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Cognitive Predictors of Academic Success: How Do the General Patterns Work in the Early Stages of Education?

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The article provides an overview of modern works devoted to the study of cognitive predictors of academic success. The general patterns of forecasting are revealed: the most powerful and universal predictor of academic success at different stages of school education is psychometric intelligence; creativity is less significant and rather unstable. It is argued that these patterns are poorly traced at the level of preschool education. Particular cognitive functions are significant for predicting the future educational achievements of preschoolers: information processing speed, visual perception (in combination with motor functions), short-term memory, and attention. Spatial abilities have a certain prognostic potential, though reasoning in preschoolers is not a strong predictor of academic success; executive functions have the greatest predictive power. It is noted that the general patterns in predicting the academic success of students can be traced in elementary school: the predictive potentials of psychometric intelligence are revealed, the power of individual cognitive abilities (in particular, spatial abilities) increases, the contribution of executive functions to the prediction decreases. The general tendency for non-cognitive factors (educational motivation, some personality traits) to increase with age also begins to appear in elementary school.

Keywords: cognitive predictors, intelligence, creativity, executive functions, spatial abilities, academic success, academic achievement, academic performance, pre-school education, elementary school, early stages of education.

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Когнитивные предикторы академической успешности: как общие закономерности «работают» на ранних этапах образования?

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Представлен обзор современных работ, посвященных исследованиям когнитивных предикторов академической успешности. Выделяются общие закономерности: наиболее сильным и универсальным предиктором академической успешности на разных этапах школьного образования является психометрический интеллект; роль креативности менее значительна и достаточно нестабильна. Утверждается, что данные закономерности слабо прослеживаются на уровне дошкольного образования. Обращается внимание на то, что для предсказания будущих учебных достижений дошкольника значимы роли отдельных когнитивных функций: скорости обработки информации, визуального восприятия (в комплексе с моторными функциями), кратковременной памяти, внимания. Определенными прогностическими возможностями обладают пространственные способности, однако мышление у дошкольников не является сильным предиктором академической успешности; наибольшей предсказательной силой обладают управляющие функции. Отмечается, что общие закономерности в предсказании академической успешности обучающихся начинают прослеживаться в начальной школе: выявляются предсказательные возможности психометрического интеллекта, возрастает роль отдельных когнитивных способностей (в частности, пространственных способностей), уменьшается прогностический вклад управляющих функций. Общая тенденция к нарастанию с возрастом роли некогнитивных факторов (учебной мотивации, некоторых личностных характеристик) также начинает проявляться в начальной школе.

Ключевые слова: когнитивные предикторы, интеллект, креативность, управляющие функции, пространственные способности, академическая успешность, учебные достижения, академическая успеваемость, дошкольное образование, начальная школа, ранние этапы образования.

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Introduction

In today's world, the formats, tools, and methods of both pedagogical and educational activities are changing quite rapidly. The COVID-19 pandemic which has changed educational processes on a global scale

has become a separate challenge for the last two years. Under these conditions, the benchmarks and criteria of academic success are gradually being redefined, which in turn raises the question of what predictors can be used to forecast students' academic achievement.

As early as the late 1930s, psychological research on predictors of academic success had established that *psychometric intelligence* and *motivation* were the key predictors of academic achievement. And at present, there are few scientists who would disagree with the significance of these factors.

The analysis of publications shows the massive research work that has been done to identify cognitive predictors of academic success in school education. Today we can state that general patterns in the prediction of academic achievement of schoolchildren have been identified. At the same time, the number of publications reflecting the results of the search for cognitive predictors of academic success in certain educational stages (preschool, primary, secondary, etc.) is noticeably growing. Researchers of this issue note the need to identify prognostic parameters in the earliest stages of education [26]. This review seeks to answer the question: do the general patterns of predicting academic success that are the characteristic of an individual's educational path in general emerge already in the early stages of his or her education (preschool and elementary school)?

The *methodology* of the review included the selection of mostly new publications containing empirical data (original research and meta-analyses). The main criteria for including the source in the review were the completeness of the data description and their evidentiary strength due to the research design and the statistical model which allowed identifying precisely the predictors of academic success.

Intelligence as a Predictor of Academic Success in Schoolchildren

Many studies of cognitive predictors of school success point to intelligence — the ability to solve problems mentally — as the most important prognostic parameter. Regardless of what specific diagnostic tools researchers apply to measure intelligence, this ability clearly shows its high predictive value.

In particular, a meta-analysis by K. Kriegbaum et al. summarizing the results of 74 studies conducted between 1980 and 2016 with subjects totaling N=80145 schoolchildren examine the predictive power of psychometric intelligence and motivation for school achievement. It was found that school performance correlated moderately with intelligence (0.44) and somewhat less intensively with achievement motivation (0,27). At the same time, the relationship between intelligence and motivation was generally low (0.17). The statistical model chosen by the authors was able to explain 24% of the cumulative variance in school performance. 66,6% of this explained variance, according to the authors, is unambiguously explained by psychometric intelligence, while only 16,6% — by achievement motivation. Thus, in total, both predictors explain 16,6% of the cumulative variance [19]. These findings suggest that intelligence remains the strongest predictor of academic success in school, while motivation also plays a role in educational outcomes, but apparently to a less extent.

Another meta-analytical research conducted by B. Roth et al. summarizes the results of studies of 240 independent samples with a total number N=105185 of schoolchildren of different grades [30]. This work also confirms the high predictive power of the general intelligence factor (g-factor) for school marks which, according to

the authors, have a greater impact on later professional careers than other methods of measuring academic success, such as teacher ratings, school achievement tests. The strength of this predictor is ρ=0,54, which confirms earlier but insufficiently empirically based estimates of about 0,5 (e.g., L.S. Gottfredson, U. Neisser, R.J. Sternberg). At the same time, the great predictive capacity of the intelligence has been reliably confirmed on both verbal and nonverbal materials. The moderation analysis revealed that school factors — such as subject matter and year of schooling — influenced the relationship between intelligence and school grades, but gender did not. In addition, the type of the test applied to measure intelligence appears as a moderator. This study also shows that the predictive power of intelligence in relation to school marks changes over the years: it is now lower than it was before 1983 [30].

The latter important circumstance can be explained by certain changes in the cultural and educational environment. Firstly, the intensive digitalization of today's life leads to the comprehensive restructuring not only of educational methods and technologies but also of mental functioning, especially in modern children — those who begin to develop in the digital reality at birth. The digital gadget becomes, in the words of L.S. Vygotsky, a new cultural 'tool' that mediates the child's mental development and is embedded in his or her cognitive processes. The boundaries between an individual's cognitive system and a technical device have become blurred [12]. In this regard, the predictive value of intelligence taken outside its 'digital pillar' naturally decreases. Secondly, this decrease can also be explained by the transformation of modern education which now follows the path of humanization. The increased variability, differentiation, and individualization of education in the late 19th and early 21st centuries are due to the growing role of the learner's personality in learning. This, in turn, could not help but affect the systems for assessing academic achievement, which greater than before include a personalistic learning component.

For school achievement in mathematics (children and adolescents aged 5-19 years were examined), cognitive factors such as fluid reasoning, crystallized intelligence, and information processing speed showed a ***direct*** effect, while general intelligence factor had an ***indirect*** effect in all stages of schooling [34]. In this case, the indicators of fluid reasoning are possible to increase through the training of working memory, which in turn will contribute to the success of learning [1].

If we consider the predictive power of intelligence in combination with personality traits of children taken as predictors of school performance (measured by the grade point average — GPA), we find that intelligence remains the strongest predictor in all stages of schooling, despite the fact that the predictive power of individual personality traits increases in grades 2—4 and 6—12 [21].

Studies of the predictive power of a basic cognitive characteristic such as information processing speed show the conflicting data. In one case, this parameter had a unique effect on academic success, and when this relationship was mediated by intelligence, its predictive power was insignificant [11]. In another case, it was found that the processing speed does not affect the academic success directly but affects indirectly through the higher cognitive abilities: intelligence and creativity [27]. Compared to working memory, reasoning is a more reliable predictor of school performance [20]. Such results seem to suggest that information processing speed is an important predictor of academic success when it determines the effectiveness of intellectual problem solving in a learning process.

Creativity as a Predictor of Academic Success in Schoolchildren

In school educational practice and in a number of studies, creativity is considered as a predictor of academic success of students along with intelligence. However, compared to intelligence, creativity is usually a less reliable predictor of academic achievement, despite being important for life success in general. The role of creativity in educational outcomes of students varies greatly depending on a particular educational program or pedagogical methods used. Divergent thinking and creativity are not always encouraged in school education; often the ability to make logically correct judgments and convergent thinking are more relevant to a particular educational system. As a result, regarding the predictive power of creativity, the data are highly variable: 0,66; 0,41; 0,20; —0,03 (H.E. Anderson, K. Maejoribanks, I.A. Tatlah, Y.C. Yeh, etc.).

One of the recent key studies of creativity as a predictor of academic success is a meta-analysis conducted by A. Gajda et al. [16]. The paper presents a summary of 120 studies conducted since the 1960s with a total subject population of N=52578. This study elicited an average correlation between creativity and academic success (0,22). Nevertheless, the analysis of moderation showed that this relationship is stable over the years but expressed more strongly if special creativity tests are applied as diagnostic tools (compared to self-assessment methods), and if academic success is measured by standard tests (compared to GPA). It is also noted that the results of verbal tests of creativity have a stronger connection with academic success than the results of drawing tests [16].

These findings are generally confirmed by the results of other studies. The relationship between creativity and academic success in school is positive but weak and varies depending on the level of education (upper elementary school, secondary school, high school) and which indicator of academic success is used (stronger relationships were found with the achievement tests than with the GPA). Intelligence and motivation act as mediating links in these relationships [15]. General intelligence shows a rather stronger predictive relationship with GPA scores than creativity. Although being a statistically significant predictor, the combination of both g-factor and creativity has even less power than these factors taken individually. The predictive power of creativity varies by school grade, indicating that some teachers are more appreciative of their students' creativity than others [14]. In elementary school, creativity predicts students' success in native language and mathematics [17].

From a temporal perspective, creativity better predicts academic performance than explains past performance. And the contribution of creativity as a predictor complements the predictive value of student's academic skills and is not negated by them.

In general, there are at least two competing explanations for the low contribution of creativity to the forecast of academic success and the high variability of this predictor. Firstly, the school cannot sufficiently provide students with the necessary conditions for creativity — autonomy and freedom, due to which students often realize their creative abilities outside of the school. There is even a certain negative correlation between the average scores in mathematical creativity and the average performance in mathematics [31]. Secondly, the weak relationship between creativity and educational outcomes can be explained by the moderate correlation of creativity with psychometric intelligence which in turn is a strong predictor of academic success. However, it should be taken into account that intelligence is a necessary but not sufficient condition for high creative abilities.

Cognitive Predictors of Academic Success in the Early Stages of Education

Scholars' search for cognitive predictors of academic success in the stage of preschool education has focused mostly on the role of individual cognitive functions of children. The complex of visual-motor skills makes an important contribution to the subsequent success of preschool children [6; 24]. Thought functions have some predictive capabilities: causal inferencing [5], patterning [28], relational thinking (combined with symbolic mapping) [8]. Spatial abilities (spatial perception, spatial visualization, visual-spatial working memory) also have predictive power, especially in relation to the mathematical achievement of preschoolers [29; 36].

Overall, however, reasoning process is not a strong predictor of academic success in this stage of education [10]. According to the results of numerous studies, the most significant cognitive predictors in preschoolers are executive functions (working memory, inhibitory control, cognitive flexibility). Their prognostic power in preschool children is about 1,5 times greater compared to spatial abilities [36]. Shortcomings in the development of executive functions predict subsequent academic deficits in elementary school [23].

The analysis of studies shows that executive functions forecast the development of a wide range of academic skills in preschoolers, in particular, literacy, reading, and vocabulary. However, the strongest predictive relationships of the executive functions are revealed with the mathematical achievement of preschool children [36]. In this case, this relationship is bilateral, which can be considered as a marker of causality. It is important that the predictive power of executive functions is preserved when controlling the factors of general intelligence, information processing speed, and, to some extent, school readiness determined by the type of kindergarten (for high- or low-income children) [13], and the factors of gender and education level of the preschooler's mother [22]. All of this demonstrates the fundamental nature of executive functions as predictors of academic success in preschool education.

Meanwhile, the predictive power of individual executive functions varies. According to one data, the strongest predictor of academic success in general (both math and reading) is working memory. The predictive power of inhibitory control and cognitive flexibility is less expressed [25]. According to other data, inhibitory control forecasts early numeracy skills stronger than working memory does [22].

D. Stipek, R.A. Valentino found that memory and attention are also reliable predictors of academic success in preschool children, noting that these functions can improve academic achievement in the early years of learning. Subsequently (by the end of elementary school) their role decreases, and success is determined to a greater extent by mastering the specific subject content of learning [33].

In general, as we see, the role of reasoning processes in predicting academic success is low in the stage of preschool education. This can be explained by the limited intellectual capabilities of a preschooler who is at the preoperational stage of intellectual development (according to J. Piaget). Creativity in preschool education is not found by researchers as a significant predictor of academic success.

In elementary school, intelligence forecasts more than 50% academic success in math, less than 50% in native language [9]. A similar predictive power was found in such predictor as working memory [4; 37]. Among all prognostic parameters reasoning and executive functions (working memory, cognitive flexibility) predominate in elementary schoolchildren, while reasoning and speech then dominate in secondary school. The predictive power of cognitive abilities decreases

with age, while the power of cognitive self-representation and personality increases.

The executive functions show reliable links to academic achievement and academic skills in elementary school. However, in comparison with numeracy skills and spatial abilities, the prognostic role of executive functions is less significant. This is not surprising since the formation of the child's internal plan of action, his or her ability to use symbolic means and manipulate them logically determine the success of mastering the subject content of learning in elementary school.

Empirical evidences also prove that the spatial abilities of elementary schoolchildren confidently predict their future mathematical achievement [7; 18] and success in STEM learning [32]. Interesting facts were established by T.N. Tikhomirova et al. They found that such cognitive characteristics as information processing speed, working memory, number sense, and nonverbal intelligence form a consistent universal structure with academic success throughout the school period [3]. In this case, the information processing speed plays the key role [35]. Some dependence of cognitive predictors of academic success in elementary school on the gender factor is also found, but its role is not high [2]. Thus, if we consider cognitive characteristics not separately but in the relationship with one another and academic success, we should recognize that the latter is contributed by executive functions and basic cognitive characteristics — those predictors which usually stand 'in the shadow' of the main prognostic parameter — intelligence.

The predictive power of general creativity is statistically significant in elementary school but quite low — substantially lower than in secondary school [16].

Conclusion

The strongest and most universal predictor of academic success in different stages of schooling was and remains psychometric intelligence. It mediates the influence of motivation and personality traits on academic success, which gain predictive power in later stages of education (especially in highly intelligent students). The role of creativity in predicting school success is less significant and rather unstable. It varies depending on the model for measuring the predictive power of creativity and, apparently, on the educational program and pedagogical methods used.

These general patterns work differently in the early stages of education. In whole, they are poorly traceable in the stage of preschool education. The individual cognitive functions are significant for predicting the future educational achievement of preschoolers: information processing speed, visual perception (in complex with motor functions), short-term memory, attention. Spatial abilities have a certain prognostic potential, though reasoning is not a strong predictor of academic success in this stage of education. Executive functions (inhibitory control, cognitive flexibility, and working memory, in particular) have the greatest predictive power.

The described general patterns of predicting students' academic success begin to emerge in elementary school. Predictive capabilities of psychometric intelligence (especially nonverbal intelligence) are revealed, and the role of individual cognitive abilities (in particular, spatial abilities) increases, while the predictive contribution of executive functions decreases. The general tendency for non-cognitive factors (educational motivation, some personality traits) to increase with age begins to appear gradually in elementary school.

From all of the above, the practical pedagogical implications follow.

In order to achieve academic success in the preschool stage of education, it is advisable to pay attention to the development of the child's executive functions, as well as information processing speed when solving intellectual problems.

In elementary school, nonverbal, particularly spatial abilities, should be the key target of developmental interventions to achieve

academic success, and without adjusting for gender differences.

As promising lines of future research, we should note the clarification of the prognostic role of creativity in the preschool stage, as well as the role of different cognitive strategies and style characteristics of students' cognitive processing.

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