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Predicting and analyzing secondary education placement-test scores: A data mining approach

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ABSTRACT

Understanding the factors that lead to success (or failure) of students at placement tests is an interesting and challenging problem. Since the centralized placement tests and future academic achievements are considered to be related concepts, analysis of the success factors behind placement tests may help understand and potentially improve academic achievement. In this study using a large and feature rich dataset from Secondary Education Transition System in Turkey we developed models to predict secondary education placement test results, and using sensitivity analysis on those prediction models we identified the most important predictors. The results showed that C5 decision tree algorithm is the best predictor with 95% accuracy on hold-out sample, followed by support vector machines (with an accuracy of 91%) and artificial neural networks (with an accuracy of 89%). Logistic regression models came out to be the least accurate of the four with and overall accuracy of 82%. The sensitivity analysis revealed that *previous test experience, whether a student has a scholarship, student's number of siblings, previous years' grade point average* are among the most important predictors of the placement test scores.

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1. Introduction

Rapid development of a variety of information technologies increased the amount of data collected and used in decision making processes. As the amount of data collected increased in size and complexity, so did the challenges associated with storing, managing and analyzing it. Incapacitating the capabilities of simple relational database systems, such an exponential surge led to development of new data management systems called data warehouses. On the analysis side of data, a new term coined “data mining”. Simply put, data mining is the non-trivial, iterative process of extracting novel patterns (e.g., associations, trends, relationships, natural groupings, etc.) from large data sources in order to enhance evidence-based decision making. Even though data mining is still considered a new paradigm, it has been successfully applied to a variety of domains including education.

Understanding the factors that lead to success (or failure) of students at secondary education is an interesting and difficult

problem. Therefore, determining the variables that are related to academic achievement of students have always been aroused the curiosity of the researchers. Often centralized placement tests and future academic achievements are considered as related concepts that are derivative of each other. That is, students who are successful in placement tests are assumed to be (in general) successful in their academic endeavors. Though controversial, reasoning behind many of the placement-tests is accredited to this assumption.

Placement of students to secondary education institutions in Turkey is being realized by a centralized and standardized placement test since the 2007–2008 academic year. Scores obtained from examination taken by primary education students are combined with other factors using a preset formula to determine the final placement scores of the Secondary Education Transition System (SETS). The aim of this study is twofold: (i) to investigate predictive power of different data mining methods by employing a *k*-fold cross validation methodology, and (ii) to determine the ranked-importance of predictive variables (i.e., factors) by applying sensitivity analysis on already trained prediction models. It is thought that revealing these variables that directly or indirectly affect achievement would be beneficial to students, parents, teachers, and administrators who are interested in maximizing success. Moreover, the results of the study would be of great value to researchers as well as practitioners in evaluating the effectiveness of these single-test based placement systems.

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This manuscript is organized as follows. In the next section (Section 2) a literature review of analysis of centralized placement testing is presented. In Section 3 the research methodology is given, where data, prediction and analysis methods and evaluation techniques are all explained in detail. In Section 4, the comparative analyzes of the prediction models and the results of the aggregated sensitivity analyzes are presented. In the last section (Section 5) the discussions of the results as well as the concluding remarks are given.

2. Literature review

Understanding the factors (i.e., the predictor variables) that affect students' academic achievement is a critical input to understanding and improving the educational landscape. Many of the previous studies analyzed this phenomenon one variable at a time. They tried to collect data, mostly from survey type instruments, to understand the relationship between a single factor and its impact on academic achievement. For instance, some researchers studied the correlation between academic achievements and parenting styles (Attaway & Bry, 2004; Steinberg, Lamborn, Darling, Mounts, & Dornbusch, 1994), others focused on socio-economic status (Goddard, Sweetland, & Hoy, 2000). Some others investigated the impact of teacher aid to academic achievement (Gerber & Fin, 2001) while others looked at the significance of different schools types (Carpenter, 1985). On the behavioral side, some researchers looked into the perception of personal control (Stipek, 1981), others looked into the efficiency of principals (Gentilucci, 2007), gender (Kelly, 1993), and locus of control (Bain, Boersma, & Chapman, 1983). Some of these studies found statistically strong relationships between the individual factors and academic achievement based on the limited data that they have based their studies on.

Some researchers looked into a pseudo representation of academic achievement, namely the level of success in centralized placement test. Some claimed to have found strong relationship between test scores and family income. Their results pointed out that the level of income has a positive effect on test scores and further academic achievements (Carneiro, 2008; Yenilmez & Duman, 2008). On the other hand, some other researchers have stated that income does not directly affect academic achievement, but affects the beliefs and attitudes of the family, which in turn affects the ultimate outcome (Davis-Kean, 2005). For instance, the families on a high income can afford to send their children to private schools, and provide them with additional private tutoring, which, at the end, may translate to higher academic achievement (in general, but not always).

Standardized tests have become a key component for many institutions in assessing the potential academic success of students. An initial review of past relevant studies shows that, for the most part, the actual prediction of standardized test scores is a relatively unexplored area. Most related studies involve the prediction value of such standardize test scores; in other words, such studies generally do not attempt to use rigorous analytical techniques (e.g., data mining and/or statistical analysis) to predict actual scores, but instead attempt to gauge students' expected performance based upon already known scores (Boaler, 2003; Minaei-Bidgoli, Kashy, Kortmeyer, & Punch, 2003; Suttle, 2010). Also troublesome, yet significant within such studies is the fact that standardized testing itself is extremely controversial in nature. The validity of tests such as the SAT has been (and remains) a major source of contention within academia: the key issue involves the applicability, comprehensiveness and fairness of the test. Again, many analytical studies, some of which involve prediction, thus seek to understand the relationships between test scores and academic success, grades, demographics, testing environment, etc. Yet despite years of research on this very issue, an overview of related studies suggests that the answer remains nebulous at best.

The concept of fairly measuring intelligence (and hence, future academic potential) within a broad spectrum of students (from inner-city schools to poor rural schools to "upscale" private institutions) may be the goal of such tests, however, in the case of the SAT in particular, some research indicates that this is an unrealistic notion (Suttle, 2010). Indeed, considering the SAT's "pure aptitude" theory, one must merely scratch the surface of standardized testing/demographics research to find evidence to the contrary. Milewski, Camara, and Kobrin (2002) for example, collected and contrasted individual SAT scores and high school grades within several diverse student bodies. Each individual was categorized based on the presence of a statistically "significant" difference in high school grades and SAT score. The students were thus effectively divided into three groups: those with no significant variance in grades/test scores; those with SAT scores "significantly" better than grades would suggest; and finally, those whose SAT scores were abnormally low in comparison to high school performance. Needless to say, the most significant finding in said study was the fact that "females and minority students were more heavily represented" in the final group. Such a finding was worrisome, the authors concluded, in that it suggested the SAT may not be "accurately measuring the ability of female and minority students and may unfairly disadvantage them in college admission."

In addition to measuring the validity of standardized tests, predictive models have been shown to facilitate the educational process itself. Although such studies do not necessarily predict standardized test outcomes in every case, they do use various methods in an attempt to predict course and/or final grade outcomes. For instance, Feng, Beck, Heffernan, and Koedinger (2008) conducted a study, a significant portion of which involved the prediction of standardized tests scores in middle/high schoolers. The focus of this study was significantly less policy-oriented in that it is not necessarily contradicting or confirming the validity of standardized tests as much as suggesting possible (equally effective) alternative methods of measuring student development. The regressions they have developed produced impressive results: the 25 variables within the model accounted for 79.4% of the variance in Massachusetts Comprehensive Assessment System (MCAS) scores. Even more impressive was the fact that the model and actual 8th grade MCAS results had nearly identical correlation coefficients in relation to 10th grade MCAS results.

Although it is one of the most critical factors to the success of any prediction model, feature selection within the context of this problem has not necessarily received due attention. In a relatively recent study, Ramaswami and Bhaskaran (2009) compared various methods of feature selection in relation to performance prediction. Overall, the study was of particular interest in that it (1) included several interesting features, including student's "vision", student's "food habit", and other generally more in-depth features relating to the student's family, and (2) presented alternative criteria for the analysis of classifier performance.

Having established the importance of the placement tests in assessing the academic success, this study leverages large datasets with more diverse feature sets (as compared to the previous studies), and multiple advanced prediction methods, including artificial neural networks, support vector machines, decision trees, and logistic regression in an attempt at clarifying some of the factors that determine the outcome of such standardized tests. Whereas research has shown the success of using prior academic data—grades, e-learning usage statistics, etc.—in predicting student performance, this study likewise factors past performance while simultaneously acknowledging the proven impact of demographic traits on test outcomes. As the above review has hopefully indicated, such findings are no doubt critical to discussions of both test validity and educational improvement.

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