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Executive Functions as Predictors of Mathematical Problem-Solving Skills: Unpacking the Centrality of Planning in Middle School Students

Aboosaeed Davarpanah[1], **Bahman Kord**[2]✉

1. Assistant Professor Department of Education, Faculty of Educational Sciences and Psychology, University of Sistan and Baluchestan, Zahedan, Iran

2. Association Professor Department of Psychology, Mah.C., Islamic Azad University, Mahabad, Iran, bahmankord@iau.ac.ir

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ABSTRACT

Objective: This research aimed to predict mathematical problem-solving skills based on executive functions (working memory, planning, and organization) among middle school students in District 7 of Tehran's Department of Education.

Methods: This was an applied study employing a descriptive-correlational methodology. The statistical population consisted of female middle school students in District 7 of Tehran during the 2024–2025 academic year. A sample of 150 students was selected via multi-stage cluster random sampling. Data were collected using the Executive Functions Questionnaire (Baron, 2000) – Teacher Form and the Mathematical Problem-Solving Skills Questionnaire developed by Hasani (2018). Data were analyzed using stepwise regression analysis with SPSS-22 software.

Results: Findings indicated that mathematical problem-solving skills were significantly predicted by working memory (r=.418), planning (r=.488), and organization (r=.354). The standardized coefficients and the proportion of variance explained by each component of executive functions are as follows: planning entered at the first step (β=.488, accounting for 23.8% of the variance); planning combined with organization entered at the second step (β=.271, accounting for 29.8%); and finally, the combination of planning, organization, and working memory (β=.186) accounted for 32.4% of the total variance in mathematical problem-solving skills.

Conclusions: These findings highlight the significant impact of the planning component of executive functions on students' mathematical problem-solving skills and can inform the design of instructional programs aimed at enhancing problem-solving competence. Accordingly, greater emphasis on strengthening planning and organization within the educational process is recommended.

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Introduction

Higher-order cognitive abilities in adolescence, such as problem-solving, reasoning, and planning, become particularly important and play a decisive role in the academic and social success of adolescents (Lemos et al., 2025; Rubio-Sánchez et al., 2026). Given the high volume of educational content and the complexity of mathematical concepts at the secondary level, studying the factors affecting students' mathematical problem-solving skills is of great significance. Mathematics is one of the most important subjects in secondary education, and problem-solving is recognized as a key skill within it. Research indicates that many students face difficulties in mathematical problem-solving, and this issue negatively impacts not only their learning of mathematics but also their self-confidence and academic motivation (Swanson et al., 2021). One of the main reasons for this difficulty is the lack of systematic training in problem-solving skills and insufficient attention to foundational cognitive abilities (Ji & Guo, 2023).

Problem-solving is a higher-order mental function and a component of life skills and self-regulation. In this process, the individual must establish relationships between past experiences and the problem, discover connections, and adopt an appropriate solution. A crucial point in the problem-solving process is the simultaneous role of memory, emotion, and imagination. These three elements are not formed independently and purely in the mind; rather, at least two or all of them are present together and interact with each other. In problem-solving, senses are activated for precise observation, memory recalls past experiences to identify the current situation, and imagination allows the individual to construct innovative solutions and new hypotheses. These mental processes operate simultaneously and interactively, continuing the stream of thought until a solution is reached. Thus, all mental faculties act actively and in a coordinated manner at every stage of problem-solving (Pegah et al., 2026).

In the past, it was believed that problem-solving was an innate ability and could not be taught. However, subsequent research demonstrated that problem-solving skills are teachable (Tokuhama-Espinosa et al., 2023; Ghazizadeh Fard et al., 2023). Mathematical problem-solving is a cognitive skill that involves understanding mathematical vocabulary and concepts, translating verbal problems into mathematical symbols, and flexibly applying learned strategies in new situations. This process necessitates the transfer of knowledge from prior experiences to solve unfamiliar problems (Amalina & Vidákovich, 2023).

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One of the primary cognitive frameworks related to problem-solving is executive functions. Executive functions are a set of higher-order skills responsible for controlling, directing, and coordinating cognitive processes. They include working memory, planning, organization, response inhibition, and cognitive flexibility (Demeyer et al., 2026; Sosic-Vasic et al., 2017). Research has shown that weaknesses in executive functions are associated with academic underachievement, difficulty in problem-solving, and reduced social adjustment (Jahani & Vatankhah, 2026 ; Koltiz, 2021; Ma et al., 2026).

Studies have indicated that individuals with weak executive functions, despite considerable effort, cannot perform activities like summarizing, planning, and completing projects within specific timeframes (Chen & Bailey, 2021; Kord, 2025). Executive functions help us maintain information relevant to a particular problem in our working memory, disregard irrelevant information, and inhibit responses that hinder goal achievement. Furthermore, these abilities correlate with academic success, social adaptation, and career success (Pelegrina, et al., 2024; Ma et al., 2026). Executive functions encompass a broad range of cognitive abilities. Consequently, problem-solving processes and their training are central to fostering success and achieving goals at various stages and academic dimensions of students' educational journey (Teng et al., 2025).

The first critical component of executive functions is working memory, which plays a role in the simultaneous retention and processing of information. This ability allows students to hold data related to the problem in mind and establish connections between them. Domestic and international research indicates that working memory deficits are linked to significant difficulties in mathematical problem-solving and other academic activities (Gilmore, 2023). Planning, the next component, refers to the ability to design steps for solving a problem and select effective strategies. Students who have difficulty with planning often cannot identify the solution path or employ the best methods. Researches Partanen et al. (2020) and Gilmore (2023) have shown that planning serves as a crucial mediating role between working memory and problem-solving skills. Organization, as another fundamental dimension of executive functions, relates to the capacity to sort information, prioritize activities, and manage mental resources. Weakness in organization prevents students from processing data in a logical sequence, resulting in lower performance in solving mathematical problems (Ji & Guo, 2023; Domic-Siede et al., 2026).

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Numerous domestic studies have also confirmed the importance of these components. For example, Pegah et al., (2026) found that working memory-based cognitive rehabilitation improved planning and organization in children with specific reading learning disorders. Mousavi et al. (2022) reported the effect of aerobic exercise on working memory and planning in children with dyslexia. Furthermore, Lemos et al., (2025) confirmed the impact of working memory training on improving planning and organization skills in students with specific learning disabilities. At an international level, research by Abreu-Mendoza et al. (2018) demonstrated that diverse executive functions are linked to mathematical learning difficulties and mathematical talent. Medrano & Miller-Cotto (2025) also emphasized that working memory directly and indirectly affects mathematical achievement.

Executive functions play a fundamental role in students' adaptation to school, its rules, and demands, including successful interaction with peers and teachers, and cognitive activities such as learning mathematics (Blair & Raver, 2015). Problem-solving is a coping and practical skill that boosts self-confidence and self-efficacy, correlates with environmental adaptation. During the problem-solving process, individuals can discover, create, or identify effective ways to cope with challenging life events (Babaei, 2023).

A review of theoretical and empirical literature reveals that prior domestic and international studies have predominantly focused either on the efficacy of cognitive rehabilitation interventions on executive functions in clinical populations (such as students with learning disabilities and dyslexia) or on examining simple, isolated relationships between cognitive components and academic achievement. Consequently, the simultaneous and distinct contributions of core executive functions: working memory, planning, and organization; within an integrated predictive model for mathematical problem-solving skills among mainstream middle school students have remained largely unaddressed. Furthermore, despite theoretical insights linking mathematical problem-solving to metacognitive and self-regulatory processes, the central and dominant predictive role of “planning” compared to other cognitive functions had not been empirically investigated within the educational context of Iranian schools. Therefore, the primary research gap addressed by this study is the lack of comprehensive research among mainstream middle school students to determine which dimension of executive functions possesses the highest explanatory power for the variance in mathematical problem-solving, and whether planning occupies a central role in this prediction?

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Accordingly, the present study aims to answer the following research question: Can the mathematical problem-solving skills of middle school students be predicted based on their executive functions, namely working memory, planning, and organization?

Materials and Methods

Participants and Procedure

This study is applied in terms of its objective and descriptive in terms of its data collection method. As it investigates the relationships between variables, it is categorized as a correlational study. Thus, the research can be described as a descriptive-correlational study. The statistical population consisted of total female middle school students in District 7 of Tehran's Department of Education during the 2024-2025 academic year. Sampling was conducted using a multi-stage cluster method: initially, several schools were randomly selected from among the schools in District 7. Then, three classes were randomly selected from each school, and finally, the students in these classes were chosen as the research sample. Stepwise regression analysis was used to analyze the data. This method allows for simultaneous examination of multiple relationships between independent and dependent variables. The collected data were processed using SPSS-22 software.

Participants and Sampling Procedure

The statistical population of this study comprised all female middle school students enrolled in District 7 of Tehran’s Department of Education during the 2024–2025 academic year. A total sample of 150 female students was recruited using a multi-stage cluster random sampling method. In the first stage, several middle schools were randomly selected from District 7. Subsequently, three classes were randomly chosen from each school, and all eligible students within these classes constituted the final research sample.

To ensure the validity and homogeneity of the sample, specific eligibility criteria were established. Inclusion criteria were: (a) being officially enrolled in female public middle schools within District 7 during the 2024–2025 academic year; (b) exhibiting normal cognitive development with no documented history of neurodevelopmental disorders, sensory-motor impairments, or psychiatric conditions (based on school health records and teacher reports); © having active educational attendance without prolonged absence during the current term; and (d) willingness to participate, verified by written informed consent from both the students and their legal guardians. Exclusion

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criteria encompassed: (a) students who had received any specialized cognitive rehabilitation, tutoring in executive function skills, or psychiatric/psychological medication within the past six months; (b) experiencing severe and acute stressful life events (such as recent bereavement or parental divorce) over the preceding three months; © transfer or withdrawal from school during the data collection phase; and (d) incomplete or careless responses to the assessment instruments (e.g., leaving more than 10% of questionnaire items blank or patterned responding).

Instruments

Behavior Rating Inventory of Executive Function (BRIEF): Teacher Form This Questionnaire was developed by Baron (2000). It is designed to evaluate executive functions in children and adolescents aged 5 to 18 in school and home settings. The questionnaire has two rating forms (for parents and teachers) and consists of 86 questions and measures 8 components including inhibition, attention shifting, emotional control, initiation, working memory, planning, organization, and control. In the present study, only working memory, planning, and organization were studied. Each item is scored based on the student's behavior using options "Never," "Sometimes," and "Often," assigned scores of 1 to 3, respectively. The teacher form typically takes 10 to 15 minutes to complete. the highest test-retest reliability coefficients are 0.88 for teachers and 0.82 for parents, and the internal consistency coefficient (Cronbach's alpha) is 0.88 for the teacher form. The correlation between the teacher and parent forms ranges from 0.64 to 0.68. Evidence for convergent validity has been obtained through correlations with other measures of behavioral and emotional functioning (Baron, 2000; Gioia et al., 2000). In the current study, the internal consistency of the instrument was confirmed using Cronbach’s alpha: Working Memory (α=.84), Planning (α=.87), Organization (α=.81), and overall composite score (α=.89), indicating high measurement reliability in the studied sample.

Mathematical Problem-Solving Skills Questionnaire: Mathematical problem-solving skills were assessed using the standardized questionnaire developed by Hasani (2018). This measure comprises 38 items structured across four cognitive dimensions: Understanding the Problem, Analysis, Integration/Synthesis, and Trial-and-Error. Responses are scored on a 6-point Likert scale. Hasani (2018) reported strong content validity (CVI = .86) evaluated by expert consensus, as well as satisfactory internal consistency with an overall Cronbach’s alpha of .92 (subscales ranging from .77 to .91). In the present study, the internal reliability calculated via Cronbach’s

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alpha yielded coefficients of .89 for Understanding, .88 for Analysis, .85 for Synthesis, .78 for Trial-and-Error, and an overall scale alpha of .91, confirming robust reliability for this cohort.

In this study, Informed consent was obtained from all participants. Anonymity and confidentiality were ensured throughout the data collection and analysis process. Participants were informed of their right to withdraw at any time without penalty.

Results

Initially, it shows descriptive findings including mean, standard deviation, minimum and maximum scores, skewness, standard error of skewness, kurtosis, and standard error of kurtosis for the research variables (mathematical problem-solving skills, working memory, planning and organization) for the participants.

Table 1. Descriptive Statistics for Research Variables

Variable	Mean	S.D	Minimum Score	Maximum Score	Skewness	Std. Error of Skewness	Kurtosis	Std. Error of Kurtosis
Problem-Solving Skills	125.46	46.74	46	215	0.175	0.198	-1.146	0.394
Working Memory	11.30	4.64	4	19	0.62	0.198	-1.225	0.394
Planning	14.30	5.49	6	23	0.116	0.198	-1.040	0.394
Organization	5.82	2.52	2	11	0.276	0.198	-0.828	0.394

As shown in Table 1, the means and standard deviations for the variables are: mathematical problem-solving skills (*M*=125.46, *SD*=46.74), working memory (*M*=11.30, *SD*=4.64), planning (*M*=14.30, *SD*=5.49), and organization (*M*=5.82, *SD*=2.52).

Prior to hypothesis testing, the assumptions of multiple regression analysis were verified. The normality of the score distributions was also assessed using skewness and kurtosis coefficients. Values with an absolute skewness or kurtosis greater than 2 indicate a violation of normality. The results showed that the data were within an acceptable range. Furthermore, multi collinearity among predictor variables was assessed using the Tolerance statistic and the Variance Inflation Factor (VIF).

Table 2. Multi Collinearity Indices and Durbin-Watson Test for Error Independence

Variable	Multi collinearity Indices		model Durbin-Watson Test		
	Tolerance		Adjusted R2	E.S.E	Durbin-Watson
Working Memory	0.728	1.374			
Planning	0.751	1.331			
Organization	0.735	1.370	.311	38.832	1.924

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Table 2 shows that the tolerance and VIF values for the predictor variables are acceptable: working memory (tolerance = .73, VIF = 1.37), planning (tolerance = .75, VIF = 1.33), and organization (tolerance = .74, VIF = 1.37). Because tolerance values are above .10 and VIF values are below 10, no substantial multicollinearity is present. The Durbin-Watson test was used to examine the independence of errors. This test checks whether the residuals of the regression model are correlated with one another. The Durbin-Watson value for the model was 1.92, which falls within the acceptable range of 1.5 to 2.5, supporting the assumption of independent errors.

Table 3. Correlation Matrix for Research Variables

Variables	1	2	3	4
1.Mathematical Problem-Solving Skills	1	.428**	.488**	.354**
2.Working Memory		1	.427**	.453**
3.Planning			1	.423**
4.Organization				1

**p ≤ .01

Table 3 shows the matrix of correlation coefficients of the predictor and criterion variables. The correlation between working memory and mathematical problem-solving skills was r =.428, p <.01, planning and mathematical problem-solving skills was r =.488, p <.01, and organization and mathematical problem-solving skills were r =.354, p <.01, all of which were significant. Therefore, there is a significant correlation between the components of executive functions and problem-solving skills.

Table 4. Stepwise Regression Analysis of Predictor Variables With Mathematical Problem-Solving Skills

Step	Predictor Variables	MR	R2	B	β	*t*	p.value	Intercept (a)
1	Planning	0.488	.238	4.153	.488	6.802	.001	66.075
2	Planning	0.546	.298	3.173	.373	4.094	.001	50.859
	Organization			3.017	.271	3.958	.001	
3	Planning	0.569	.324	2.721	.280	2.842	.001	42.836
	Organization			2.674	.210	2.631	.001	
	Working Memory			1.873	.186	2.335	.001	

Table 4 Shows That the Stepwise Regression Analysis Was Performed in Three Stages. First, Planning (B =.488); Which Had Only 23.8% Explanatory Power. In the Second Stage, Planning with Organization (B =.271) Which Had 29.8% Explanatory Power and Finally Planning, Organization and Working Memory (B =.186) Jointly Had 32.4% Explanatory Power of

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Mathematical Problem-Solving Skills. Which Was Significant at the p=.01 Level. This Indicates That These Three Variables Have Significant and High Predictive Power for the Criterion Variable

Discussion

The analysis of the research results indicated that three main components of executive functions—working memory, planning, and organization—play a decisive role in predicting the mathematical problem-solving skills of middle school students. Working memory showed a positive and significant relationship with problem-solving skills. Students with a greater capacity for retaining and processing information were able to perform the steps of problem-solving with more coherence, accuracy, and cognitive control. This finding aligns with previous studies, such as Demeyer et al., 2026 which identified working memory as a key component in academic success, particularly in solving mathematical problems. Theoretically, working memory enables the retention of problem information, simultaneous processing of data, and execution of solution steps. Therefore, weaknesses in working memory can lead to confusion, forgetting steps, and reduced accuracy.

Planning skills also showed a significant relationship with mathematical problem-solving skills. Students who are more capable of setting goals, selecting strategies, and organizing activities follow a step-by-step, structured approach to solving problems, avoiding errors caused by mental disorganization. This finding is consistent with research by Kusaka & Ndihokubwayo (2022); Partanen et al. (2020); Mousavi et al. (2022), and Gilmore (2023) which demonstrated that planning skills play a central role in student performance, especially when facing complex mathematical problems. Analytically, it can be argued that planning not only improves the ability to manage solution steps but also enhances the student's cognitive capacity for anticipating outcomes and selecting appropriate strategies, thereby strengthening the executive aspects of the problem-solving process.

The third component, organization, also demonstrated a positive and significant relationship with problem-solving skills. Students with good organizational skills are able to categorize, prioritize, and structure the information of a problem, leading to more accurate analysis and more effective decision-making in the solution process. These findings align with research by Medrano & Miller-

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Cotto, (2025) and Demeyer et al., (2026) emphasizing that mental organization plays an essential role in reducing confusion and increasing accuracy in solving analytical problems.

Several methodological and contextual limitations of the present study warrant careful consideration regarding their impact on the findings. First, restricting the sample exclusively to female students from District 7 of Tehran inherently constrains the external validity and generalizability of the findings across diverse socioeconomic strata, rural contexts, and male cohorts. Second, the reliance on self-report instruments introduces susceptibility to measurement errors, recall bias, and social desirability, which may artificially inflate or attenuate the observed correlation coefficients. Third, the correlational and cross-sectional nature of the research design fundamentally precludes drawing definitive causal inferences; hence, although planning demonstrated the strongest predictive weight, a causal trajectory between executive functions and mathematical problem-solving cannot be conclusively established. Finally, the lack of experimental control over situational and environmental confounders—such as state-trait stress, math anxiety, classroom climate, and immediate testing conditions—suggests that portions of the explained variance in problem-solving performance might stem from unmeasured environmental factors rather than pure cognitive mechanisms. Consequently, these findings should be interpreted with caution as correlational indicators rather than causal mandates across varying educational settings.

Based on the findings and paramount role of planning and cognitive organization identified in this study, educational policymakers and curriculum developers should transition mathematics education from routine procedural drill to cognitive-strategy training. Key actionable measures include: (a) integrating formal metacognitive and planning protocols into mathematics textbooks; (b) establishing specialized in-service training programs equipping teachers with explicit modeling techniques to demonstrate problem-solving; © incorporating cognitive-enrichment activities and executive-function-training tools within school environments to scaffold working memory; and (d) revising academic evaluation policies to prioritize structured process-based reasoning and planning protocols over mere numerical answers.

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Conclusion

The findings of the present study indicate that among the three components of executive functions, planning is the strongest predictor of mathematical problem-solving ability. This relative superiority of planning can be explained from the perspective of cognitive models of problem-solving, insofar as mathematical problem-solving—particularly in non-routine and complex tasks—is not limited to information retrieval (working memory) or data categorization (organization), but rather requires the design of a mental map of the solution pathway, prioritization of steps, anticipation of obstacles, and flexibility in strategy shifting. Previous research has also shown that planning plays a mediating role between working memory and final performance in problem-solving (Medrano & Miller-Cotto, 2025; Partanen et al., 2020), and in activities that require sequencing and monitoring, such as mathematics, it exhibits greater predictive power than other executive components (Kusaka & Ndihokubwayo, 2022). On the other hand, organization and working memory act as complements to planning; organization facilitates the segregation of relevant from irrelevant information, while working memory provides the capacity for simultaneous data retention. Together, these three components form a three-level control system in which planning serves as the primary "helmsman" guiding the solution path, and the other two components function as operational supports enhancing its efficiency. This finding is consistent with Demeyer et al., (2026) model of "executive control," which emphasizes the distinction yet dynamic interplay of these components in complex cognitive tasks.

Moreover, beyond cognitive explanation, the findings of this research can be interpreted within the framework of self-regulated learning and metacognitive skills. Self-regulation comprises three main phases—forethought, performance, and self-reflection of which the forethought phase is directly associated with planning and organization. Indeed, planning, which emerged as the strongest predictor in this study, is not merely an executive function but also a metacognitive process, as it entails awareness of one's own abilities, understanding the nature of the problem, setting subgoals, and selecting appropriate strategies. Students who are stronger in planning typically make greater use of metacognitive strategies such as self-questioning ("Is this step correct?"), self-monitoring ("How close am I to the goal?"), and self-evaluation ("Is the solution acceptable?") (Ma et al., 2026). This finding also aligns with the research of Blair & Raver (2015), who introduce self-regulation as a bridge between executive functions and academic success.

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Furthermore, domestic studies such as Kord (2025) have demonstrated that problem-solving training, in addition to improving executive functions, has a positive effect on reducing cognitive fatigue and enhancing self-regulation in students with mathematical learning difficulties. Therefore, planning constitutes the common core of both executive function and metacognition, and its strengthening can indirectly promote other components of self-regulation, including motivation, effort, and persistence. Hence, it is suggested that educational interventions, beyond working-memory-based exercises, specifically emphasize training in planning and self-monitoring strategies, so that students, when facing novel problems, adopt a flexible and goal-oriented approach rather than relying on rote application of memorized patterns.

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Data availability statement

The datasets generated and/or analysed during the current study are available from the corresponding author upon reasonable request.

Ethics statement

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki and approved by the University of Sistan and Baluchestan ethics committee. All participants provided informed consent prior to participating in the study, and data collection procedures ensured complete anonymity and confidentiality.

Author contributions

All authors contributed to the study conception and design, material preparation, data collection and analysis. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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