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Emerging Technologies for ICT based Education for Dyscalculia: Implications for Computer Engineering Education*

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In recent years there have been significant advances in the use of ICTs (Information and Communication Technologies) in the education of students with learning disabilities. In this paper we represent some important studies which highlight the importance of using ICTs, with special reference to online and mobile learning applications, both for assessment and intervention required for students with dyscalculia. Results of the studies revealed that the use of ICTs in education and especially in children with dyscalculia, may in the future become an integral part of the global education process, however there are still many parameters to be investigated.

Keywords: assessment; ICT; intervention; dyscalculia; online applications; mobile applications

1. Introduction

Dyscalculia is a Learning Disability characterized mainly the difficulty in basic arithmetic skills, such as addition, subtraction, multiplication and division [1]. Dyscalculia can occur in people from across the whole IQ range. It is wrong to be considered that those who perform poorly in mathematics have dyscalculia but only people who have specific numerical disorders [2]. Children with dyscalculia often face difficulties in daily activities such as handling money, telling the time or following directions or map reading [3].There are several factors that may cause dyscalculia such as genetic predisposition, low intelligence, not properly structured curricula, inadequate teaching in school, mathematical anxiety and neurologic deficits [4]. It is estimated that the prevalence of dyscalculia range between 3 and 6% of the world population.

Dyscalculia is a term from the Greek 'dys' and the Latin 'calculia'. There are several different terms to describe the mathematic learning disabilities. Ladislav Kosc (1974) a Czechoslovakian psychologist introduced the term "Developmental Dyscalculia". Koontz and Berch (1996) used the term "Arithmetic Learning Disabilities". Hich prefers the term "Specific Arithmetic Difficulties", while Temple and Sherwood (2002) use the term "Number fact Disorder" [5].

There is immediately correlation between dyscalculia and Working Memory difficulties, i.e. memorizing some digits in a specific order. As Geary claims, there are three cognitive components to MLD. These are the retrieval of arithmetic facts from long term semantic memory, the execution of procedures for solving arithmetic problems and the ability to represent and interpret visuospatial representations of mathematical information [6].

The most common way of subtyping dyscalculic children is whether they have or not reading disabilities, as it is estimated that the 40% of children with dyslexia also have math disability. Dysgraphia, finger agnosia, Attention-Deficit Hyperactivity Disorder and difficulties with left right discrimination have also been associated with dyscalculia. It is also evaluated that a quarter of children with dyscalculia have ADHD [7, 8]. Another classification of dyscalculia (Kosc 1974) distinguishes the following forms: verbal, practognostic, lexical, graphical, ideognostical and operational developmental dyscalculia [9].

Learning difficulties such as dyscalculia remain through life, although with early diagnosis and the appropriate intervention, students can show significant improvement [10]. The integration of ICTs in special education aims to exploit assistive technology to the inclusion of students with special education needs. A promising approach, therefore, is to construct adaptive software informed by the neuroscience findings on the core deficit in dyscalculia [11]. The studies included in this article examine what is the contribution of online, mobile and other learning applications (educational learning—psychological learning) to the assessment and intervention of dyscalculia. Primarily, using internet, which is now the largest database of information, anyone interested can be informed for everything relevant to dyscalculia or any other learning disability. Additionally, the last 2 decades there were developed several application programs

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and tools for dyscalculia detection, diagnosis or intervention, some of them free available. These applications are available on Personal Computers, Web, smartphones or tablets [12]. Furthermore, in this paper we present some virtual environment applications and some which are based on Artificial Intelligence techniques. According to the studies, the use of ICTs in teaching can deliver faster and better results in students' progress than the ordinary teaching methods applied so far, and become an additional incentive for the students' participation in class. Besides it enables autonomy and independent learning, as most of the applications allow practicing without the teacher's presence.

In order to present the following studies, we created two main sections. The first one contains diagnostic and assessment tools and the second contains intervention tools. Each one of these sections is divided into subcategories, depending on the king of software used.

2. Assessment

2.1 Web applications

In 2006 Beacham and Trott developed Dys-Calculium, an online screener that examines the understanding of number concepts and quantitative comparisons, with a view to separate students having mathematical difficulties due to dyslexia or another neurodiversity, or due to dyscalculia. The student completes online the Dyscalculium portal without time limit and after that the results are automatically analyzed. Dyscalcium provides an individual profile for the student with 11 subcategories, indicating in which parts he has weakness and an overall score which determines if the student is at risk of dyscalculia or not [13].

Dyscalc is a free online screening instrument developed and provided by Wadeson Street Dyslexia Centre, the directors of Educational Psychologist Ltd, addressed to pupils over 14 years old of average academic ability. It is structured in 20 questions, designed to assess basic arithmetic, mathematical reasoning, calculation, number sense and several more mathematical skills. After completion of the test the automated system provides the user information about whether he is at risk of dyscalculia or not, taking into account the number of correct answers and the time taken. A group composed of dyscalculic pupils and a control group tested Dyscalc. The results showed that it is a useful screening tool for students with mathematical disorders [14].

2.2 PC applications

Butterworth (2003) developed a quick and dependable tool of identifying Dyscalculia. This tool runs on a PC and uses keyboard responses. The tests that "Dyscalculia Screener" includes are mainly based on counting dots and the numerical order. The screener represents three computer controlled tests:

- Dot enumeration.
- Number comparison.
- Arithmetic achievement.

The time required for each child to respond to the tests constitutes a key criterion for evaluation, known as simple reaction time [15, 16].

2.3 Artificial intelligence

Jain et al. (2012) proposed a model based on Fuzzy Expert System, using soft computing technique which classifies learning disability into its subtypes. While the diagnostic methods used so far can detect if a child has one learning disability or not, this model which consists of four main parts, fuzzifier, Rules of Classification, inference engine and defuzzier, is able to diagnose if a child has Dyslexia, Dysgraphia, Dyscalculia, or a combination of them, with an accuracy of about 90%. The system uses Java and the data collected is registered in Excel sheets. According to the researchers, by finding the appropriate combination of algorithms, this model could guaranty even greater accuracy [17].

Livne et al. (2007) developed an online analysis system which automatically assesses students, based on their responses in mathematics questions. The parser compares each pupil's response to the answers which the teacher fed the system with and was stored in a database. Processing of the responses is carried out in three successive phases, Matching, Numerical Evaluation and Analysis. Each element of the responses is characterized by the system as correct, wrong, missing or unnecessary. Therefore the parser has the ability to categorize the students' errors in structural, conceptual or computational. The project showed that natural languages and artificial intelligence could be combined successfully for the students' mistakes detection. As shown by the test made by researchers, parser's total scaring closely matched human scoring [18, 19].

3. Intervention

3.1 PC Applications

A. Brunda and J. Bhavithra developed the Computer Assisted Instruction (CAI), including E-Learning and Adaptive E-Learning. These tools where designed to learn students the number names, counting and numerical comparison, using entertaining software with speed deadlines, sound feedback and several levels of difficulty depending on the students progress. In E-Learning students can enhance the basic skills of mathematics like counting, number knowledge, number names, simple addition and subtraction. Adaptive E-Learning helps children with entertaining problems adapted to the performance level of the individual child using 14 different levels of testing. This project interferes in children up to 8 years old with different types of Dyscalculia, unrolling cognitive and arithmetical principles [20].

Lontrup et al. developed and tested a product composed by six Sifteo cubes and an application running on a computer, for students in 7th–10th grade, coming up against problems with the complexity of equations and the methodology required to solve them. The Sifteo cubes can detect when they are placed side by side, when they are titled and when the screen on the cube is pressed down. In the beginning, there are lots of helping tools provided to the user, such as color help and automatic calculations. For each solved equation, the student is given extra points, so he can move to the next, more difficult level. So they conducted a study to find out whether 7th–10th graders, using the product, could enhance their mathematical understanding of equations. From the results of the study it is concluded that the physical objects contribute to the better understanding of equations. [21].

O'Connel et al. presented in their study two indicative examples on how Apple supports learning for students with Mathematical Disabilities. Peter is an 8th grade student with math disabilities, who has trouble to remember what the teacher says in the classroom and especially with graphing equations. To help him, teacher uploads to the class web page, classroom lecture recordings, recorded via iPhone's Voice Memos. Furthermore, Peter uses Grapher, a graphing equations tool on his Mac computer. Georgia is a 3rd grade student with Dyscalculia. Georgia, using the calculator application of her Mac computer, which 'speaks' for each key she presses and notes down on a paper-tape the individual results of her calculations, may do her homework easier, as well as she may communicate with her teacher through email in case she experiences difficulties [22].

Ginsgurg et al. [23] developed MathemAntics**,** a sequence of research-based educational computer activities for teaching mathematics to preschool students. According to the searchers, computers help mathematical skills improvement and provide collaborative teaching using interactive visual models, touch screens and computer tools. They proposed 6 cognitive design principles for the software:

- Engage children in cognitively and mathematically appropriate activities.
- Develop effective models for representing abstract ideas.
- Encourage accurate and efficient strategies.
- Identify and eliminate bugs and other misconceptions.
- Design appropriate physical interaction
- Integrate narratives and stories with mathematical concepts

3.2 Web applications

In 2005 Hesselbring et al. developed FASTT (Fluency and Automaticity through Systematic Teaching with Technology) an intervention software program, designed to assist students to develop mathematical fluency. FASTT Math uses some unique features to help the users to make a connection among the facts and their answers. The results of the study conducted to evaluate the use of the software were impressive as revealed that the math-disabled students who received 54 ten minutes sessions on the FASTT succeeded performance, in basic mathematical operations, almost identical to the non math-disabled students, trained with traditional fluency methods. The most impressive of this intervention software program is that students were tested again after summer vacation and showed that they are retained at high level [24].

Laurillard et al. (2009) developed a project with digital interventions for dyscalculic children. In that project they fully developed and tested 'Dots2-Digits' and 'Dots2Track', two programs designed to help students to attach the numerosity in a dot pattern and its representation as a digit, they tested current software against adaptive software and they built a free online collaborative environment to create an interactive website(low-numeracy.ning.-com) where teachers could find links for downloading the programs and discussion forums for their comments and feedback. As teachers said the learner can get much more practice with a digital game than is usually possible in an ordinary class [25, 26].

In the same year Räsänen et al. examined the cognitive process and development of the math skills, of two adaptive computerized games based on neuroscience findings. In their study, 30 children with low numeracy skills were randomly separated in two intervention groups. The first group played the "Number Race" game and the other group played "Graphogame-Math", a game designed in the University of Jyväskylä. The main difference between the two games is that Graphogame-Math starts with small sets of dot patterns, which are numerically close to each other, so the comparison process requires dots counting. Both groups trained on the games for three weeks, 10–15 minutes per day. According to the results of the study, children succeeded a significant improvement in number comparison, but the effect did not generalized to counting or arithmetic. Although the information feedback the tools provide, enable the child to adjust his actions in relation to the goal [27].

Käser et al. developed Calcularis, a computer based training program designed to train basic numerical cognition with the training of arithmetical abilities. The training program consists of 10 different types of games which exploit number representations, visualization of number using colored blocks, arithmetic operations and word problems. Users start the program from the lowest level of difficulty and proceed according to their skills. In the study 32 German-speaking students (2nd–5th grade of elementary school) with difficulties of learning mathematics in Switzerland participated. At the end of the study students completed a feedback questionnaire, in which they declared that the training and that helped them to improve their mathematical skills [28, 29].

Wilson et al. (2006) programmed the "Number Race" software, an adaptive game software for remediation of dyscalculia. It is a multi-platform written in Java, consisting of three difficulty dimensions: numerical distance, response deadline and conceptual complexity In Number Race, children carry out a numerical comparison task, choosing the larger of two numerosities, within a specified timeframe. As the child gives correct answers, he can move to more difficult levels, where additions or subtractions are required to make the comparison. The quantities in the tasks of the game can be presented in non-symbolic format, in symbolic Arabic digits, or in spoken number words. Software can be downloaded from the number race website in English, French, Polish or Swedish version [30].

3.3 Mobile applications

Dr Nagavalli et al., indicate two popular iPad applications which help children with Dyscalculia. 'MathBoard', a math app appropriate such as for kindergarten children, using simple addition and subtraction problems, as for elementary school students, using multiplication and division tasks, squares, cubes square root problems and 'Long Division' app, where students can study and exercise on the long division method, solving problems step by step [31].

In 2011 on a Midwestern elementary school, 4 teachers and 87 3rd grade students, arranged in two classrooms(Mobile Learning Intervention = 41, Comparison = 46), participated in a 9 week study. The MLI students used every day iPod touch devices which contained math apps to practice multiplication such as Multiplication Genius, Mad Math, Pop Math, Flash to Pass, Math Drills, Multiplication Flashcards to Go and Math Magic. The Comparison students practiced multiplication using the usual techniques, such as fact triangles, math games and number sequences. All students would practice 10 minutes every day. After 9 weeks, teachers gave the students a 100 multiplications test to answer as many as possible in ten minutes. Justifying the project the MLI students answered a greater number of these items correctly [32].

Alexander et al. used the reciprocal research and development process (RR&D) to design GoMath! Mobile applications. The 2 mobile math apps, "Go Play Ball" and "Go Road Trip" promote the mathematical awareness through daily collaboration of the members of the family, to solve life problems and participate in usual activities. Go Play Ball allows users to record their softball or baseball performances and presents graphs or charts about the statistical results of their progress and statistics of their favorite professional players. Six families from Boston used Go Play Ball for 3–4 weeks of the baseball season. Go Road Trip is a set of nine mathematics games designed to encourage mathematical talk during a long family trip. Seven families with middle grade school students tested the app while travelling by car. The project was successful as the participants could use the mobile platform anytime and anywhere, during funny activities which at the same time enhance sociability [33].

Malley et al. presented a four week study in a classroom of a special education school in an urban district in Maryland, which was attended by 10 students (12–15 years old) with cognitive disabilities. The study was designed to examine the effect of using iPads to increase math fluency, using the following measures:

- Student demographic questionnaire.
- Technology access and use.
- Basic math achievement.
- Basic math fluency.
- Fidelity of intervention.
- Social validity.
- Technology integration.

According to the results of the study, iPad was a useful learning tool that helped the reinforcement of the learning methods of the teachers and gave the students interest for the educational process [34].

3.4 Virtual environment

Marcus Vansconcelos et al. investigated the effect of a Virtual Environment in children with Dyscalculia. A study with 26 dyscalculic children, with an average age of 8 years, all in 2nd grade of primary school, took place in Brazil's Sao Paulo. The children were randomized set in two groups, the Experimental, interacted with networked computers and games developed specifically for dyscalculia, and the Control Group, where the kids participated in a reinforcement using traditional teaching techniques. Children of the Experimental group were given 1 hour virtual environment sessions, twice a week, for 5 weeks. According to the study's results, the use of the virtual environment, not only improved the mathematical skills of the participants, but also motivated the children as computer is an attractive and entertaining tool in opposition to the use of notebook and blackboard [35].

A Plerou et al. presented a study to evaluate the students' efficiently in algorithmic problem solving in interactive environments. In this study 46 first grade students (15–16 years old) of a Vocational Educational School in Corfu, Greece participated. The students were divided into 2 equal groups, the Control Group, where the students were evaluated to the classic manner by hand-writing and the Interactive Evaluate Group, using interactive virtual interface. According to the study's results, using visualization of specific algorithmic problems can enhance students' comprehension of some basic concepts related to algorithms. Furthermore most of the students followed the Interactive Evaluate Group, stated that they felt joy and excitement during the procedure and they would pleasantly repeat the test [36].

In 2008 Peltenburg et al. developed a study of 37 pupils with learning difficulties in mathematics from 2 special education schools in Utrecht with average age of 10.5 years. They used the CITO Monitoring Test for Mathematics(a frequently used assessment instrument developed by Janssen, Scheltens and Kramer in 2005) including seven subtraction problems in the number domain up to 100, and a Flash ICT assessment environment especially developed for this study based on CITO's items, using digital imaging of the problems, computer speaking, etc. The ICT version, included a dynamic visual tool with virtual manipulative, which the pupils can use while solving the problem. The comparison of scores in the 2 formats showed that the participants answered more correct answers in the ICT version of the seven items than in the standardized test format [37].

3.5 Artificial intelligence

Melis et al. (2001) used a number of Artificial Intelligence techniques to develop ActiveMath, a Web-based adaptive learning environment for mathematics with several components and interactive learning tools. It is a system with complex architecture involving interactive exercises, personal details about the pupil, pedagogical strategies, learning strategies and other functionalities and services. ActiveMath uses the semantic XML for mathematical documents and OMDoc, an extension of the OpenMath standard for mathematical symbols and expressions, for its content encording. This tutoring system could be expoiled for long distance learning, homework or teacher assisted learning. ActiveMath is designed to adapt to each student's technical equipment, environment variables and cognitive needs and allows the user to study in his own environment whenever he wants [38–40].

Anthony et al. (2008) proposed a prototype system based in intelligent tutoring systems for students learning algebra equations solving. Designers of the system were motivated by the idea that handwriting as an input instead of typing could bring much better results. The recognizer used is the Freehand Formula Entry System (FFES). To train the recognizer, researchers collected data from over 40 high school and middle school algebra students, in order to ensure the recognizers ability to adapt into different types of writing. The study developed to evaluate this project revealed that students who introduced mathematical equations via handwriting were much faster and less prone to errors than those who were typing. Out of 46 total students, over 80% claimed that they prefer handwriting [41].

4. Conclusions

The purpose of this study, was to examine some representative studies of the last two decades which utilize the use of ICTs to create diagnostic tools and intervention programs for students with dyscalculia. Diagnostic and assessment tools become increasingly easy to use and guarantee high reliability. Intervention tools show variety in software used and can be available to the greatest part of population in need. The results of these studies were encouraging, as the use of ICTs creates an accessible interactive environment, enables personalized learning, and helps students develop their cognitive skills much faster than the traditional educational practices. ICTs could be powerful and handy tools for the teachers, combining entertainment with the development of numerical and mathematical skills. It is necessary certainly further research to enable the use of ICTs to become part of the educational process, however, the existing studies make promises for the future.

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