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Modeling children's mathematical gift by neural networks and logistic regression

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ABSTRACT

The purpose of the paper was to extract important features of children's mathematical gift by using neural networks and logistic regression, in order to create a model that will assist teachers in elementary schools to recognize mathematically gifted children in an early stage, therefore enabling further development and realization of that gift. The initial model was created on the basis of a theoretical background and heuristical knowledge on giftedness in mathematics, including five components: (1) mathematical competencies, (2) cognitive components of gift, (3) personal components that contribute gift development, (4) environmental factors, and (5) efficiency of active learning and exercising methods, as well as grades and out-of-school activities of pupils in the fourth year of elementary school. The three neural network classification algorithms were tested in order to extract the important variables for detecting mathematically gifted children. The best neural network model was selected on the basis of a 10-fold cross-validation procedure. The model was also investigated by the logistic regression. Important predictors detected by two methods were compared and analyzed. The results show that both methods extract similar set of variables as the most important, including grades in mathematics, mathematical competencies of a child regarding numbers and calculating, but also grades in the literature, and environmental factors.

1. Introduction

Previous research (Johnson, 2007) emphasized the need for accurate detection and further development of mathematical gift. Mathematical giftedness of children in elementary schools was detected by using mathematical tests such as SAT-Math, as well as scientifically approved standard Raven progressive matrices in the process of psychological evaluation of a child (O'Boyle et al., 2005; Pind, Eyrún, Gunnarsdóttir, & Johannesson, 2003). In schools where psychologists are not available, teachers usually use mathematical competencies as the only criterion for determining a child's gift. Pavlekovic, Zekic-Susac, and Djurdjevic (2009) created an expert system that uses five components of mathematical gift, identified upon theoretical background (Sterberg, 2001; Tannenbaum, 1983; Terman & Oden, 1959; Vlahovic-Stetic, 2006) and heuristics, such as (1) mathematical competencies, (2) cognitive components of gift, (3) personal components that contribute gift development, (4) environmental factors, as well as (5) efficiency of active learning and exercising methods. Their research shows that MathGift ES detected more children as gifted than teachers did in their estimates, and that the expert system estimations are more similar to psychologists' estimations. The model did not include grades of the pupils which are often used by teachers in gift detection.

This paper aims to extend the previous research (Pavlekovic et al., 2009) by including pupils' grades into the model, as well as to test quantitative methods based on learning theory in order to avoid the dependence on heuristics and human expert. To identify important selectors that teachers usually use to identify gifted children, it was challenging to test an intelligent method that has abilities of dealing with nonlinear functions in the purpose of prediction, classification, and association. Therefore, three neural network (NN) algorithms were tested in order to classify children in one of the two gift categories. The model is aimed to learn psychological findings, and to be used as a part of a decision support system in schools where psychologist's estimations are not available.

A survey was conducted at 10 Croatian elementary schools where the psychologists' and teachers' estimates were obtained for each child in the sample. The results of the neural network model and logistic regression model were compared in terms of important predictors. The advantages and limitations of both approaches are also discussed.

The output of the model was binary defined representing two categories: (1) mathematically gifted children and (2) mathematically

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non-gifted children. An empirical research was conducted in 2006, including pupils of age 10 (fourth grade) in 10 elementary schools in Osijek. The estimations were compared using statistical tests.

The structure of the paper is the following: Section 2 contains a review of previous research in the area, followed by the description of neural network and logistic regression methodology used in the paper. The data about examinees are described in a separate section. After the results, the conclusion and guidelines for future research are given.

2. Review of previous research

A number of authors has tested various statistical methods and neural networks in education, but mainly in measuring the potential of students with regard to their study performance as an important step of the admission process in a school. Gorr, Nagin, and Szczypula (1994) predicted student grade point averages (GPAs) by using linear regression, stepwise polynomial regression, and NNs, and then compared the predictions with an index used by an admissions committee for predicting student GPAs in professional school. Their results show that none of the tested methods was significantly better than the practitioners' index. Hardgrave, Wilson, and Walstrom (1994) investigated NNs in predicting students' success in a graduate program. They showed that non-parametric procedures such as neural networks perform at least as well as traditional methods and are worthy of further investigation. Wilson and Hardgrave (1995) tested different classification and regression methods such as discriminant analysis, logistic regression and neural networks, in predicting graduate student success in an MBA program, and shown that non-parametric procedures, such as neural networks, perform at least as well as traditional methods and are worthy of further investigation in that area. Zeleznikov and Nolan (2001) created a decision support system based on fuzzy logic and predicated rules to assist teachers in grading essays. Paliwal and Kumar (2009) used neural networks and traditional statistical techniques, such as regression analysis, discriminant analysis, factor analysis, and logistic regression to predict academic performance of business school graduate students. Their results show that similar set of predictors is extracted by all tested methods. Stathacopoulou, Magoulas, Grigoriadou, and Samarakou (2005) propose to use the methodology of NNs and fuzzy logic for an advanced student diagnosis process in an intelligent learning system. Their model enables a system to "imitate" teacher in diagnosing student characteristics, and in selecting the learning style that suits those characteristics. The system is tested in learning vector construction in physics and mathematics. Results obtained by the system are compared to the recommendations of a group of experienced teachers, showing that the system is able to manage the diagnostic process, especially for marginal cases, where it was difficult even for teacher to bring accurate evaluation of student. Canales, Pena, Peredo, Sossa, and Gutierrez (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.

The above shows that neural networks were frequently used in addition to traditional statistics in previous research on student success. However, the area of detecting mathematical gift was not investigated enough. O'Boyle et al. (2005) investigated brain activation of mathematically gifted male adolescents, but there is a lack of research of mathematical giftedness in elementary schools. Teachers usually rely on mathematical tests and their subjective judgments in detecting mathematically gifted children. Pavlekovic et al. (2009) compared the efficiency of expert systems and neural networks in detecting a child's mathematical gift. They showed that both methods can serve as an efficient tool in detecting mathematically gifted children, on the basis of five basic components of mathematical gift, which consisted of totally 60 input variables. As an extension to that previous paper, this research adds some new input variables to the model describing pupils' grades and out-of-school activities, and compares the basic feature of mathematical gift extracted by neural networks and logistic regression.

3. Description of data and sampling procedure

The initial data sample for the research included 257 children of the fourth grade at 10 elementary schools in Osijek, Croatia at December 2006. Parents' permissions to do psychological evaluations were obtained for 106 pupils. After excluding missing data, 105 pupils were used for modeling. The input space consisted of the five components of mathematical gift identified in previous research (Pavlekovic, Zekic-Susac, & Djurdjevic, 2007), as well as of the data describing pupil's grades, and additional out-of-school activities in which a pupil was engaged. The five components of mathematical gift were (1) mathematical competencies, (2) cognitive components of gift, (3) personal components that contribute the gift development, (4) strategies of learning and exercising, and (4) environmental factors. The group of mathematical competencies was represented by the level at which a pupil deals with (a) numbers, (b) measurements, (c) shapes, and (d) solving mathematical problems. The estimation of a pupil's level of dealing with those competencies was given by a pupil's teacher. Teachers participating in the research were previously instructed on the estimation criteria. In addition to teacher estimations on the above competencies, a pupil's grade point average, individual grades in the course of mathematics and the literature, as well their out-of-school activities were also used as input data. Therefore, a total number of 18 input variables were used, and their descriptive statistics is presented in Table 1.

The output variable represented a pupil's gift in mathematics estimated by school psychologists who were specialized in education of gifted children. Although psychologists found four categories of mathematical gift, in order to pay special attention to gifted children, categories were further regrouped into two main groups: (1) group of pupils found to be mathematically gifted, consisted of pupils assigned to categories 1 and 2 by psychologists, further referred as "*gifted*" pupils, and (0) group of pupils that were not found to be mathematically gifted, consisted of pupils assigned to categories 3, and 4, further referred as "*non-gifted*" pupils. The structure of psychologists' findings is presented in Table 2.

It can be seen from Table 2 that more than 50% of pupils in the sample were recognized as mathematically gifted by psychologists. The reason for such high proportion of gifted lies in the fact that parents' permissions to do psychological evaluations were obtained mostly for children with a high grade point average (50% of pupils in the final sample have the rounded grade point average of 5). Therefore, the initial sample ($n = 257$) was representative, but the final sample ($n = 105$) consisted of mainly very good and excellent pupils (mean of the GPA = 4.7). In spite of such non-representative final sample, the research was continued since it was assumed that (1) the population of gifted pupils remained in the final sample, and (2) if the model is able to accurately recognize gifted among such above-average pupils, it should also be useful while dealing with the whole population.

In order to train and test neural networks, the total sample was randomly divided into three subsamples such that 80% of data was used for training the network, 10% of data was used to find the optimal learning time and network structure in a cross-validation