students. It generates visualizations for each of the forms, questionnaires and cognitive assessment tasks presented above. These visualizations seek to create awareness among students about their reading difficulties, learning style, and cognitive deficits in order to facilitate reflection and encourage self-regulated of their learning, especially where reading is involved.

5.1 Architecture & Implementation

PADA's architecture, as aforementioned, is based on the Activity-based Learner-models technical framework so as to have a flexible and extendable dashboard which let to open more fragments of learner model if they are later required. Basically, the PADA components are: 1) the *databases*, which implement the sensor layer to collect data from the students and their activity and performance through forms (i.e., demographics), ADDA (i.e., reading profile), ADEA (i.e., learning styles) and BEDA (i.e., cognitive traits), 2) the *aggregators*, which implement the semantic layer to transform the data from the database according to the social plane (i.e., student, peers or class) and the social perspective (i.e., student, teacher or expert) required, 3) the *data mining*, which implement the control layer to process the aggregators using different rules and statistical analysis, 4) the *learning analytics*, which implement the indicator layer to display in the corresponding interface the visualizations (i.e., Overview, Reading Difficulties,
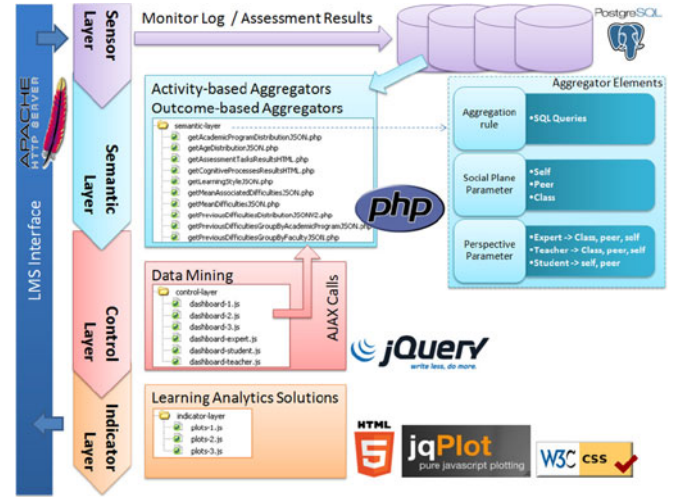

Fig. 3. Architecture and technology behind PADA.

Learning Styles, and Cognitive Processes), and 5) a *web server* that stores the implemented layers and allows communication between users and PADA by means of a browser.

Three challenges were raised in Section 3 related with the particular implementation of Activity-based Learner-models in PADA: (a) how to implement this technical framework in an independent educational software such as PADA?; (b) how can it include a new role of psychological expert?; and (c) how can be added an outcome-centered moderation?

To answer these challenges, Fig. 3 summaries technology details to implement the four layers for PADA (answer to the first challenge). There are also details of aggregators' elements (to answer the second and the third challenge). The sensor layer uses PostgreSQL databases to save assessment results and monitor logs. The semantic layer is entirely implemented with PHP. In this layer a set of classes and functions are used to define aggregators. An aggregator function receives at least two parameters: a) the social plane, and b) the perspective. Inside the aggregator function a SQL query is built and launched. This query changes depending on the value of parameters received. Thus, the same aggregator returns different semantic data.

In PADA there are two kinds of aggregators. The outcome-based aggregators collect data of detection and assessment results from the database. The activity-based aggregators collect data from monitor logs from the database. The control layer holds several Javascripts based on the jQuery Javascript library. Scripts request particular aggregators. The request is an AJAX call to the server. Then intelligent procedures (data mining algorithms) transform the information to send it to the indicator layer. A final processing is made in the indicator layer to produce adequate plots. These plots use HTML5 elements such as the <canvas> element. A particular library is used also, the jpPlot library. The final aspects of the interface are arranged using CSS. In particular, de jqPlot library was selected after testing it and other five libraries. The jqPlot library has functions to plot a wide range of charts, the aspect of plots is nice and adaptable, and finally the time of response is adequate.

To sum up the results of this architecture and their implementation are visualizations for different social planes (student, peers, and class) and social perspectives (student,

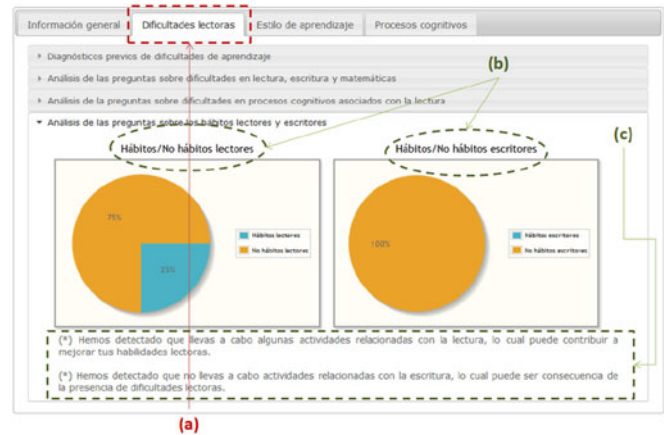Fig. 4. PADA interface: Tab of reading difficulties analytics.

Fig. 6. PADA interface: Tab of learning style analytics.

teacher, and expert); although in this paper we only consider the student's perspective in the case study reported. Therefore, in this student's perspective, the visualizations that are shown are mostly for the student's social plane, although some of them include views of the peers and class planes in order to provide comparisons and generate reflection among students taking reference points. The social plane student shows visualizations of a single student (i.e., the student logged in PADA), the social plane peers shows visualizations of the entire class minus the student logged in PADA, and the social plane class shows visualizations of the entire class.

5.2 Interfaces

The PADA interface was divided into four tabs depending on the learner submodel: 1. demographics, 2. reading profile, 3. learning styles or 4. cognitive traits. These tabs allow students to explore different visual representations of their activity and performance and provide feedback to support them to recognize strengths and weakness in their reading competences. These tabs also provide some parallel views of an individual students, her peers, and all as a class, in order to identify the severity of their difficulties according to the results of other matched by age and academic level. The analyses are made according to statistical analysis taking into account the criteria set for the construction of each of the data collection tools.

- *Overview* refers to personal details of the participant students (i.e., age, gender, academic program, etc.). The tab visualizes (1) the number of participant students, (2) the details of the student in session, (3) the time spent to complete the data collection tools, (4)
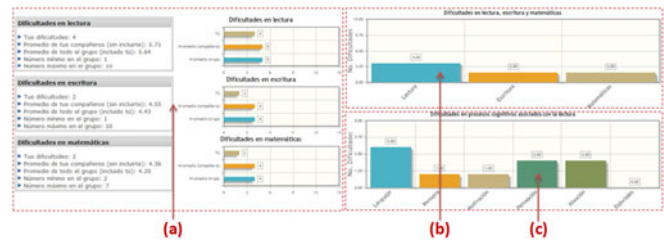
the age distributions, and (5) the number of student per academic program.

- *Reading difficulties* (see Fig. 4a) refers to reading profile of the participant students. The tab visualizes (1) the previous diagnosis of learning disabilities, (2) the number of learning difficulties in reading, writing and math reported by the students, (3) the number of associated difficulties with reading (i.e., language, memory, motivation, perception, attention, and spatial-temporal) reported by the students, and (4) the reading and writing habits reported by the students. Fig. 4b shows results of the reading (left) and writing (right) habits by the single student while Fig. 4c shows feedback provided to the student. Fig. 5a displays results of the difficulties in reading, writing and math by the single student, peers and class while Fig. 5b shows a summary by the single student. Fig. 5c reports a summary of results of the associated difficulties with reading by the single student.

- *Learning styles* (see Fig. 6a) refers to ways in which participant students prefer to learn. The tab visualizes the major preferences of these students. Fig. 6b shows result for a single student with learning style: active, sensory, visual and sequential. Fig. 6c displays feedback provided to the student.

- *Cognitive processes* (see Fig. 7) refer to processes associated with reading that were assessed. The tab visualizes (a) the results for each assessment task, (b) the percentages of successes/errors for each assessment task, (c) the result for cognitive process, and (d) the percentages of success/errors for each cognitive process. Fig. 7a shows results of the difficulties in the assessment task of phonological processing. Fig. 7b illustrates results of successes/errors for the assessment task "Segmentation into Syllables". Fig. 7c reports results for the cognitive processes by single student.

6 CASE STUDY

Our concern is whether students would find PADA useful to detect their reading difficulties and their implications for learning and cognition. More specifically, our study was based on answering the following questions: (a) Could

Fig. 5. PADA interface: Analytics with summaries of reading and associated difficulties.
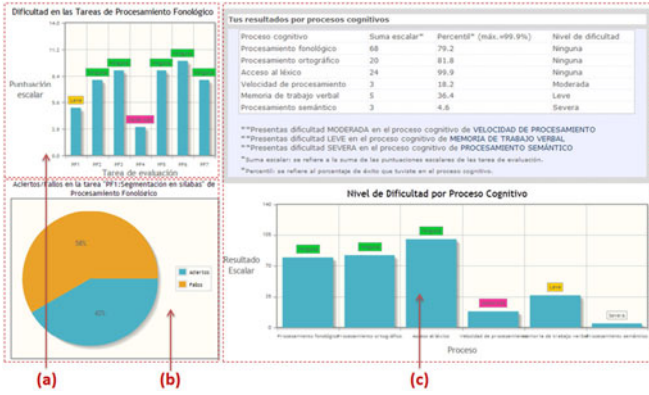
Fig. 7. PADA interface: Tab of cognitive processes analytics.

students view their student model?; (b) Could students understand that model?; (c) Did students agree with the visualizations presented in that model?; (d) Were students aware on their difficulties, learning styles and cognitive deficits?; (e) Could PADA support students to perform self-regulated learning?; and (f) Were learning analytics useful for students?.

6.1   Method

6.1.1   Participant

Participants were 26 students (11 male and 15 female), with ages ranging from 21 to 53 years (M = 27.538, SD = 6.848) and coming from 15 classrooms of different programs (including, pedagogy, psychology, law, social work, business administration, economics, and engineering) and levels, (undergraduate and graduate) at the University of Girona with basic skills for understanding statistical graphs and tables. Eight participants had a previous diagnosis of dyslexia, i.e., they had been formally diagnosed with dyslexia during their primary or secondary schooling, through an official psychoassessment procedure. All others students were affected with some reading difficulties which may be related to symptoms of dyslexia. Participants were recruited by the coordinators of the faculties and/or schools through e-mail and website announcements. However, most dyslexic participants were recruited in collaboration with the *Program to Support People with Disabilities of the University of Girona*. Participants took part in an individual session that lasted an average of 60 minutes. Seven of them needed an average of two sessions to complete the tests without feeling tired.

6.1.2   Instruments

In previous research work done by authors in [61], a pilot study was conducted with some tools including PADA, in a computer lab using a Windows desktop computer equipped with a screen, a keyboard, a mouse, headphones, microphone, and Internet connection. In this work the case study was conducted in a different computer lab using the software and hardware tools. Other software requirements were installing Java and an appropriate version of the Firefox web browser.

To carry out the case study all the web-based tools presented in Section 4 were required: (a) forms, (b)ADDA, (c) ADEA, and (d) BEDA. After all data were collected, PADA tool was enabled and became operational for participants. To gather participants' feedback about whether PADA could assist them in understanding their student models and could

be useful to identify reading difficulties, learning styles and cognitive deficits, we provided them with an online survey.

As shown in Table 1, the survey consisted of 37 statements as follows. One question to inquire whether participants have previous diagnosis of dyslexia ('yes' or 'no'). Eight 5-point Likert scale questions to inquire about navigation, and understanding of the visualizations were presented in each tab of PADA ('1 = never' to '5 = always'). Nine 5-point Likert scale questions inquired about the agreement or disagreement with the contents of the student model in term of reading difficulties, learning style and cognitive deficits detected ('1 = strongly disagree' to '5 = strongly agree'). Seven 5-point Likert questions inquired about the awareness and self-regulation that can support PADA ('1 = never' to '5 = always'). There were three open-end questions to clarify the moments reported by students regarding awareness of difficulties, learning styles and cognitive deficits. Four open-end questions accompanied each of the awareness questions to inquire about more visualizations which could improve the experience with PADA. Four 5-point Likert questions inquired about PADA's big-picture usefulness ('1 = never' to '5 = always'). One rank order scale question to inquire about the opinion on the type of recommendations that the participants would prefer to receive. Finally, one open-ended question gave the opportunity for additional comments.

6.1.3   Procedure

Prior to the case study, PADA was studied to evaluate the performance and usability in a pilot study with some students from the University of Girona. Once PADA was improved based on the findings of the pilot study, it was given to the participants. The present study focused on the use of PADA for visualizing and inspecting student models. Participants were given an explanation of the web-based tools so as they could familiarize themselves with them, before commencing their sessions. Once the participants started a session, first, they could register their personal details information. Then, they were asked to enter ADDA and fill in the self-report questionnaire in order to detect reading difficulties. Afterwards, they were asked to access ADEA to fill in the self-report questionnaire for detecting their learning styles. Subsequently, they completed all tasks of BEDA which evaluates their cognitive processes associated with reading. They were then asked to enter PADA and navigate the entire tool. Finally, when participants had browsed through PADA, the teacher gave them access to the online survey.

During the process, participants were accompanied by one teacher with experience in using all of the tools. To complete this survey, they were left alone in order to not bias the responses. Approximately, this survey takes 10 to 20 minutes to complete.

6.2   Results

This study allows evaluating students' opinions of the support for activity and performance analytics (i.e., visualizations) provided by PADA. These results presume to give a possible answer to the research questions.

From the *navigation* category, the results indicated that all 26 participants navigated through the different tabs and visualizations presented in the graphical user interface of

TABLE 1
Overview of Case Study Survey

Descriptive information	
DES.1.	Have you been diagnosed with dyslexia?

Navigation

A.1. to A.4.	Did you check graphical and textual visualizations in... Table 1?, Table 2?, Table 3, Table 4?

Understanding

B.1. to B.4.	Was it easy for you to understand the meaning of the visualizations displayed on... Table 1?, Table 2?, Table 3?, Table 4?

Inspection

C.1.	Do you agree with the visualizations about your particular reading difficulties?
C.2.	Do you agree with the visualizations about your associated difficulties (i.e., languages, memory, etc.)?
C.3.	Do you agree with the visualizations about your reading habits?
C.4.	Do you agree with the visualizations about your writing habits?
C.5.	Do you agree with the visualizations about your learning style?
C.6.	Do you agree with the visualizations about your successes/errors in each cognitive assessment task?
C.7.	Do you agree with the visualizations about your successes/errors in each cognitive process?
C.8.	Do you agree with the visualizations about your results in the cognitive assessment tasks?
C.9.	Do you agree with the visualizations about your cognitive deficits?

Awareness

D.1.	Was it possible for you to be aware about your reading difficulties?
D.1.*	The former was possible by means of...
D.2.	Was it possible for you to be aware about your learning style?
D.2.*	The former was possible by means of...
D.3.	Was it possible for you to be aware about your cognitive deficits?
D.3.*	The former was possible by means of...
D.4.	Was it helpful for your awareness process to view your learning analytics versus the performance of others (i.e., "peers" and "class"?
D.5.	Did you learn more about your difficulties than you knew previously?
D.6. to D.9.	What other visualizations do you think could improve your experience in... Table 1?, Table 2?,Table 3?, Table 4?

Self-regulation

E.1.	Do you think that PADA can help you in reflecting and making decisions to self-regulate your learning process?

Usefulness

F.1.	Was it useful for you to check the visualizations in multiple views (i.e., graphical and textual)?
F.2.	Did the presented learning analytics provide feedback on your reading performance?
F.3.	Do you think PADA helps to recognize strengths and weaknesses in your reading process you could use to improve your academic performance?
F.4.	Did you find all the visualizations you expected?

Recommendations

REC.1.	Finally, if you could have a recommender system in PADA, what kind of recommender do you prefer? '1 - advices recommended by dyslexia-affected peers', '2 - activities/tasks recommended by expert', '3 - exercises, games, and other resources recommended by experts'.

Comments

COM.1.	Please, if you have more comments about your experience with PADA ...

Note. Table 1 = tab of overview; Table 2 = Tab of reading difficulties; Table 3 = Tab of learning styles; Table 4 = tab of cognitive processes.

PADA. In terms of *understanding*, 84.6 percent of the participants always (53.8 percent) and almost always (30.8 percent) understood the meaning of the visualizations shown in the tab of overview (question B.1.). 96.1 percent of the participants always (53.8 percent) or almost always (42.3 percent) understood the visualizations in tab of reading difficulties (question B.2.). 80.8 percent of the participants always understood the visualizations in tab of learning styles (question B.3.), while the remaining 19.2 percent of them almost always understood. Regarding the tab of cognitive processes (question B.4.), 69.3 percent of participants always (30.8 percent) and almost always (38.5 percent) understood the visualizations presented, while 30.8 percent sometimes and 3.8 percent almost never understood them. A multivariate analysis of variance with the independent variable of dyslexia (dyslexic or non-dyslexic) and the four dependent variables of understanding visualizations (overview, reading difficulties, learning styles, cognitive processes) was statistically significant (Roy's largest root = 1.01, $F_{(4, 21)} = 5.31$, $p = 0.004$). However, a multivariate analysis of variance with the independent variable of gender (female or male) and the four dependent variables of understanding visualizations was not significant (Roy's largest root = 0.33, $F_{(4, 21)} = 1.71$, $p = 0.18$).

With regard to the remaining categories (i.e., inspection, awareness, self-regulation, and usefulness), we present the results considering separated groups of participants in students with and without diagnosis of dyslexia (i.e., dyslexic and non-dyslexic, respectively). This is because participants with previous diagnosis of dyslexia may be familiar with similar tools, since they could have received training, they could have a clear picture of their difficulties, and/or they could have adopted effective compensatory strategies to overcome their difficulties, which could provide us different perspectives on the visualizations of PADA.

In the *inspection* category, participants indicated being agreed or disagreed with the visualizations of the student model. As shown in Table 2, 92.4 percent of the participants strongly agreed (46.2 percent) or agreed (46.2 percent) with the reading difficulties detected (question C.1.). 84.6 percent of the participants strongly agreed (42.3 percent) or agreed (42.3 percent) with the visualizations for associated difficulties with reading (question C.2.) and reading practices (questions C.3.), while 11.5 percent were indifferent to these visualizations. 76.9 percent of the participants strongly agreed (32.3 percent) or agree (34.6 percent) with their writing practices (question C.4.), 15.4 percent were indifferent and 7.7 percent were disagreeing with them. Regarding the visualizations of learning style (question C.5.), all participants strongly agreed or agreed with them. With regard to the visualizations of cognitive processes (questions C.6. to C.9), we found that participants strongly agreed or agreed with 80-92 percent of the analytics presented. The dyslexic participants not revealed significant differences in questions C.1. to C.7. compared to their non-dyslexic peers. However, in questions C.8. and C.9. some differences were showed. Multivariate analyses of variance of the nine dependent variables of inspection (reading difficulties, associated difficulties, reading habits, writing habits, learning style, cognitive assessment task, cognitive process, results, and cognitive deficits) was insignificant for both the independent variable

TABLE 2
Results of Inspection Category

Question	Responses (n = 26)					Non-dyslexic (n = 18)		Dyslexic (n = 8)	
	Strongly disagree	Disagree	Indifferent	Agree	StronglyAgree	M	SD	M	SD
C.1.	0	2 (7.7%)	0	12 (46.2%)	12 (46.2%)	4.44	0.784	4.00	0.926
C.2.	0	1 (3.8%)	3 (11.5%)	11 (42.3%)	11 (42.3%)	4.28	0.752	4.13	0.991
C.3.	0	0	3 (11.5%)	14 (53.8%)	9 (34.6%)	4.22	0.732	4.25	0.463
C.4.	0	2 (7.7%)	4 (15.4%)	11 (42.3%)	9 (34.6%)	3.94	1.056	4.25	0.463
C.5.	0	0	0	9 (34.6%)	17 (65.4%)	4.78	0.428	4.38	0.518
C.6.	0	1 (3.8%)	3 (11.5%)	16 (61.5%)	6 (23.1%)	4.11	0.832	3.88	0.354
C.7.	0	2 (7.7%)	3 (11.5%)	13 (50%)	8 (30.8%)	4.11	1.023	3.88	0.354
C.8.	0	2 (7.7%)	3 (11.5%)	14 (53.8%)	7 (26.9%)	4.17	0.857	3.63	0.744
C.9.	1 (3.8%)	1 (3.8%)	0	17 (65.4%)	7 (26.9%)	4.28	0.752	3.63	1.061

of dyslexia (Roy's largest root $= 1.03$, $F(9, 15) = 1.71$, $p = 0.17$) and gender (Roy's largest root $= 0.76$, $F(9, 15) = 1.27$, $p = 0.32$).

Table 3 shows the findings in the *awareness* category that participants could achieve by interacting with PADA. Although most participants always (42.3 percent) or almost always (26.9 percent) indicated that they were able to be aware of their reading difficulties (question D.1.), it is worth noting that 28 percent of them indicated that sometimes (19.2 percent), almost never (7.7 percent) or never (3.8 percent) achieved such awareness. Regarding the visualizations of learning style (question D.2.), we found that almost all participants achieved the awareness. For visualizations of cognitive processes (question D.3.), 77 percent of the participants indicated they achieved be aware of their cognitive deficits, while 23 percent indicated that they did it only sometimes (3.8 percent), almost never (11.5 percent) or never (7.7 percent). Comparing non-dyslexic and dyslexic, we did not find significant differences for these two groups in the aforementioned questions (D.1. to D.3.). However, analyzing questions about peer or group comparison (question D.5.) and increased knowledge of difficulties (question D.5.) revealed some differences. In question D.4. (non-dyslexic M $= 4.11$, SD $= 1.231$; dyslexic M $= 3.88$, SD $= 0.835$) and question D.5. (non-dyslexic M $= 4.22$, SD $= 0.808$; dyslexic M $= 3.50$, SD $= 0.926$).

A multivariate analysis of variance with the independent variable of dyslexia (dyslexic or non-dyslexic) and the five dependent variables of awareness (reading difficulties, learning styles, cognitive deficits, peer or group comparison, and increased knowledge) did not yield statistically significant results (Roy's largest root $= 0.40$, $F(5, 19) = 1.52$, $p = 0.23$). Similarly, a multivariate analysis of variance with the independent variable of gender (female or male) and the five

dependent variables of awareness was also not significant (Roy's largest root $= 0.10$, $F(5, 19) = 0.39$, $p = 0.84$). Questions D.6. to D.9. collected several opinions given by participants for improving their experience with each tab of PADA.

The *self-regulation* evaluation that can support PADA was represented in the E.1. question. We found that 61.5 percent of the participants always (11.5 percent) or almost always (50 percent) took conscientious that PADA could encourage self-regulation in the learning process, 30.8 percent indicated that only sometimes could it, while 7.6 percent indicated that almost never or never could it. A univariate analysis of variance with the independent variable of dyslexia and the dependent variable of self-regulation was not significant ($F(1, 23) = 0.03$, $p = 0.85$) and neither were there any significant differences with respect to gender ($F(1, 23) = 0.14$, $p = 0.71$)

In relation to the *usefulness* of PADA (see Table 4), participants reacted positively to the idea of multiple views (question F.1.), with 88.5 percent always and 11.5 percent almost always useful as response. Also, they were positive about how easily they could recognize the strengths and weaknesses of their reading process using PADA (question F.2.), with 23.1 percent always, 50 percent almost always and 23.1 percent sometimes useful as response. But, they were not so positive about the use of PADA to improve their academic performance (question F.3.), since 23.1 percent of participants almost never found it useful. However, participants indicated that PADA showed the visualizations that they expected to find (question F.4.). Comparing the responses of dyslexic and non-dyslexic participants, we only found a significant difference in question F.4. (non-dyslexic M $= 4.22$, SD $= 0.548$; dyslexic M $= 3.50$, SD $= 0.535$). A multivariate analysis of variance with the independent variable of

TABLE 3
Results of Awareness Categories

Question	Responses (n = 26)					Non-dyslexic (n = 18)		Dyslexic (n = 8)	
	Never	Almost never	Sometimes	Almost always	Always	M	SD	M	SD
D.1.	1 (3.8%)	2 (7.7%)	5 (19.2%)	7 (26.9%)	11 (42.3%)	4.00	1.237	3.88	0.991
D.2.	0	0	2 (7.7%)	5 (19.2%)	19 (73.1%)	4.72	0.575	4.50	0.756
D.3.	2 (7.7%)	3 (11.5%)	1 (3.8%)	12 (46.2%)	8 (30.8%)	3.78	1.263	3.88	1.246
D.4.	0	3 (11.5%)	6 (23.1%)	4 (15.4%)	13 (50%)	4.11	1.231	3.88	0.835
D.5.	0	2 (7.7%)	4 (15.4%)	12 (46.2%)	8 (30.8%)	4.22	0.808	3.50	0.926

TABLE 4
Results of Usefulness Categories

Question	Responses (n = 26)					Non-dyslexic (n = 18)		Dyslexic (n = 8)	
	Never	Almost never	Sometimes	Almost always	Always	M	SD	M	SD
F.1.	0	0	0	3 (11.5%)	23 (88.5%)	4.94	0.236	4.75	0.463
F.2.	1 (3.8%)	0	6 (23.1%)	13 (50%)	6 (23.1%)	3.94	1.056	3.75	0.463
F.3.	0	6 (23.1%)	5 (19.2%)	8 (30.8%)	7 (26.9%)	3.72	1.274	3.38	0.744
F.4.	0	0	5 (19.2%)	16 (61.5%)	5 (19.2%)	4.22	0.548	3.50	0.535

dyslexia (dyslexic or non-dyslexic) and the four dependent variables of usefulness (multiple views, reading performance feedback, reading process evaluation, and expected visualizations) was statistically significant (Roy's largest root = 0.58, $F(4, 20) = 2.87$, $p = 0.05$). However, a multivariate analysis of variance with the independent variable of gender (female or male) and the four dependent variables of usefulness was not significant (Roy's largest root = 0.17, $F(4, 20) = 0.83$, $p = 0.52$).

Concerning the rank order question, participants organized three options of recommender systems from most to least important to them. Option R2 is the most preferred by participants (15 of 26; 57.7 percent). Option R3 is the second, which was selected by 7 participants (26.9 percent). While option R1 is the less preferred, since only 4 participants (15.4 percent) reported they preferred this option.

Finally, some additional comments made by participants suggest their interest in PADA and willingness to contribute to its improvement:

- "It is a very useful tool—it helped me to reflect on the difficulties I have; it was good to learn about my learning style to reinforce my strategies for studying. I think the cognitive processes analytics are fine, but I missed more feedback on them."
- "It is very gratifying to see the results both textual and visual, since the reports I used to receive they are all textual and also hard to understand."
- "It would be interesting to have available a tutorial explaining the issues addressed by PADA which includes: symptoms, causes and solutions, cognitive processes, and so on."
- "I would appreciate to see some recommendations for dealing with my difficulties and strengthening my abilities."
- "I never had the opportunity to know such information, and I think that can be very helpful to improve my studying habits. I also believe that this information can be very useful for our teachers."
- "I think PADA may show more information. I spent almost 2 hours completing questionnaires and doing exercises. I would like to see more details of what I did."

7 DISCUSSION

There is abundant evidence that dyslexia does not disappear with age or training [62], [63]. On the contrary, despite their effort, when compared to their peers, affected students still show significant difficulties in reading tasks [64], [65], [66], [67]. Despite their difficulties, many dyslexic students could develop compensatory strategies to help them succeed in their studies [3], [4], [68], [69] and get into university, although they still underperform in reading-related tasks [62], [70]. For example, according to the Dyslexia Association of Jaen between 6 percent and 8 percent of the university students are dyslexics.

Surprisingly, not all students whose performance is affected by dyslexia are diagnosed and/or assisted before starting their studies at university; therefore, there are many students with symptoms or reading difficulties who have not been diagnosed with an official psychoassessment procedure. Consequently, a considerable number of students enter university without having reading skills expected, and would require support to cope with high reading demands.

Thus, higher educational institutions are in clear need of specific resources to detect students with or without a previous diagnosis of dyslexia that still show reading difficulties, and to provide assistance to them. In this sense, PADA and its complementary services for data collection could be a suitable tool to achieve these two goals. According to [22], [71], appropriate tools in Spanish cannot be found to assist these difficulties in adult dyslexics.

The main focus of this study was assessing the usefulness of PADA in term of assisting university students with dyslexia or reading difficulties to achieve awareness, so that, reflection and self-regulation could be facilitated during their learning process. Findings of previous studies of [8], [9], [10], [42] revealed that awareness is a powerful predictor for their academic success. In this regard, a survey was created which explores PADA's aspects such as navigation, understanding, and inspection capabilities. In particular, the survey investigated awareness, as well as, support for reflection and self-regulation which PADA sought to provide. Finally, overall usefulness of PADA was assessed.

According to the *navigation* results, the PADA tool is found to be well implemented. Students reported viewing their entire student model by browsing through all the tabs of PADA and checking different graphical and textual visualizations. They also commented that PADA adequately respond to their navigation pace, it was friendly and intuitive, and it graphical user interface was suitable.

On the other hand, although students reported that it was easy to *understand* the different visualizations displayed, they also commented that it took them quite some time, mainly those related to cognitive processes. We believe this could be due to two factors: (a) there are many visualizations in this tab which makes students take longer to understand, and (b) the cognitive process concept is new for students which makes it difficult for quick comprehension. Furthermore, multivariate analysis showed significant

differences between dyslexic and non-dyslexic students. Surprisingly, dyslexic students found it a little more difficult to understand the meaning of the cognitive processes visualizations. It was expected that these students with previous diagnosis were more familiar with this concept. At this point, it is worth noting that dyslexia definitions and diagnostic criteria have changed since these students were first identified during childhood.

Regarding the *inspection*, overall, students were rather agreeing with the visualizations presented. This could indicate that PADA is reliable, though this claim may require further analysis of the system's confidence as presented by [48]. However, it is worth noting that a slightly significant percentage of students were "indifferent" and "disagreed" with the visualizations of reading and writing habits. We are assuming that students who were "indifferent" might not have understood the visualizations presented, while students "agreed" or "disagreed" had understood the visualizations. Accordingly, it was expected that the inspection of the student model would lead to awareness and subsequent reflection and self-regulation. On the other hand, multivariate analyses were insignificant between dyslexic and non-dyslexic, but analysis showed slight differences in visualization of cognitive processes. Some dyslexic students expected greater cognitive deficits than those presented in PADA.

In relation to *awareness*, although most students reported having reached awareness, a slight percentage reported not having succeeded with a few visualizations of reading difficulties and cognitive processes. On the one hand, we assumed that the positive perceptions of most of the students are due to the novelty of incorporating the cognitive processes concept across students' learning process. On the other hand, it was observed that both dyslexic and non-dyslexic students require more feedback on the visualizations presented to increase their awareness. To understand better why the slight percentage of students did not increased their awareness, we highlight some of their comments: *"I need more feedback to understand the difficulties presented and be aware of them"*, *"I've had dyslexia for years. So, I know what my reading difficulties are. Then, I didn't have an increased awareness"*, *"I enjoyed the visualizations presented, but it's not clear the meaning of each cognitive processes"*, *"I do not quite understand the percentages that it shows to me"*. In addition, from the comments it was identified that some dyslexic students did not increase their awareness because they already knew their particular difficulties since childhood. This would indicate that the visualizations of reading difficulties increase more awareness among non-dyslexic students. This was also supported by peer or group comparisons which are presented in these visualizations, as well as the acceptance of these students to increase knowledge of their difficulties.

Similarly, the results on *self-regulation* showed that PADA can provide successful mechanisms to encourage student independence in overcoming their difficulties during the learning process.

Although the results of *usefulness* category were generally positive, i.e., students were satisfied about multiple views, reading performance feedback, and expected visualizations, these results were not so positive in recognizing the strengths and weaknesses in reading. Again, it confirmed the need to include more feedback on the visualizations presented.

Furthermore, multivariate analysis showed significant differences between dyslexic and non-dyslexic students, particularly because dyslexic students expected more visualizations of their model. Emerging research findings indicate relationships between emotional, notational, and social aspects of learning analytics. These aspects could be considered in the usefulness evaluation of PADA's visualizations. For example, studies of [72] show that the traffic lights representations followed by smile notations have high emotional activation in students, because of their general socio-cultural availability and quick comprehension. In [73], the notations and social aspects also are studied in order to increase the interest of the students in their learner models. Further, in [74], authors note that release of model fragments to peers could help to find suitable collaborators peers with common difficulties. Additionally, facilitating collaboration between partners can improve understanding of themselves and each other by gaining information from their respective learner model. Here, it is worth noting that visualizations could play a role in guiding collaborative learning by amplifying certain kind of social interactions [75], [76].

Regarding students' gender, there were no significant differences between female and male students in any of the aspects evaluated (i.e., navigation, understanding, inspection, awareness, self-regulation, and usefulness). This is a topic of interest since previous studies have often reported a higher rate of difficulties for males than females [77], [78], as well as differences in the particular difficulties presented by males and females, and the specific assistance that they require [79], [80]. For instance, regarding attitude to technology, males generally are performing better in learning conditions which included visual resources, while females perform better with the traditional text-based resources [81].

Finally, over 100 comments were made by students. It was surprising that students made comments as the open-ended question was not mandatory. They made comments to clarify some answers, they suggested more visualizations to improve their experience, and they made comments that contribute to the overall enrichment of PADA (see Section 5). All in all, based on the empirical case study results, we believe that PADA was well-received, and it could be used to facilitate the learning process of students with dyslexia or reading difficulties.

Nevertheless, the findings of this study need to be viewed in light of some limitations. First, PADA is a tool to visualize the presence of reading difficulties or subjective symptoms implying dyslexia, the learning styles, and the presence of cognitive deficits, as well as to provide feedback. However, this feedback is still limited, so this may lead to the creation of specific and necessary recommendations to support reflection and self-regulation of difficulties and learning process. Taking into consideration students' suggestions, a recommender system of learning activities provided by expert (e.g., psychologist, pedagogue, or counselor) could be implemented as future work. In addition, the students also offered some suggestions for improvement of the dashboard with new functionalities such as extend visualizations, giving more detail feedback on, and creating a tutorial. Second, PADA displayed visualizations for each of the tools that collect data (namely demographic data forms, ADDA, ADEA, and BEDA), but it does not create aggregators that combine data between tools. Further

research is proposed to analyze the influence between data collected in order to improve the assistance. Finally, future work includes the execution of additional experiments with more dyslexic students, so as to evaluate the feedback provided by them about the effectiveness of the dashboard compared with the feedback of non-dyslexic students (i.e., have a balanced group of dyslexic and non-dyslexic participants). We also believe that using PADA in a LMS can be useful in terms of improving the student's academic performance in general and this needs to empirically investigated.

8 CONCLUSION

This paper has introduced PADA, a web-based tool for visualization and inspection of reading difficulties in university students. With PADA experts, teachers and students are involved in a new approach to support a better learning in higher education classes. Particularly, this novel tool generates automatic visualizations from the detection and assessment tools designed previously in collaboration with experts in learning disabilities. A case study and survey with dyslexic and non-dyslexic students was described.

Based on the results of this study it has been demonstrated that PADA is a useful tool. It was shown that PADA's functionality and navigability are good. Students were capable of understanding and inspecting their own student model through different visualizations. More interestingly, PADA was shown to be able to assist students in creating awareness, as well as facilitate reflection and self-regulation in the learning process.

To sum up, PADA is first to provide a tool of assistance for university students affected with dyslexia or reading difficulties. PADA is based on the fundamentals of open learner modeling and learning analytics [12]. Particularly, its architecture is based on Activity-based Learner-models technical framework proposed by [16] and extended with Outcome-based Learner-models for new roles in an independent web-based tool. PADA displayed visualizations of different tools previously implemented such as forms, ADDA, ADEA, and BEDA. Results of the case study shown that PADA is a usefulness tool, however, it is necessary to continue this work to study this usefulness with larger samples of dyslexics and non-dyslexics. Future research may provide a clearer picture of the learning analytics for awareness, reflection and self-regulation in the learning process among Spanish-speaking affected students. There is, of course, a need to replicate these findings and to validate them in other university contexts.

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