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Expert System for Learning Disability Classification in School-Age Children

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***Abstract*—Learning disabilities are generally defined as disorders of one or more basic psychological processes including the use of spoken or written language shown by children with poor ability to hear, think, read, write, spell, or solve mathematic problems. The purpose of this research is to classify learning disabilities in children using a fuzzy expert system as a step in recognizing the learning abilities of school-age children so that treatment can be done early on. This expert system is built with several modules, namely a knowledge base, memory, fuzzy inference engine, and a web-based interface. Answers from users will be processed using a fuzzy expert system based on the scores obtained from each category of reading, writing, math and logic, and heredity. The output of this system answers whether the child is normal, dyslexia, dysgraphia, dyscalculia, or a combination of the types of learning disabilities. The expert system was conducted on 20 school-age children (6-12 years old). The classification results of three types of learning disabilities using a fuzzy expert system showed an accuracy of 95%.**

Keywords—learning disability; dyslexia; dysgraphia; dyscalculia; fuzzy expert system

I. INTRODUCTION

According to the Individuals with Disabilities Education Act (IDEA), the term "learning disability" refers to a disorder in one or more of the basic psychological processes involved in understanding or in using language, spoken or written, which may manifest itself in an imperfect ability to listen, speak, read, write, spell, or do mathematical calculations. The term includes such conditions as perceptual handicaps, brain injury, and developmental aphasia. The term does not include learning problems that are primarily the result of visual, hearing, or motor disabilities, of intellectual disability, of emotional disturbance, or of environmental, cultural, or economic disadvantage.

In the learning process, the ability of children with learning disabilities to absorb stimuli is different from other children. The most common causes of this disability are heredity and neurological disorders [1]. Children with learning disabilities are at high risk for having poor social skills and self-esteem as well as being depressed so that they have difficulty relating to peers and stunted development [2]. There are 3 types of learning disabilities, namely dyslexia (disabilities in reading), dysgraphia (disabilities in writing), and dyscalculia (disabilities in solving math problems) [3].

Based on the results of the Indonesian National Assessment Programme (INAP) conducted by the Ministry of Education and Culture in 2016 [4], 46.83% of students in Indonesia have less reading ability, 77.13% have less mathematical skills, and 73.61% have less science skills. This illustrates that learning disorders among elementary school students need to get serious attention from all parties concerned, whether from education sector, medical, psychological, and parents because the elementary school stage is a preliminary stage in reaching the next level of education.

According to the World Health Organization (WHO) [5], world disability studies show that low-income countries pointed to the problems in identifying and characterizing disability as a result of the lack of assessment tools. This may suggests that children with disabilities are not receiving needed services. On the other hand, learning disabilities can become worse if not immediately treated, especially because parents and schools do not understand or recognize the type of learning disabilities that occur in children. To help overcome this, an expert system using fuzzy was developed so that the symptoms of learning disabilities shown in children can be immediately recognized, classified, and handled properly.

II. LITERATURE REVIEW

There are several studies that have been done previously that serve as a reference in this study.

Munir et al [6] created an expert system to diagnose learning disability which includes dyslexia, dysgraphia, and dyscalculia. Categories of diagnostic results are divided into 5 criteria, which are extremely heavy, heavy,

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medium, light, and extremely light. The testing system was conducted on children aged 8-12 years (elementary school). The filling of symptoms questionnaire was conducted by the teacher and parents.

Kurniawan et al [7] created an expert system for diagnosing dysgraphia using writing tests and questionnaires based on the results of the previous writing test related to the symptoms of dysgraphia. The diagnostic results classify dysgraphia into Normal, Light, Moderate, and Severe. The GUI is using Java, and it is expected to be developed into a web-based or mobile-based app.

Devi et al [3] created an online test for 7 or 8 years old kids to identify learning disabilities. The statistical analyses were taken for obtaining the mean and standard deviation of kids for both times taken for completing the test and correct responses in the test.

III. MATERIAL AND METHOD

3.1 Fuzzy Expert System

Expert System (ES) is a knowledge-based system that uses knowledge of its application domain and uses inference reasoning procedures to solve problems that require human expertise. The expert system contains four main modules: knowledge-based, working memory, inference engine, and graphical user interface [8]. In the knowledge base module, knowledge can be collected based on a direct approach such as interviews with experts, using a questionnaire, or an indirect approach using data [9]. This knowledge is represented by constructing a relational proposition from the IF-THEN rule [10]. The facts of the formed rules are stored in a memory module which functions as thoughts or considerations. In the Fuzzy Expert System (FES) architecture, Fuzzification and Defuzzification modules are added to the ES module.

A typical process in developing the fuzzy expert system incorporates the following steps [11]:

1) Specify the problem and define linguistic variables.
2) Determine fuzzy sets.
3) Elicit and construct fuzzy rules.
4) Encode the fuzzy sets, fuzzy rules, and procedures to perform fuzzy inference into the expert system.
5) Evaluate and tune the system.

3.2 Learning Disability Types

According to the National Institute of Neurological Disorders and Stroke, although learning disorders occur in very young children, they are usually not recognized until the child reaches school-age and only occur in children with a normal level of intelligence that is at least 90 based on the Wechsler Intelligence Scale for Children (WISC). There are 3 types of learning disabilities that can occur in children, namely dyslexia, dysgraphia, and dyscalculia.

Dyslexia is a type of learning disorder that specifically interferes with a person's learning ability which involves reading and spelling. These people usually read at a much lower level than expected despite having normal intelligence. Although the disorder varies from person to person, a common characteristic among people with dyslexia is difficulty with phonological processing (sound manipulation), spelling, and/or rapid visual-verbal responses. Dyslexia can run in families, and recent research has identified a number of genes that can predispose a person to dyslexia [12]. Some typical symptoms used in this study include [13][14][15]:

- The child feels anxious or refuses activities related to reading.
- Shows an attitude of not wanting to go to school.
- The child looks hyperactive to divert his problems.
- Difficulty interpreting the other person's gesture.
- Difficulty focusing.
- Difficulty following and remembering visual sequences.
- Difficulty reading unfamiliar words or new words.
- Difficulty associating sounds with letters.
- Write or add a series of letters, symbols, or words that are not in the text being read or intended.
- Too slow to read and seem unsure of what to say.
- Spelling difficulties and tends to be inverted (e.g. the letter “d” is often confused with the letter “b”, “p” with “g”, “u” with “n”, “m” with “w”, or the number “6” with “9”).
- Ignoring punctuation in the texts he was reading.
- Has low phonological sensitivity (e.g. they will have difficulty answering the question “How would it sound if the letter “b” in “book” was replaced with “l””?).
- Skip syllables, phrases, or even lines in text.
- Difficulty understanding the meaning of sentences that are read or heard.

Dysgraphia is a neurological disorder characterized by the inability to write well. In particular, this distraction causes a person's writing to become distorted or incorrect. In children, this disorder usually appears when they are first introduced to writing. They make letters of inappropriate size and spacing, write very slowly, write wrong or misspelled words despite complete instructions, and their writing can be very illegible. Children with this disorder may have other learning disorders [12]. Some typical symptoms used in this study include [14][15][16]:

- The child feels anxious or refuses activities related to writing.
- Has very messy handwriting (hard to read).

- It is difficult to hold a pen or pencil firmly, the way to hold the writing tool is often too close, even almost sticking to the paper.
- Mixing lowercase and uppercase Has problems with correct letter spacing in and/or between words.
- Writing either letters or numbers in the reverse form (as reflected).
- Difficulty writing on lines and within margins or borders on paper.
- Has problems with punctuation when writing.
- Has problems with consistency of spelling.
- Difficulty putting thoughts on paper.
- Difficulty completing writing assignments independently.
- Trouble copying text.
- Inconsistent or proportional letterforms.
- Write slowly.
- Easily tired or cramped when writing.

According to the National Center for Learning Disabilities (NCLD), dyscalculia is a term that refers to a variety of learning disabilities involving mathematics including difficulty solving arithmetic problems and understanding mathematical concepts. In school-age children with language processing disabilities may have difficulty solving basic math problems using addition, subtraction, multiplication, and division where 56% of children with dyslexia also show poor math achievement, and 43% of children with problems dyscalculia indicates poor reading ability [17]. Some typical symptoms used in this study include [14][15][16]:

- The child feels anxious or refuses activities related to arithmetic or math.
- Difficulty remembering or being confused with mathematical symbols and/or operations (e.g. addition, subtraction, multiplication, or division including 2 digits, decimals, or fractions).
- Difficulty with the concepts of “more than” and “less than” (e.g. bigger / smaller, more / less, heavier / lighter, etc.)
- Difficulty comparing sizes of integers and/or fractions (for example, largest: 34 or 43? Largest: ¼ or ½?).
- Trouble counting backward (e.g. 10, 9, 8, etc.) and/or reversing numbers frequently (e.g. 81 to 18).
- Difficulty with time-related concepts (e.g. day, week, month, hour, the day after tomorrow).
- Difficulty with money-related concepts (e.g. calculating change).
- Difficulty differentiating right and left.
- Difficulty understanding that numbers can consist of any combination of two or more separate numbers.
- They may see a number like 7 as a unit and have a hard time understanding that it can also be made by bonding the numbers 3 and 4, or 5 and 2.
- Low scores on math assignments or numerical concepts.

IV. Classification Process

The process in this system starts with input processing to get a classification. Input is entered on a web application that provides initial instructions to ensure that the child has a normal IQ (minimum 90). Users who in this case are parents, teachers, or children's companions will answer according to the child's conditions or symptoms by selecting 1 of 5 available answers for each statement. The frequency and level of confidence measurement scale used is a Likert Scale (0-4). The input processing is carried out on a web server and involves a database containing symptoms data and their categories, types of learning disabilities data, the user answers data, and score data. From the user's answers, the total score of each category/input variable is calculated to be processed using the Fuzzy-Tsukamoto method. The input and output variables have the following fuzzy sets:

TABLE I. Fuzzy Sets

Functions	Variables	Fuzzy Sets
Input	Reading Score	Very Low
		Low
		Medium
		High
		Very High
	Writing Score	Very Low
		Low
		Medium
		High
		Very High
	Math and Logic Score	Very Low
		Low
		Medium
		High
		Very High
	Heredity Score	Low
		Medium
		High
Output	Dyslexia	Normal
		Mild
		Moderate
		Severe
		Very Severe
	Dysgraphia	Normal
		Mild
		Moderate
		Severe
		Very Severe
	Dyscalculia	Normal
		Mild
		Moderate

Functions	Variables	Fuzzy Sets
		Severe
		Very Severe

In determining the threshold value into 3 or 5 criteria, the norms used are as follows [18]:

TABLE II. NORMS FOR 3 CRITERIAS

Criteria	Formula
Low	$X < M - 1\sigma$
Medium	$M - 1\sigma \leq X < M + 1\sigma$
High	$M + 1\sigma \leq X$

TABLE III. NORMS FOR 5 CRITERIAS

Criteria	Formula
Very Low	$X \leq M - 1{,}5\sigma$
Low	$M - 1{,}5\sigma < X \leq M - 0{,}5\sigma$
Medium	$M - 0{,}5\sigma < X \leq M + 0{,}5\sigma$
High	$M + 0{,}5\sigma < X \leq M + 1{,}5\sigma$
Very High	$M + 1{,}5\sigma < X$

X is the total score of each respondent
M is the mean
σ is the standard deviation

For this reason, the mean and standard deviation are formulated through the following equations:

Xmax = Total Statement Items × Highest Score

Xmin = Total Statement Items × Lowest Score

Mean (M) = (Xmax — Xmin)

Standard Deviation (σ) = (Xmax — Xmin)

4.1 Fuzzification

The crisp value in this classification is in the form of total scores from the Reading and Heredity categories for the dyslexia classification, the Writing and Heredity categories for dysgraphia, and the Math and Logic and Heredity categories for dyscalculia. Fuzzification aims to find the degree of membership function based on the crisp value. In this study, the representation model used is a trapezoidal representation. Based on the representation, to calculate the degree of membership function using the following equation:

$$\mu_A(x) = \begin{cases} 0, (x \leq a) \text{ or } (x \geq d) \\ \frac{x-a}{b-a}, \quad a \leq x \leq b \\ 1, \quad b \leq x \leq c \\ \frac{d-x}{d-c}, \quad c \leq x \leq d \end{cases} \tag{5}$$

The input membership function of the Reading Score is shown in Fig. 1 with a range of scores or domains obtained through the table of norms and related equations previously mentioned.

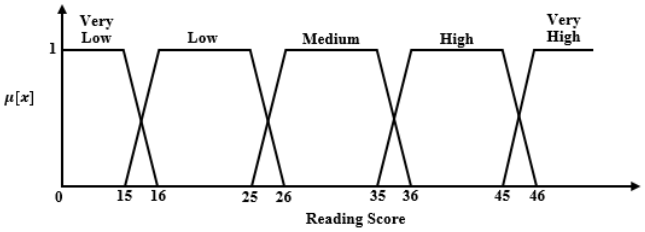

Fig. 1. The input membership function of the Reading Score

The input membership function of the Writing Score is shown in Fig. 2.

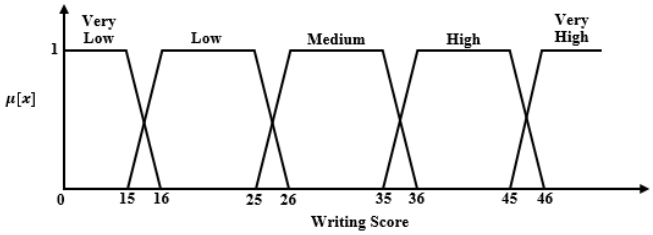

Fig. 2. The input membership function of the Writing Score

The input membership function of the Math and Logic Score is shown in Fig. 3.

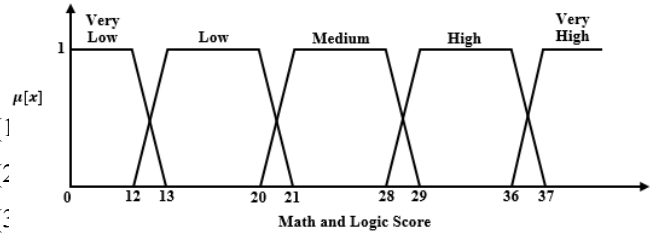

Fig. 3. The input membership function of the Math and Logic Score

The input membership function of the Heredity Score is shown in Fig. 4.

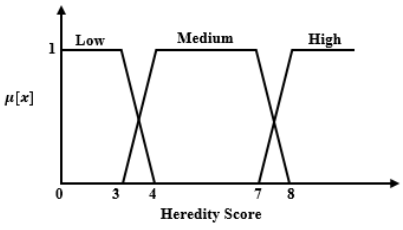

Fig. 4. The input membership function of the Heredity Score

4.2 Inference

After obtaining the membership degree value, the next step is to find the smallest degree or antecedents of a fuzzy rule using MIN function. In the process, fuzzy rules are needed to obtain these antecedents (α-predicate). The proposed system is designed with 45 rules. Some of the designed rules are listed below:

1. If reading score is very low and heredity score is low then normal
2. If reading score is low and heredity score is low then mild dyslexia
3. If reading score is medium and heredity score is low then moderate dyslexia
4. If reading score is high and heredity score is low then severe dyslexia
5. If reading score is very low and heredity score is medium then normal
6. If reading score is very low and heredity score is high then normal
7. If reading score is low and heredity score is medium then mild dyslexia
8. If reading score is low and heredity score is high then mild dyslexia
9. If reading score is medium and heredity score is medium then moderate dyslexia
10. If reading score is medium and heredity score is high then moderate dyslexia

4.3 Defuzzification

The last step is deffuzification. Defuzzification is the process of converting a fuzzified output into a single crisp value. This process is carried out to obtain the classification of learning disabilities. In this study, the defuzzification method used is the weighted average defuzzifier method shown in equation (6) with the value of z obtained from the inference results and output membership functions.

$$Z = \frac{\sum(z \times \alpha_{-predicate})}{\sum \alpha_{-predicate}} \quad (6)$$

V. RESEARCH RESULTS

The web application of this expert system is built using PHP language and MySQL database management system. Expert system users who in this case are parents, teachers, psychologists, and/or children's companions answer the suitability of the statement with the child's condition by selecting one answer on the web application from Never, Rarely, Sometimes, Often, and Always for the categories of Reading, Writing, Math and Logic and Very Unsure, Not Sure, Quite Sure, Sure, and Very Sure for the Heredity category as shown in Figure 5. The test was conducted on 20 school-age children (6-12 years old) from 1st until 6th grade from several different elementary schools.

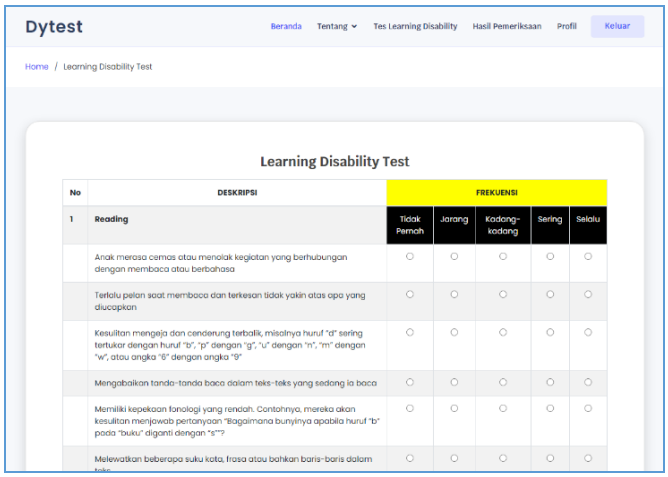

Fig. 5. The learning disability test web application page

5.1 Classification Results

The classification results from the system are compared with expert results. Table V is a table of dyslexia classification results and it can be seen that the 20 data tested using the system with the proposed method have the same results as the expert results.

TABLE IV. DYSLEXIA CLASSIFICATION RESULT

No	Reading Score	Heredity Score	Child's Age	Application Result	Expert Result
1.	7	4	11	Normal	Normal
2.	19	3	6	Mild Dyslexia	Mild Dyslexia
3.	18	8	7	Mild Dyslexia	Mild Dyslexia
4.	9	1	7	Normal	Normal
5.	10	4	8	Normal	Normal
6.	7	7	12	Normal	Normal
7.	21	4	9	Mild Dyslexia	Mild Dyslexia
8.	8	0	12	Normal	Normal
9.	6	3	9	Normal	Normal
10.	35	7	10	Moderate Dyslexia	Moderate Dyslexia
11.	20	6	8	Mild Dyslexia	Mild Dyslexia
12.	6	2	9	Normal	Normal
13.	7	4	10	Normal	Normal
14.	4	0	7	Normal	Normal
15.	36	7	11	Severe Dyslexia	Severe Dyslexia
16.	22	8	7	Mild Dyslexia	Mild Dyslexia
17.	15	3	8	Normal	Normal
18.	30	4	10	Moderate Dyslexia	Moderate Dyslexia

No	Reading Score	Heredity Score	Child's Age	Application Result	Expert Result
19.	23	8	8	Mild Dyslexia	Mild Dyslexia
20.	6	1	9	Normal	Normal

Table VI is a table of dysgraphia classification results and it can be seen that 18 of the 20 data tested using the system with the proposed method have the same results as the expert results.

TABLE V. DYSGRAPHIA CLASSIFICATION RESULT

No	Writing Score	Heredity Score	Child's Age	Application Result	Expert Result
1.	11	4	11	Normal	Normal
2.	11	3	6	Normal	Normal
3.	37	8	7	Severe Dysgraphia	Severe Dysgraphia
4.	10	1	7	Normal	Normal
5.	24	4	8	Mild Dysgraphia	Mild Dysgraphia
6.	27	7	12	Moderate Dysgraphia	Moderate Dysgraphia
7.	26	4	9	Moderate Dysgraphia	Mild Dysgraphia
8.	9	0	12	Normal	Normal
9.	8	3	9	Normal	Normal
10.	15	7	10	Normal	Normal
11.	23	6	8	Mild Dysgraphia	Mild Dysgraphia
12.	6	2	9	Normal	Normal
13.	8	4	10	Normal	Normal
14.	5	0	7	Normal	Normal
15.	25	7	11	Mild Dysgraphia	Mild Dysgraphia
16.	22	8	7	Mild Dysgraphia	Mild Dysgraphia
17.	14	3	8	Normal	Normal
18.	19	4	10	Mild Dysgraphia	Normal
19.	20	8	8	Mild Dysgraphia	Mild Dysgraphia
20.	6	1	9	Normal	Normal

Table VII is a table of dyscalculia classification results and it can be seen that 19 of the 20 data tested using the system with the proposed method have the same results as the expert results.

TABLE VI. DYSCALCULIA CLASSIFICATION RESULT

No	Math and Logic Score	Heredity Score	Child's Age	Application Result	Expert Result
1.	24	4	11	Moderate Dyscalculia	Moderate Dyscalculia
2.	7	3	6	Normal	Normal
3.	18	8	7	Mild Dyscalculia	Mild Dyscalculia
4.	9	1	7	Normal	Normal
5.	9	4	8	Normal	Normal
6.	30	7	12	Severe Dyscalculia	Severe Dyscalculia
7.	7	4	9	Normal	Normal
8.	4	0	12	Normal	Normal
9.	23	3	9	Moderate Dyscalculia	Mild Dyscalculia
10.	20	7	10	Mild Dyscalculia	Mild Dyscalculia
11.	8	6	8	Normal	Normal
12.	6	2	9	Normal	Normal
13.	18	4	10	Mild Dyscalculia	Mild Dyscalculia
14.	6	0	7	Normal	Normal
15.	11	7	11	Normal	Normal
16.	16	8	7	Mild Dyscalculia	Mild Dyscalculia
17.	6	3	8	Normal	Normal
18.	8	4	10	Normal	Normal
19.	27	8	8	Moderate Dyscalculia	Moderate Dyscalculia
20.	6	1	9	Normal	Normal

Based on the three classification results from Table V, VI, and VII, the average system accuracy is as follows:

$$\text{Accuracy} = \frac{57}{60} \times 100\% = 95\%$$

The accuracy value indicates that the system is running well. For some differences in results, it could be because expert diagnoses can be influenced by tolerances that can still be given for the diagnosis of learning disabilities, especially for children who do not have families with learning disabilities (heredity factor). In addition, it could also be that the system has not fully acquired expert knowledge because there are symptoms that can still be added to improve the system's accuracy.

VI. CONCLUSION

In this study, the expert system for classifying learning disabilities in school-age children is successfully made. From the testing results, the use of the fuzzy expert system method with the Fuzzy-Tsukamoto type in classifying learning disabilities in school-age children,

which are dyslexia, dysgraphia, and dyscalculia, has an accuracy value of 95%.

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