# RECOGNIZING MATHEMATICALLY GIFTED CHILDREN BY USING EXPERT SYSTEMS', TEACHERS', AND PSYCHOLOGISTS' ESTIMATIONS

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A scientifically approved psychological finding of gift is usually not available to all schools. In order to obtain an accurate and early detection of mathematically gifted children, an intelligent expert system MathGift is proposed to assist teachers in making decision about a child's gift in mathematics in the fourth grade of elementary school. Besides mathematical competencies, the system includes other components while deciding about the giftedness in mathematics, such as cognitive components of gift, personal components that contribute to gift development, strategies of learning and exercising, as well as some environmental factors. A survey was conducted at ten elementary schools where the expert system's, psychologists' and teachers' estimates were obtained for each child in the sample. The paper discusses some differences among the estimations of children's mathematical gift obtained by the ES, psychologists and teachers. The results show that the expert system can be suggested as a methodological tool to assist teachers in making decision about children's gift in mathematics.

Keywords: expert system, mathematical gift, psychologists' estimation of gift, teachers' estimation of gift, t-test, McNemar test

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## INTRODUCTION

One widespread assumption is that mathematically gifted students are born that way and eventually blossom (Marjoram, Nelson, 1985). However, this is not always the case. Some mathematically gifted individuals may never be recognized. The usual method for identifying such students in European countries is through competitions, but it is generally accepted that many gifted students in mathematics are never discovered due to the fact that they do not participate in competitions or simply because they were not among the top ten during the competition process. Furthermore, some gifted students may find themselves in mathematically "poor" learning environments and never reach their highest potential. Still, others are not motivated enough and find that other things are far more rewarding and they lose their interest in mathematics for pursuits that offer tangible rewards (Mingus, 1999). Only a few find themselves in mathematically "rich" learning environments in which the teacher is well versed in mathematics, the school is supportive, they have ample opportunities to develop their abilities, and the public/private organizations and universities reward and promote mathematical achievement (Perleth, Heller, 1994). These children require appropriate and challenging learning experiences to facilitate their cognitive and emotional development (Henningsen, Stein, 1997; Hoeflinger, 1998). As a first step, mathematically gifted students need to be identified in early stages and in a systematic way (Kissane, 1996). The information available on mathematically gifted children is mostly based on research conducted on children at secondary school level (Niederer et al., 2003). However, researchers and educators emphasize the value of early identification of gifted children (Clark, 1997; Johnson, 2000).

Various approaches to mathematical giftedness are present in literature. Some of them are oriented to genetic factors (Terman, Oden, 1959), others to cognitive models (Sterberg, 2001), achievement (Renzuli, 1986), and there is a system approach (Tannenbaum, 1983). In order to pay special attention to gifted children, teachers usually use mathematical competencies as the only criterion for determining a child's gift. However, it is also important to include other components while deciding about giftedness in mathematics.

The paper proposes an expert system (ES) called MathGift for detecting a child's mathematical gift in the fourth grade of elementary school. Besides mathematical competencies, the system also includes cognitive components of gift, personal components that contribute to gift development, strategies of learning and exercising, as well as some environmental factors. The initial survey (Pavleković et al., 2007) showed that the system detected more children as gifted than teachers did in their estimates. In order to further prove the efficiency of the proposed ES it was necessary to compare its estimates to the psychological evaluations of the same children.

The purpose of the paper is to compare the estimates obtained by the ES, teachers, and school psychologists in order to test the ability of an intelligent system to efficiently detect gifted children in situations where psychological estimations are not available. An empirical research was conducted at the end of 2006, including 106 pupils aged 10 (fourth grade) in different elementary schools in Osijek.[1] Estimations were obtained for each pupil, and the estimations were compared using statistical tests.

The structure of the paper is the following: the second section contains a review of previous research in the area, followed by the description of artificial intelligence (AI) methodology used to develop the ES. Then the model variables for determining the potential gift in mathematics used by ES and by psychologists are explained. The data about examinees are described in a separate section. After the results, the conclusion and guidelines for future research are given.

## REVIEW OF PREVIOUS RESEARCH

From the first appearance of the term *artificial intelligence* as a scientific discipline until today, a number of techniques have been developed with the aim of creating intelligent machines (Russell, Norvig, 2002). Some of those techniques are expert systems, problem solving, machine learning, natural language understanding, speech recognition, pattern recognition, robotics, neural networks, genetic algorithms, intelligent agents, and others. Research in the area of intelligent systems in education mostly focused on developing tutoring systems that can support learning and teaching a specific topic, with the ability of including multimedia and personalized approach to each pupil (student). For example, Stathacopoulou et al. (2005) propose to use the methodology of neural networks and fuzzy logic for advanced student diagnosis process in an intelligent learning system. Canales et al. (2007) developed an adaptive and intelligent web-based education system (WBES), which takes into account individual student learning requirements and enables the usage of different techniques, learning styles, learning strategies, and ways of interaction. Zeleznikov and Nolan (2001) created a decision support system based on fuzzy logic and predicated rules to assist teachers in grading essays.

Less research attention is given to the area of intelligent systems for detecting children's gift in particular areas such as mathematics. Johnson (2000) emphasizes the importance and need for accurate detection and further development of mathe-

[1] The research is a part of the project *Little school of mathematics* started at the Faculty of Teacher Education at the University of Osijek. The project was announced at the Congress of mathematical teachers in Zagreb, in July 2004 (Goljevački, Moguš, 2004), with the aim of raising the quality of education of future teachers.

matical gift, as well as for including criteria other than mathematical competencies. The lack of school psychologists in some countries makes the process of detecting gifted children even more difficult. For example, only 140 psychologists are employed in 931 elementary schools in Croatia (Vlahović-Štetić, 2005). Generally, previous research implies that there is a great expansion of intelligent methods in education tutoring tools in the last few years. However, the area of determining the giftedness in mathematics should be more investigated and it is necessary to design an intelligent system that will include other than mathematical competencies exclusively.

## METHODOLOGY

In order to provide an intelligent decision support tool that will be able to support teachers in detecting a child's gift in mathematics, the ES is chosen as one of the AI techniques aimed at replacing a human expert in the decision-making process. Besides offering advice for reaching a decision, such systems are capable of explaining the decision process, therefore belonging to the "white box" methods. Another reason for choosing this methodology is that ES can be combined with other AI techniques, such as neural networks or intelligent agents, enabling the design of a more complex hybrid decision tool. Knowledge in an ES represents a set of information "structured to be appropriate for usage in the process of problem solving within a problem domain" (Čerić, Varga, 2004).

A standard ES consists of the following structural elements: (1) knowledge base, (2) base of facts, (3) inference engine, and (4) user interface. The knowledge base is a source of knowledge about a particular domain acquired from an expert in that area (Čerić et al., 1998). Knowledge can be represented in the form of production rules, semantic networks, predicate logic, etc. Due to their frequent usage, production rules were applied to construct the knowledge base of the suggested system. The base of facts presents a set of facts that describe the problem under consideration (for example, facts can be pupil's grades). Inference engine is a search path towards the solution, where the search is conducted by examining facts in the base of facts, as well as knowledge in the knowledge base. The user interface enables communication between users and the ES, and it also contains a mechanism of explaining a path used to find a solution. It is important to design a user-friendly interface that will enable easy communication of humans with the system.

Among a number of specialized software tools called "ES shells" that provide a user-friendly interface for designing ES based on knowledge representation and search, the Exsys Corvid is used to create a knowledge base for the problem of detecting a child's mathematical gift in the fourth grade of elementary school. Forward chaining is used as a search method. Production rules in intelligent systems consist of (Russel, Norvig, 2002): data describing the current state of environment, a set of rules in the form: IF <condition> THEN <action>, and rule interpreters that determine the order of rule execution.

In order to create the ES the following steps were used in the paper:

(1) defining the problem to be solved, and possible options
(2) knowledge base design
(3) defining the search engine
(4) user interface design
(5) ES usage
(6) statistical comparison of estimations

The knowledge base of the ES is created on the basis of four years of team work and research conducted by the faculty members, students, and teachers at *Little school of mathematics* at Faculty of Education, University of Osijek. During the winter semester 2006/07, an expert in the area of mathematical methodics was working in collaboration with colleagues, students, teachers, and parents, with a group of pupils from the fourth grade of elementary school (aged 10) that had special interest in mathematics. Knowledge acquired from literature, heuristics on the methodology of teaching, completed project assignments, as well as pupils' achievements were the construction thread of the ES knowledge base.

## Defining the problem to be solved by the expert system

ES makes the decision about the category of a child's gift (aged 10). Possible options of the decision are:

A) *potentially gifted child in mathematics* – the pupil is motivated and supported by external factors, according to its achievements in knowledge, skills, and application of mathematics on the level that overcomes expectations of mathematics curriculum for that age. The pupil learns actively, controls its progress and prepares for public assessment of its knowledge and skills, i.e. competition in mathematics.

B) *child with mathematical competencies above the average* – the pupil's knowledge, skills and mathematical application is on the level or somewhat above the level of expectations of mathematics curriculum for that age. However, a pupil belonging to this category expresses an extra interest towards mathematics and is also supported by the environment, although she/he is not willing to expose its knowledge and skills to public assessment at competitions in mathematics.

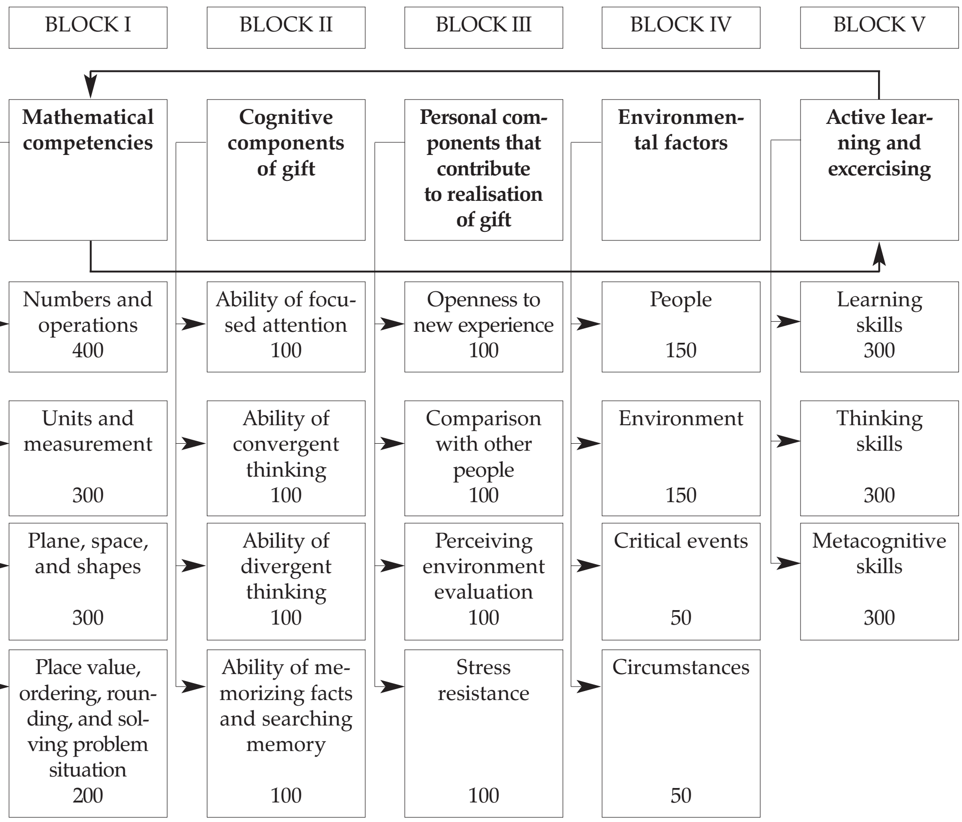
C) *child with average mathematical competencies* – the pupil shows no interest for additional practice in mathematics, but her/his achievements are on the level of expectations of mathematics curriculum for that age.

D) *child with mathematical competencies below the average* – the pupil whose knowledge and skills in mathematics show that in order to achieve expected mathematical competencies she/he needs additional support of parents and environment.

## Knowledge base design – defining variables (attributes)

In the process of defining variables (i.e. attributes) that will constitute the ES knowledge base, the following components were included: (1) assessment of mathematical competencies of pupils, (2) cognitive components of gift, (3) personal components that contribute to the development of gift, (4) environmental factors, as well as (5) efficiency of active learning and exercising methods that enhance the development of mathematical competencies and possible realization of gift. Each of the five model components is represented by blocks, divided into sub-blocks, i.e. groups of different competencies, and finally into variables that constitute production rules. Depending on the importance of a particular block for the final decision, points are determined for each block. The framework of the knowledge base model, together with appropriate points, is presented in Figure 1.

FIGURE 1
Components of mathematical gift included in the ES knowledge base together with points representing the weight of a particular component



The block of mathematical competencies (block I) includes four groups of variables in the area of: (a) numbers and counting, (b) units and measurement, (c) plane, space, and shapes, and (d) place value, ordering, rounding, and solving problem situations. In that way, a child's knowledge and skills in counting and measurement, usage of mathematical language and communication, solving problems and modeling, as well as skills of mathematical argumentation are included in the assessment of gift. Each sub-block is additionally divided into variables whose values are loaded from the user, i.e. teacher. In the block of cognitive components (block II), the intellectual potential of a pupil is evaluated. By adjusting and changing the strategies of active learning and exercising, we examine a pupil's ability of focusing attention, ability of finding a path towards the solution, and ability of fast searching from long-term memory. Within personal components that contribute to the realization of gift (block III), we observe: openness to new approach of learning, positive image of herself/himself, autonomy (not being afraid to be alone, fulfilled by activities they do, believing that they can influence their success, being persistent in work, taking responsibility and initiative), resistance to stress (perceiving failure as an opportunity for acquiring new experience). In order to determine the giftedness in mathematics it is also important to consider the improvement in active learning and exercising, described in block V, which includes: learning skills (distinguishing important from unimportant, combining and organizing information in a meaningful structure, selective comparison and connecting new information with the existing information in long-term memory), thinking skills (judgment, comparison, assessment, estimation, evaluation, imagination, discovering and creating new, as well as bringing thoughts into action), and meta-cognitive skills (planning exercises, "keeping track" of self improvement, regulating its behavior if it does not give certain results) in the fourth grade of elementary school. The detection of giftedness in mathematics is also influenced by environmental factors that can affect the development of a potential giftedness towards its realization (block IV). Those environmental factors are: support of teachers (additional courses), support of parents (help in exercising mathematics, financial support), and support of the mentor.

## Defining production rules and evaluating options

On the basis of variables mentioned above, logic blocks were created in the form of *if-then* production rules, whose logical values (*true* or *false*) imply appropriate evaluation of options of the ES decision. The total knowledge base of the ES consists of 250 production rules grouped into five main blocks presented in Figure 1. The process of evaluating options is defined on the basis of heuristics. The method used for searching for production rules is forward chaining, meaning that the search starts from the attribute values at marginal nodes and moves up accumulating points towards the final goal – to make a decision about the category in which the system places a child according to her/his gift in mathematics.

## User interface design

Using the Exsys Corvid ES shell, a visual user interface is designed, aimed to conduct communication of the system with a user in two ways: off-line (on a local computer), and on-line through a web interface based on Java runtime technology. Criteria for designing the interface were the following: simple usage, clarity, and availability to the final users through the web. An example of a user interface window is presented in Figure 2. Using the interface, a user enters the values of variables (attributes) that are considered as input values by the system in production rules, and transformed into output values for each decision option.

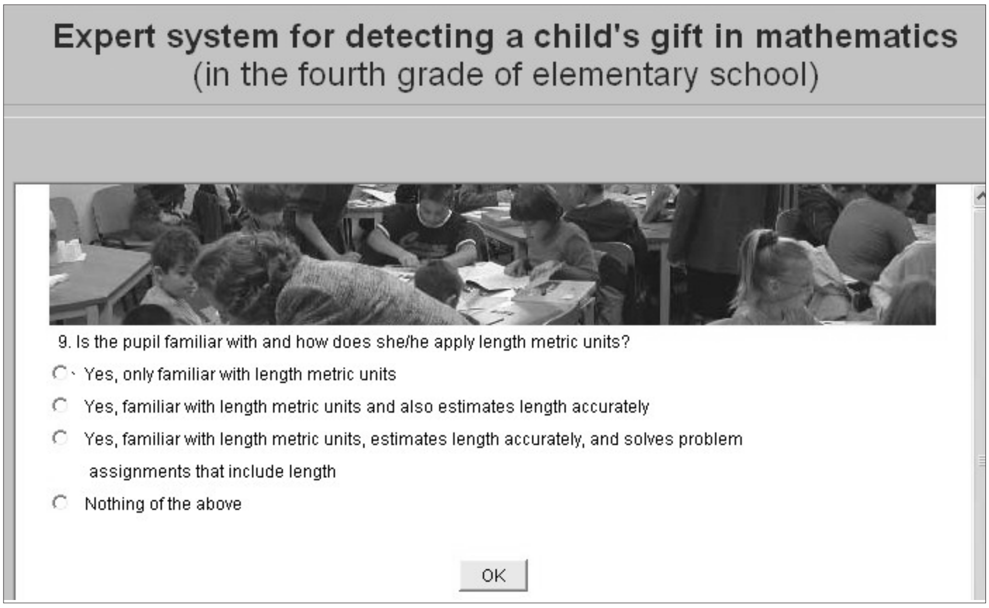



FIGURE 2
User interface of the expert system

After testing its formal and logical accuracy, the ES is used to detect children's gift in mathematics in a survey conducted in ten elementary schools in Osijek.

## DESCRIPTION OF DATA

The initial sample for the survey consisted of 247 pupils aged 10 (fourth grade of elementary school) from ten elementary schools in Osijek, Croatia, in December 2006. Mathematical gift of those pupils was estimated by teachers and an ES. According to legislative regulations, we were obliged to ask for parent's permission in order to do the psychological evaluations of each child. The permission was obtained for 106 pupils, and further analysis is focused on that smaller sample. It is important to notice that parent's permission was obtained for pupils with higher average grades. Table 1 shows the average grades of pupils from the smaller sample for each of the first three grades of elementary school. A five-point discrete numeric evaluation is used in Croatian schools (5=excellent or superior, 4=very good or above average, 3=good or average, 2=sufficient or below average, minimum passing grade, 1=insufficient or failing grade).

➲ TABLE 1
Average grades of the pupils from the sample

| Description | Grade 1 | Grade 2 | Grade 3 |
|---|---|---|---|
| Average grade in all courses for all 106 pupils | 4,7453 | 4,7170 | 4,7264 |
| Average grade in mathematics for all 106 pupils | 4,5094 | 4,4340 | 4,3868 |

The ES decision was based on the created knowledge base and inference engine described previously. All the input variables of the ES and their descriptive statistics are provided in the Appendix. The values of the input variables were provided by a child's teacher. Before making their assessments, teachers were previously trained so that the training included two main parts: (1) education on using the ES interface, and (2) education on understanding the input questions and response options that were offered for each question. Teachers were also instructed on which mathematical tests to use to estimate a pupil's mathematical competency. Such training enabled teachers to be familiar with assessment criteria they needed to make. The system categorized each child into one of the four categories of gift. The teachers separately estimated a child's gift without knowing the ES decision.

School psychologists – specialists in educational psychology (gifted education) were also used as estimators in our research. They used a classic set of Standard Progressive Raven's matrices (SPM) and their own interviews to find the category of mathematical gift for each child. The SPM is a widely used, nonverbal test of analytic intelligence designed to assess a person's intellectual and reasoning ability and the ability to make sense of complex data (Carpenter et al., 1990). The SPM test was used in this research due to its proven validity (Moran, 1986), and a high correlation of the score obtained by Raven's matrices and scholastic achievements in mathematics (Pind et al., 2003). The research of Pind et al. (2003) examined the criterion-related validity of the SPM with respect to scholastic achievement. Their results show that the highest correlation was obtained for mathematics, and lower correlations for the language subjects. Correlations ranged from 0.38 to 0.75. Laidra et al. (2007) used SPM on Estonian children and found a high correlation between intelligence, as measured by Raven's SPM, and students' grade point average (GPA) in all grades. Raven's matrices are also suitable for all ability levels, they have extensive norms for different ages and cultures, they are easy to administer and score, and they overcome cultural and language bias.

Although Raven's matrices generally measure cognitive ability and highly correlate with Spearman g (general intelligence) factor, their intercorrelations are the highest with arithmetic, technological and scientific abilities. Results of Pind et al. (2003) encouraged us to use it as an indicator of mathematical giftedness. In addition to that, the school psychologists used one-to-one interviews with each child in order to finally estimate a child's mathematical gift.

## RESULTS

Descriptive statistics of the estimates of the ES, teachers, and psychologists shows that the highest mean value of estimated gift category is obtained by teachers (2.7264), followed by the mean value obtained by psychologists (2.5377), while the ES estimation produced the lowest mean value of gift category (2.4057). The highest standard deviation exists in the finding of psychologists (1.0795), while the deviation of teacher's estimations is the lowest (0.8894). The correlation coefficients in Table 2 show that a strong connection is present among teachers' and ES decisions (0.76), while the correlations among psychologists and ES, as well as among psychologists and teachers are also statistically significant, but lower.

➲ TABLE 2
Correlation matrix among the estimations obtained by the expert system, teachers, and psychologists

| Estimation | Teachers | ES | Psychologists |
|---|---|---|---|
| Teachers | 1.00 | 0.76 | 0.42 |
| ES | 0.76 | 1.00 | 0.57 |
| Psychologists | 0.42 | 0.57 | 1.00 |

Table 3 shows the frequencies of pupils assigned to one of the four categories of gift obtained by the three estimators. It can be noticed that the largest number of pupils is categorized as gifted (category 1) by the ES (25 pupils or 23.58% of the sample). Psychologists assigned 20 pupils or 18.87% to the same category, while the smallest number of pupils estimated as gifted is obtained by teachers (7 pupils or 6.67%).

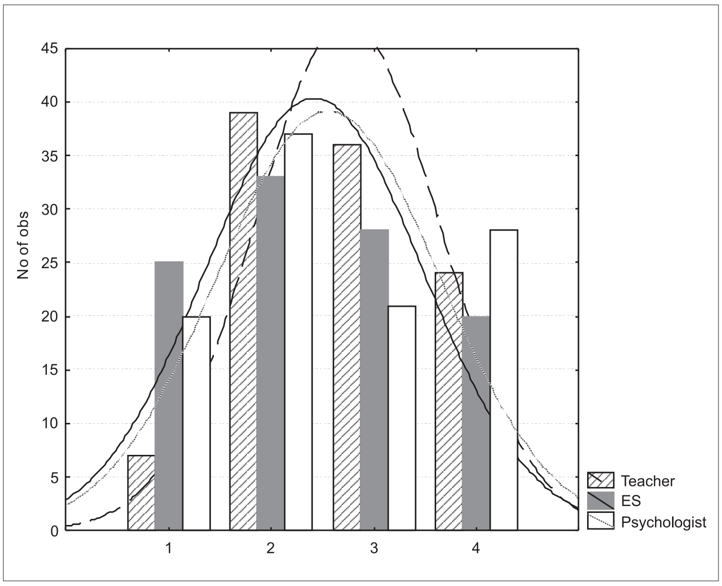
➲ TABLE 3
Frequencies of pupils assigned to categories of gift obtained by the expert system, teachers, and psychologists

| Category | Teacher's estimation | | ES decision | | Psychologist's finding | |
|---|---|---|---|---|---|---|
| | No. of pupils | % | No. of pupils | % | No. of pupils | % |
| 1 | 7 | 6.667 | 25 | 23.58 | 20 | 18.87 |
| 2 | 40 | 37.73 | 33 | 31.13 | 37 | 34.91 |
| 3 | 36 | 34.29 | 28 | 26.42 | 21 | 19.81 |
| 4 | 23 | 21.91 | 20 | 18.87 | 28 | 26.41 |
| Total | 106 | 100.00 | 106 | 100.00 | 106 | 100.00 |

When the frequency of pupils is assigned to category 2 (pupils with mathematical competencies above the average), it is obvious that teachers assigned the largest number of pupils to that category (40 pupils or 37.73%). The psychologists find category 2 in 34.91% of pupils, while the lowest number of pupils estimated to have mathematical competencies above the average is obtained by teachers (31.13%). The situation is different if category 3 (pupils with average mathematical competencies) is analyzed. The teachers assigned 34.29% of pupils to that category, the psychologists found that 19.81% pupils belong in that category, while the ES assigned only 26.42% of pupils to that category. The largest number of pupils assigned to the last category of gift (pupils with insufficiently developed mathematical competencies) is obtained by psychologists (26.41%), followed by the estimation of teachers (21.91%) and ES (18.87%).

The frequency histograms for the estimations obtained by the ES, teachers and psychologists with the normal fitting curve are shown in Figure 3.

➲ FIGURE 3
Frequency histograms of pupil categories according to estimations of ES, teachers and psychologists



The t-test of differences in proportions shows that there is a statistically significant difference in proportions of pupils assigned to category 1 by the teachers and the ES (p=0.004), and in proportions of pupils assigned to the same category by the teachers and psychologists (p=0.0043), while the difference among the proportions of pupils assigned to category 1 by the ESs and psychologists is not statistically significant (p=0.2013) on the 0.01 level.

In order to check if there is a connection among the estimations of pupils' gift in mathematics and their gender, the one-way analysis of variance (ANOVA) was conducted. It shows that there is no statistically significant influence of gender on the estimations of gift in mathematics (F=0.0177, p=0.8944 between teachers' estimations and gender, F=0.1248, p=0.7246 between the ES estimations and gender, F=0.05, p=0.8227 between psychologists' findings and gender).

For a better insight into the differences among the estimations made by the ES, teachers, and psychologists, the rate of agreement was computed (see Table 4). Teachers and the ES agreed in categorizing 22 pupils, yielding the rate of agreement of 20.75%.

➲ TABLE 4
Number and percentage of pupils according to existence of a match in estimations by the expert system, teachers and psychologists

| Description | Number of pupils | % |
|---|---|---|
| Existence of a match in estimates of ES, teachers and psychologists | 22 | 20.75 |
| No match in estimates of ES, teachers and psychologists | 84 | 79.25 |
| Total | 106 | 100.00 |

If the agreement in estimations is investigated in more detail in relation to categories, Table 5 can be observed. It shows the proportion of each category in the number of pupils that are assigned to the same category by teachers and the system (for 22 pupils in total that have a match).

➲ TABLE 5
Number and percentage of pupils with a match in estimations by the ES, teachers, and psychologists according to categories

| Category | Number of pupils | % |
|---|---|---|
| 1 | 3 | 13.64 |
| 2 | 8 | 36.36 |
| 3 | 4 | 18.18 |
| 4 | 7 | 31.82 |
| Total | 22 | 100.00 |

It is obvious that, when all three estimators agree in their estimations, they assign most of the pupils to category 2 (8 pupils or 36.36%), followed by category 4 (7 pupils or 31.82%), while only 3 pupils (or 13.64%) were assigned to category 1 by all three estimators, and only 4 pupils (or 18.18%) to category 3.

Confusion matrices shown in Tables 6, 7, and 8 give pairwise comparison of estimations obtained by the ES, teachers and psychologists.

➲ TABLE 6
Confusion matrix of the estimations by teachers and the expert system

| Gift – teacher's estimation | Gift – ES decision 1 | 2 | 3 | 4 | Total number of pupils |
|---|---|---|---|---|---|
| 1 | 7 | 0 | 0 | 0 | 7 |
| 2 | 17 | 15 | 8 | 0 | 40 |
| 3 | 1 | 18 | 14 | 3 | 36 |
| 4 | 0 | 0 | 6 | 17 | 23 |
| Total number of pupils | 25 | 33 | 28 | 20 | 106 |

Values on the diagonal of the confusion matrix in Table 6 present the number of pupils estimated in the same category by the ES and teachers. It can be seen that the largest absolute match is present in category 4, where 17 pupils are assigned to that category by the teacher and the system. It is interesting to observe the numbers above and below the matrix diagonal that explain the differences in assessments by each category in detail. If we look at the data in the first row of the table, it can be seen that all 7 pupils assigned to category 1 by teachers are also assigned to the same category by the system. However, 17 out of a total number of 40 pupils assigned to category 2 by teachers, are assigned to category 1 by the system, while 8 of them the system assigned to category 3. The third row of the matrix shows that out of 36 pupils assigned to category 3 by teachers, 1 of them was assigned by the system to category 1, and 18 of them to category 2, while 3 of them were assigned to category 4. Data in columns of the confusion matrix show the way teachers estimated pupils assigned to a certain category by the system.

Table 7 on its diagonal presents the number of pupils estimated in the same category by the teachers and psychologists. It can be seen that teachers and psychologists mostly agree when assigning pupils to category 2 – child with mathematical competencies above the average. Out of 20 pupils assigned to category 1 by the psychologist, only 3 pupils were also assigned to the same category by teachers. The agreement for category 2 and category 3 is higher (20 out of 37 pupils assigned to category 2 by psychologists are also assigned by teachers, while 7 out of 21 pupils assigned to category 3 by psychologists are also assigned by teachers). When category 4 is observed, 10 pupils were assigned to that category by both estimators.

The comparison of estimations made by the ES and psychologists is presented in Table 8. It can be seen from the figures at the matrix diagonal that the ES and psychologists mostly agree when assigning pupils to category 2. Out of 20 pupils assigned to category 1 by the psychologist, 10 pupils were also assigned to the same category by the ES. The agreement in category 2 is present with 15 pupils, in category 3 with 8 pupils, while 9 out of 28 pupils assigned to category 4 by psychologists are also assigned by the system).

➲ TABLE 7
Confusion matrix of the estimations by teacher and psychologist

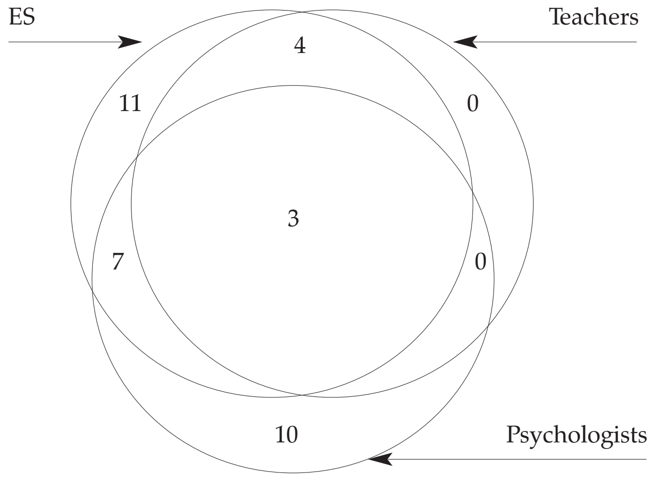
| Gift – teacher's estimation | Gift – psychologist's finding 1 | 2 | 3 | 4 | Total number of pupils |
|---|---|---|---|---|---|
| 1 | 3 | 3 | 0 | 1 | 7 |
| 2 | 10 | 20 | 6 | 4 | 40 |
| 3 | 6 | 10 | 7 | 13 | 36 |
| 4 | 1 | 4 | 8 | 10 | 23 |
| Total number of pupils | 20 | 37 | 21 | 28 | 106 |

➲ TABLE 8
Confusion matrix of the estimations by the expert system and psychologist

| Gift – ES decision | Gift – psychologist's finding 1 | 2 | 3 | 4 | Total number of pupils |
|---|---|---|---|---|---|
| 1 | 10 | 13 | 0 | 2 | 25 |
| 2 | 9 | 15 | 5 | 4 | 33 |
| 3 | 1 | 6 | 8 | 13 | 28 |
| 4 | 0 | 3 | 8 | 9 | 20 |
| Total number of pupils | 20 | 37 | 21 | 28 | 106 |

Since we are especially interested in the estimations for category 1 – a child with a potential gift in mathematics, those estimations will be further analyzed. Graphical presentation of the above estimations in the form of Venn's diagrams is given in Figure 4.

➲ FIGURE 4
Venn's diagram of the estimations for category of potentially gifted children



It can be seen from Figure 4 that more overlapping is present between estimations of ES and psychologists than between teachers and psychologists. Besides 3 pupils that were assigned to category 1 by all three estimators, 7 pupils were also assigned to that category by both ES and psychologists. Therefore, the figure also expresses that ES decisions are closer to psychologists' findings than the teachers' estimations are.

In order to examine the way the two estimators classify the pupils into potentially gifted or not, the McNemar test is employed so that pairwise comparison of estimations is conducted. The McNemar test is generally used to evaluate an experiment in which a sample of n subjects is evaluated on a dichotomous dependent variable and assumes that each of the n subjects contributes two scores on the dependent variable (Sheskin, 1997). For the purpose of this test, the estimations made by teachers, ES, and psychologists are grouped in two basic categories coded as 1 if a pupil was assigned to category 1, and 0 if a pupil was assigned to one of the other three categories of gift (category 2, 3, and 4). The hypotheses used in our research: $H_0$: $p_b=p_c$, and $H_1$: $p_b \neq p_c$ were tested for each pair of two estimators using McNemar's test:

$$\chi^2=\frac{(b-c)^2}{b+c} \qquad (1)$$

where *b* is the number of pupils assigned to category 1 by estimator 1 and to category 0 by estimator 2, and *c* is the number of pupils assigned to category 0 by estimator 1 and to category 1 by estimator 2. If the two estimators tend to assign different pupils to category 1, there should be a significant difference in probabilities in the distribution table in positions of score *b* and score *c*. If the difference is not shown, it should be concluded that both estimators categorize pupils with the same probability. To perform the test, the values in Table 9 are computed.

TABLE 9
McNemar distributions for the comparison of teachers', expert system's and psychologists' estimations

| | ES decision | | Psychologists' findings | | Psychologists' findings | |
|---|---|---|---|---|---|---|
| | not gifted | gifted | not gifted | gifted | not gifted | gifted |
| Teachers' estimations | | | | | | |
| not gifted | 81 | 18 | 82 | 17 | | |
| gifted | 0 | 7 | 4 | 3 | | |
| ES decision | | | | | | |
| not gifted | | | | | 71 | 10 |
| gifted | | | | | 15 | 10 |

Teachers' vs. ES estimations: $\chi^2=18$; teachers' vs. psychologists' estimations: $\chi^2=8.048$; ES vs. psychologists' estimations: $\chi^2=1.0$.

With the degree of freedom 1, the results of comparison by the McNemar test show that the difference among teachers' and ES estimates is significant ($\chi^2=18.0$) at 0.05 level, as well as the difference among teachers' and psychologists' estimates ($\chi^2=8.048$), while there is no significant difference among the estimates by ES and psychologists ($\chi^2=1.0$).

## CONCLUSION AND GUIDELINES FOR FUTURE RESEARCH

The paper discusses the problem of recognizing a child's mathematical gift in the fourth grade of elementary school. In order to support teachers in their decision about the category of gift, an ES MathGift is created whose knowledge base includes five groups of competencies while determining the mathematical gift. A survey is conducted in ten elementary schools where teachers, the ES and psychologists estimated pupils into one of the four categories of gift. Teachers estimated pupils based on their subjective evaluation and experience, psychologists used standard progressive Raven's matrices, and their interviews, while the ES based its decision on five different groups of competencies. The comparison of their estimations shows a statistically significant difference between estimations of teachers and psychologists, as well as between teachers and the ES, while the difference in proportions between the ES and psychologists is not statistically significant. The same is confirmed by the McNemar test which showed that only the difference in estimations between the ES and the psychologists was not significant. It implies that the ES decisions are more similar to psychologists' findings than teachers' estimations, and that the ES could support teachers in deciding about a pupils' gift in mathematics in schools with a lack of psychologists.

Due to the fact that teachers estimated the values of the input variables in the ES, it was expected that the final estimations of giftedness obtained by teachers and the ES would be more correlated. However, teachers gave their own independent assessments of a child's gift without knowing the decision of the ES. The decision of the ES was generated on the basis of a decision tree and search methods included in the system knowledge base, where the variables i.e. attributes were mutually connected. The differences in final assessments of giftedness obtained by teachers and the ES show that teachers have a different way of making their decisions, regardless of the fact that they use the same input values. It implies that the knowledge incorporated in the system is able to add some new value to teachers' estimations of giftedness.

An important issue raised in this research is connected with the fact that psychological estimations estimate general giftedness although correlate to mathematical achievement, while the teachers' and the ES estimates are focused on mathematical giftedness exclusively. It emphasizes the need to further analyze dimensions of mathematical giftedness in more detail. The mathematical giftedness identified by the ES represents the giftedness as a structural form of five components included in the ES knowledge base. On the other hand, teachers, although instructed to include all of those five components as criteria in their assessments, are subject to their personal perception of a child. Therefore, the comparison of the assessments should be taken cautiously, and more effort is to be made in synchronizing criteria among estimators. In spite of this disadvantage, this research could expand the horizons of teachers in detecting gifted children. The ES offers an ability to include more information when making a decision about a child's gift, and also opens up a possibility to include other artificial intelligence techniques into the process of detecting children's gift, such as decision trees, neural networks, or intelligent agents. Those techniques open a way to provide qualitative assistance to teachers in detecting gifted children, therefore ensuring that pupils who need gifted education are recognized and matched with appropriate services. The MathGift ES could serve as an effective solution for universal and equal, culture independent detection of mathematically gifted children. This research could contribute to the process of designing models for educating gifted pupils, which is listed as one of the priority areas for both pre-service and continuing training for educators and teachers in many countries. Furthermore, it governs teachers and educators to use information and communication technology, therefore playing an important role in supporting innovations in the education system.

Future research could also investigate the efficiency of the ES in educating students of teacher education schools in order to enhance their competencies towards discovering, stimulating, and educating mathematically gifted children.

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## APPENDIX

### Statistical descriptive analysis of the input variables on the whole sample

| Variable code | Variable description | Frequencies |
|---|---|---|
| | *Group 1: Mathematical competencies – Numbers and calculation* | |
| V1 | Does the pupil know how to graphically write large numbers? (1=yes, 2=no) | 1 = 85.85%<br>2 = 14.15% |
| V2 | If the answer to V1 is "yes":<br>Does the pupil know how to graphically read large numbers? (1=yes, 2=no) | 0 = 13.21%<br>1 = 77.36%<br>2 = 9.43% |
| V3 | Can the pupil successfully solve assignments that include one arithmetic operation? (1=yes, 2=no) | 1 = 87.74%<br>2 = 12.26% |
| V4 | If the answer to V3 is "yes":<br>Can the pupil follow the correct order of different arithmetic operations in calculation? (1=yes, fast, 2=yes, slow, 3=no) | 0 = 12.26%<br>1 = 47.17%<br>2 = 32.08%<br>3 = 8.49% |
| V5 | If the answer to V4 is "yes, fast":<br>Does the pupil successfully apply associative and distributive laws? (1=yes, 2=no) | 0 = 53.77%<br>1 = 40.57%<br>2 = 5.66% |
| V6 | If the answer to V4 is "yes, slow":<br>Does the pupil successfully apply associative and distributive laws? (1=yes, 2=no) | 0 = 71.70%<br>1 = 13.21%<br>2 = 15.09% |
| V7 | How does the pupil estimate result? (1=The estimation improves by practicing, 2=Practice gives no improvement) | 1 = 88.68%<br>2 = 11.32% |
| V8 | Does the pupil recognize Roman digits and how does she/he use Roman numbers? (1=Yes, but only reads Roman numbers, 2=Yes, reads and writes Roman numbers, 3=Yes, reads, writes Roman numbers, and also solves assignments with matches used in calculating with Roman numbers, 4=Nothing of the above) | 1 = 16.04%<br>2 = 43.40%<br>3 = 33.02%<br>4 = 7.55% |
| | *Measurements and measuring* | |
| V9 | Is the pupil familiar with and how does she/he apply length metric units? (1=Yes, only familiar with length metric units, 2=Yes, familiar with length metric units and also estimates length accurately, 3=Yes, familiar with length metric units, estimates length accurately, and solves problem assignments that include length, 4=Nothing of the above) | 1 = 45.28%<br>2 = 28.30%<br>3 = 17.92%<br>4 = 8.49% |
| V10 | Is the pupil familiar with liquid metric units? (1=yes, 2=no) | 1 = 85.85%<br>2 = 14.15% |
| V11 | If the answer to V10 is "yes":<br>Can the pupil estimate and measure liquid? (1=yes, 2=no) | 0 = 9.43%<br>1 = 38.68%<br>2 = 51.89% |
| V12 | If the answer to V11 is "yes":<br>Can the pupil "discover" the volume of an irregular 3-D shape by diving it into liquid in a gauge glass? (Perceiving the relationship between cubic decimetre and litre, as well as between cubic centimetre and millilitre.) (1=yes, 2=no) | 0 = 61.32%<br>1 = 9.43%<br>2 = 29.25% |
| V13 | If the answer to V12 is "yes":<br>Can the pupil solve problem assignments that include liquid? (1=yes, 2=no) | 0 = 79.25%<br>1 = 10.38%<br>2 = 10.38% |

(continued)

| Variable code | Variable description | Frequencies |
|---|---|---|
| V14 | Is the pupil familiar with and how does she/he apply mass metric units? (1=Yes, only familiar with mass metric units, 2= Yes, familiar with mass metric units and estimates mass properly, 3=Yes, familiar with mass metric units, estimates mass properly, and solves problem assignments that include mass, 4=Nothing of the above) | 1 = 50.94%<br>2 = 31.13%<br>3 = 11.32%<br>4 = 6.60% |
| | *Plane and shape* | |
| V15 | Does the pupil distinguish 2-dimensional shapes from 3-dimensional shapes? (1=yes, 2=no) | 1 = 84.91%<br>2 = 15.09% |
| V16 | Can the pupil distinguish different 2-D shapes (1=yes, 2=no) | 1 = 87.74%<br>2 = 12.26% |
| V17 | If the answer to V16 is "yes":<br>Does the pupil understand the terms: perimeter, flooring? (1=yes, 2=no) | 0 = 6.60%<br>1 = 30.19%<br>2 = 63.21% |
| V18 | If the answer to V17 is "yes":<br>Can the pupil split a shape into similar shapes? (1=yes, 2=no) | 0 = 68.87%<br>1 = 23.58%<br>2 = 7.55% |
| V19 | If the answer to V18 is "yes":<br>Does the pupil understand the relationship between perimeter and flooring (area)? (1=yes, 2=no) | 0 = 76.42%<br>1 = 18.87%<br>2 = 4.72% |
| V20 | If the answer to V19 is "yes":<br>Does the pupil solve problem assignments including shapes? (1=yes, 2=no) | 0 = 81.13%<br>1 = 13.21%<br>2 = 5.66% |
| V21 | Does the pupil recognize the parallel and perpendicular lines in the environment and in 2-D and 3-D shapes? (1=Yes, recognizes only, 2=Yes, recognizes and constructs given positions, but does not solve position assignments, 3=Yes, recognizes and solves position assignments, but is not able to construct given positions, 4=Yes, recognizes, constructs given positions, and is able to construct position assignments, 5=No, nothing of the above) | 0 = 0.94%<br>1 = 28.30%<br>2 = 33.02%<br>3 = 25.47%<br>4 = 6.60%<br>5 = 5.66% |
| | *Data manipulation and problem solving* | |
| V22 | Does the pupil know the elements of statistics (counting)? (1=yes, 2=no) | 1 = 40.57%<br>2 = 59.43% |
| V23 | If the answer to V22 is "yes":<br>Can the pupil read graphical data (for example charts)? (1=yes, 2=no) | 0 = 55.66%<br>1 = 31.13%<br>2 = 13.21% |
| V24 | If the answer to V23 is "yes":<br>Can the pupil interpret text graphically? (1=yes, 2=no) | 0 = 68.87%<br>1 = 20.75%<br>2 = 10.38% |
| V25 | If the answer to V24 is "yes":<br>Can the pupil solve problem assignments with graphical interpretation of text? (1=yes, 2=no) | 0 = 78.30%<br>1 = 16.98%<br>2 = 4.72% |
| V26 | Can the pupil solve problem assignments using step by step method? (1=yes, 2=no) | 0 = 0.94%<br>1 = 35.85%<br>2 = 63.21% |
| V27 | Can the pupil solve problem assignments using backward method? (1=yes, 2=no) | 1 = 30.19%<br>2 = 69.81% |
| V28 | Can the pupil solve problem assignments in equation form understanding that addition is the inverse of subtraction, and multiplication is the inverse of division? (1=yes, 2=no) | 1 = 38.68%<br>2 = 61.32% |



(continued)

| Variable code | Variable description | Frequencies |
|---|---|---|
| | *Group 2: Cognitive components of gift* | |
| V29 | Does the pupil have the ability of focused attention? (1=yes, 2=no) | 1 = 51.89%<br>2 = 48.11% |
| V30 | Does the pupil have the ability of finding a path towards the solution (convergent thinking)? (1=yes, 2=no) | 1 = 39.62%<br>2 = 60.38% |
| V31 | Does the pupil have the ability of constructing complex problem situations after solving simple ones (divergent thinking)? (1=yes, 2=no) | 1 = 32.08%<br>2 = 67.92% |
| V32 | Does the pupil have the ability of memorizing the facts and searching the long term memory? (1=yes, 2=no) | 1 = 30.19%<br>2 = 69.81% |
| | *Group 3: Components of gift that contribute to gift realization* | |
| V33 | Is the pupil open to new experience? (1=Yes, she/he is open to constant changes, 2=Yes, accepts some changes, and then "freezes", 3=No) | 1 = 49.06%<br>2 = 37.74%<br>3 = 13.21% |
| V34 | How does the pupil see herself/himself in comparison with other people? (1=positive, 2=negative) | 1 = 82.08%<br>2 = 17.92% |
| V35 | How does the pupil perceive the environment evaluation of herself/himself (evaluation that comes from the people important to her/him? (1=positive, 2=negative) | 1 = 88.68%<br>2 = 11.32% |
| V36 | How does the pupil react to stress (does she/he accept problems and failure as an opportunity for acquiring new experience)? (1=positive, 2=negative) | 1 = 72.64%<br>2 = 27.36% |
| | *Group 4: Environment factors* | |
| V37 | Does the pupil get additional assignments from the teacher during regular courses of mathematics? (1=yes, 2=no) | 1 = 51.89%<br>2 = 48.11% |
| V38 | Does the pupil have the support of parents in the sense of additional practicing of mathematics at home? (1=yes, 2=no) | 1 = 72.64%<br>2 = 27.36% |
| V39 | Does the pupil have the financial support of her/his parents (such as financing additional instructions in mathematics or similar)? (1=yes, 2=no) | 1 = 33.02%<br>2 = 66.98% |
| V40 | Does the pupil have the support of mentor towards achieving necessary mathematical knowledge and skills? (1=yes, 2=no) | 1 = 47.17%<br>2 = 52.83% |
| V41 | Does the pupil have the support of mentor towards achieving average mathematical competencies? (1=yes, 2=no) | 0 = 0.94%<br>1 = 37.74%<br>2 = 61.32% |
| V42 | Does the pupil have the support of mentor towards acknowledgment of her/his competencies (training for math competitions)?" (1=yes, 2=no) | 1 = 29.25%<br>2 = 70.75% |
| V43 | Does the pupil have the support of her/his school? (1=yes, 2=no) | 1 = 53.77%<br>2 = 46.23% |
| V44 | Does the pupil have the support of her/his family? (1=yes, 2=no) | 1 = 80.19%<br>2 = 19.81% |
| V45 | Does the pupil have the support of society? (1=yes, 2=no) | 1 = 78.30%<br>2 = 21.70% |
| V46 | Did the pupil receive any prizes or acknowledgements in the area of mathematics? (1=yes, 2=no) | 1 = 0.00%<br>2 = 100.00% |
| V47 | Did the pupil receive any prizes or acknowledgements in other areas? (1=yes, 2=no) | 1 = 33.96%<br>2 = 66.04% |



(continued)

| Variable code | Variable description | Frequencies |
|---|---|---|
| V48 | Did the pupil participate in any meetings in the area of mathematics? (1=yes, 2=no) | 1 = 5.66%<br>2 = 94.34% |
| V49 | Is the pupil involved in additional mathematical (or computer or technical) courses at school? (1=yes, 2=no) | 1 = 28.30%<br>2 = 71.70% |
| V50 | Is the pupil involved in additional mathematical (or computer or technical) courses out of school? (1=yes, 2=no) | 1 = 16.04%<br>2 = 83.96% |
| V51 | Does the pupil use any other professional services in the area of mathematics (instructions, computer or technical courses, mathematical magazines...)? (1=yes, 2=no) | 1 = 16.98%<br>2 = 83.02% |
| | *Group 5: Active learning and exercising* | |
| V52 | Does the pupil have the skill of distinguishing important from unimportant? (1=yes, 2=no) | 1 = 67.92%<br>2 = 32.08% |
| V53 | Does the pupil have the skill of combining and organizing information into a meaningful structure? (1=yes, 2=no) | 1 = 47.17%<br>2 = 52.83% |
| V54 | Does the pupil have the skill of selective comparison and connecting new information with the existing information in long term memory? (1=yes, 2=no) | 1 = 52.83%<br>2 = 47.17% |
| V55 | Does the pupil have analytical thinking skills (reasoning, comparing, estimating, evaluating)? (1=yes, 2=no) | 1 = 55.66%<br>2 = 44.34% |
| V56 | Does the pupil have creative thinking skills (discovering, imagination, creating new)? (1=yes, 2=no) | 1 = 57.55%<br>2 = 42.45% |
| V57 | Does the pupil have practical skills (bringing thoughts into action)? (1=yes, 2=no) | 1 = 51.89%<br>2 = 48.11% |
| V58 | Does the pupil have planning skills? (1=yes, 2=no) | 1 = 40.57%<br>2 = 59.43% |
| V59 | Does the pupil have the skill of "keeping track" of self improvement? (1=yes, 2=no) | 1 = 48.11%<br>2 = 51.89% |
| V60 | Does the pupil have the skill of regulating her/his behaviour (is she/he ready for changes in the way of learning if it does not give certain results)? (1=yes, 2=no) | 1 = 48.11%<br>2 = 51.89% |

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# Prepoznavanje matematički darovite djece s pomoću ekspertnoga sustava, nastavnika i psihologa

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Znanstveno dokazana psihološka detekcija darovitih učenika obično nije dostupna u svim školama. Kako bi se omogućilo točno i rano prepoznavanje matematički darovite djece, predložen je inteligentni ekspertni sustav MathGift kao pomoć učiteljima u donošenju odluke o matematičkoj darovitosti djece u četvrtom razredu osnovne škole. Osim matematičkih kompetencija, sustav uključuje ostale komponente darovitosti u donošenju odluke, kao što su kognitivne komponente darovitosti, osobne komponente koje pridonose razvoju darovitosti, strategije učenja i vježbanja, kao i neke činitelje okoline. Istraživanje je provedeno u deset osnovnih škola, pri čemu su prikupljene procjene ekspertnoga sustava, psihologa i učitelja za svako dijete u promatranom uzorku. Rad opisuje neke razlike između procjena darovitosti djece dobivenih u ekspertnom sustavu psihologa i učitelja. Rezultati pokazuju da se ekspertni sustav može predložiti kao metodološki alat koji će pomoći učiteljima u odlučivanju o matematičkoj darovitosti djece.

Ključne riječi: ekspertni sustav, matematička darovitost, psihološke procjene darovitosti, učiteljeve procjene darovitosti, t-test, McNemarov test

# Das Erkennen mathematisch begabter Kinder mit Hilfe von Lehrern, Psychologen und eines Expertensystems

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Eine objektiv nachweisbare psychologische Detektierung begabter Schüler ist an Schulen gemeinhin nicht möglich. Um eine exakte Früherkennung mathematisch begabter Kinder zu ermöglichen, wurde vorgeschlagen, Grundschullehrern der vierten Klasse das Expertensystem MathGift als Hilfsmittel an die Hand zu geben, um ihnen den Einblick in die Begabung von Schülern zu erleichtern. Neben mathematischen umfasst das Expertensystem auch andere zur Begabungsentfaltung beitragende Kompetenzen, so kognitive Fähigkeiten, persönliche Merkmale, Lern- und Übungsstrategien sowie einige Faktoren aus dem sozialen Umfeld. Eine entsprechende Untersuchung wurde an zehn kroatischen Grundschulen durchgeführt, wobei die auf ein bestimmtes Kind bezogenen Resultate des Expertensystems sowie Einschätzungen von Psychologen und Lehrern festgehalten wurden. Die Verfasser beschreiben, welche Abweichungen dabei zu verzeichnen waren. Die Untersuchungsergebnisse zeigen, dass das Expertensystem als methodologisches Hilfsmittel zur Erkennung mathematischer Begabung vorgeschlagen werden kann.

Schlüsselbegriffe: Expertensystem, mathematische Begabung, Begabungseinschätzung durch Psychologen und Lehrer, t-Test, McNemar-Test