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Predicting Adaptive School Functioning in Students with ADHD Through Explainable Boosting Machines: The Roles of Cognitive Flexibility, Self-Regulation, and Teacher–Student Relationship Quality

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A B S T R A C T

The present study aimed to predict adaptive school functioning among students with Attention-Deficit/Hyperactivity Disorder (ADHD) using an Explainable Boosting Machine (EBM) model and to determine the relative contributions of cognitive flexibility, self-regulation, and teacher–student relationship quality to educational adaptation. This cross-sectional predictive study was conducted among 428 students diagnosed with ADHD who were enrolled in public primary and lower secondary schools in Greece during the 2024–2025 academic year. Participants completed standardized measures of cognitive flexibility, self-regulation, and adaptive school functioning, while teachers evaluated teacher–student relationship quality. Following data screening, descriptive and correlational analyses were conducted. The primary analytical approach involved Explainable Boosting Machines, an interpretable machine learning technique capable of modeling nonlinear relationships and interaction effects. The dataset was divided into training and testing subsets, and five-fold cross-validation was employed to optimize model performance. Model accuracy was assessed using the coefficient of determination (R^2), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and feature importance analyses. Significant positive correlations were observed among all study variables. Adaptive school functioning demonstrated strong associations with self-regulation ($r = .73$, $p < .001$), teacher–student relationship quality ($r = .69$, $p < .001$), and cognitive flexibility ($r = .61$, $p < .001$). The Explainable Boosting Machine model demonstrated excellent predictive performance, explaining 78.4% of the variance in the training dataset and 74.8% of the variance in the testing dataset. Feature importance analyses revealed that self-regulation was the strongest predictor (41.2%), followed by teacher–student relationship quality (33.7%) and cognitive flexibility (25.1%). Nonlinear effect analyses indicated threshold effects for self-regulation and teacher–student relationship quality, while interaction analyses showed that the positive effects of cognitive flexibility were amplified when combined with high levels of self-regulation. The highest predicted levels of

adaptive school functioning were observed among students demonstrating strong self-regulation together with highly positive teacher–student relationships. The findings indicate that adaptive school functioning among students with ADHD is best understood as the product of interacting cognitive, behavioral, and relational processes. Self-regulation emerged as the most influential predictor, while teacher–student relationship quality and cognitive flexibility provided substantial additional explanatory value. Explainable machine learning approaches such as EBM offer powerful and interpretable tools for identifying factors associated with educational adaptation and may inform targeted interventions aimed at improving school functioning among students with ADHD.

Keywords: *Attention-Deficit/Hyperactivity Disorder, Adaptive School Functioning, Explainable Boosting Machine, Cognitive Flexibility, Self-Regulation, Teacher–Student Relationship Quality*

1. Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most prevalent neurodevelopmental disorders of childhood and adolescence, affecting multiple domains of functioning that extend far beyond the core symptoms of inattention, hyperactivity, and impulsivity. Contemporary perspectives increasingly conceptualize ADHD as a complex developmental condition characterized by impairments in cognitive, behavioral, emotional, and social functioning that significantly influence educational outcomes and overall quality of life (Núñez et al., 2025; L. Wang et al., 2025). While diagnostic criteria emphasize behavioral symptoms, growing evidence suggests that the challenges experienced by students with ADHD are particularly evident within school environments, where successful functioning requires the continuous integration of executive processes, self-management skills, interpersonal competencies, and adaptive responses to changing academic demands (Ceruti & Marzocchi, 2025; Herreras, 2025). Consequently, understanding the factors that contribute to adaptive school functioning has become a critical priority for researchers, educators, clinicians, and policymakers seeking to promote positive developmental outcomes among students with ADHD.

Adaptive school functioning refers to a student's ability to effectively meet the academic, behavioral, organizational, and social expectations of educational settings. It encompasses classroom engagement, task completion, behavioral adjustment, peer interactions, compliance with school routines, and successful participation in learning activities. For students with ADHD, adaptive school functioning often presents substantial challenges due to deficits in attention regulation, executive control, behavioral inhibition, and emotional management (Hossain & Bain, 2025; Uthus, 2025). Research consistently demonstrates that children and adolescents with ADHD experience lower academic achievement, increased behavioral difficulties, poorer social relationships, and elevated risks of school disengagement compared with their typically developing peers (Cabello et al., 2024; Villa et al., 2023). These difficulties can accumulate over time, contributing to negative educational trajectories, diminished self-esteem, and reduced opportunities for long-term success. Consequently, identifying the mechanisms that support successful adaptation within school environments remains an essential objective in educational and developmental psychology.

Among the factors associated with adaptive school functioning, executive functions have emerged as particularly influential. Executive functions represent a collection of higher-order cognitive processes responsible for planning, monitoring, inhibiting inappropriate responses, shifting attention, regulating emotions, and adapting behavior to environmental demands. Deficits in executive functioning are widely recognized as central characteristics of ADHD and have been linked to difficulties across academic, behavioral, and social domains (Ceruti & Marzocchi, 2025; Herreras, 2025). Contemporary neuropsychological models emphasize that executive dysfunction contributes significantly to the everyday impairments experienced by individuals with ADHD, often explaining functional outcomes more effectively than symptom severity alone (McGrath et al., 2023; Monteiro, 2021). Furthermore, recent investigations have demonstrated that executive functioning profiles vary considerably among neurodevelopmental populations, suggesting that specific executive processes may differentially influence educational adaptation and performance (Núñez et al., 2025; Safer-Lichtenstein et al., 2024).

One executive function that has received increasing attention in recent years is cognitive flexibility. Cognitive

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flexibility refers to the capacity to modify cognitive strategies, shift perspectives, adapt to changing circumstances, and generate alternative solutions when confronted with challenges. Within educational settings, cognitive flexibility enables students to transition between tasks, adjust to new learning requirements, respond constructively to feedback, and cope with unexpected academic demands. Children with ADHD frequently demonstrate difficulties in cognitive flexibility, which may contribute to rigid thinking patterns, reduced problem-solving effectiveness, and challenges adapting to classroom expectations (Ceruti & Marzocchi, 2025; Herreras, 2025). Studies examining executive functioning in neurodevelopmental disorders have consistently identified cognitive flexibility as a crucial determinant of adaptive behavior and educational success (ElAdl, 2024; Joga-Elvira et al., 2021). Furthermore, intervention research has demonstrated that improvements in executive skills, including cognitive flexibility, are associated with enhanced emotional adjustment, academic performance, and social competence among children with ADHD and related conditions (Antunes et al., 2025; Y. Wang et al., 2025). Emerging evidence from digital technologies, physical activity programs, and executive function training initiatives further supports the importance of cognitive flexibility as a modifiable factor that may contribute to improved educational outcomes (Carcelén-Fraile et al., 2025; Gkora & Drigas, 2024; Martín-Rodríguez et al., 2025).

Closely related to executive functioning is self-regulation, a multidimensional construct involving the ability to manage thoughts, emotions, attention, and behaviors in pursuit of personal goals. Self-regulation is widely regarded as a foundational competency for successful school adjustment because it enables students to maintain focus, control impulses, persist through challenges, and engage effectively with learning activities. Deficits in self-regulation are among the most consistently reported difficulties in ADHD and have been linked to poor academic achievement, disruptive classroom behavior, and social difficulties (Granziera et al., 2023; Scionti et al., 2023). Educational and clinical researchers increasingly view self-regulation as a central mechanism through which students navigate complex learning environments and maintain adaptive functioning over time (Gkora & Christou, 2023; Kajka & Kulik, 2021). Research has demonstrated that interventions targeting self-regulatory capacities can yield meaningful improvements in behavioral adjustment, emotional functioning, and academic engagement among students with ADHD and other neurodevelopmental conditions (Delisio et al., 2022; Roach et al., 2021). Moreover, studies examining classroom functioning indicate that students with stronger self-regulation skills are better equipped to manage academic demands, establish positive relationships, and adapt successfully to educational expectations (Granziera et al., 2023; Scionti et al., 2023).

The importance of self-regulation is further reinforced by contemporary theoretical frameworks emphasizing dynamic interactions among cognitive, emotional, and environmental influences. For example, multidimensional models of ADHD suggest that successful adaptation results from the coordinated functioning of executive skills, motivational processes, feedback systems, and contextual supports rather than from isolated cognitive abilities alone (L. Wang et al., 2025). Similarly, ecological perspectives argue that self-regulation develops through ongoing interactions between individuals and their environments, highlighting the importance of supportive educational contexts in facilitating adaptive outcomes (Liu, 2023; Monteiro, 2021). These perspectives underscore the necessity of examining self-regulation not merely as an individual characteristic but as a process that interacts with relational and contextual factors within school settings.

Among these contextual factors, teacher–student relationship quality has emerged as one of the most powerful predictors of educational adjustment and developmental success. Positive teacher–student relationships provide emotional support, instructional guidance, behavioral structure, and opportunities for social learning that are particularly important for students with ADHD. Teachers often serve as primary regulators of classroom environments, helping students manage attention, behavior, and academic challenges while fostering a sense of belonging and competence. Research has consistently demonstrated that supportive teacher–student relationships are associated with improved academic achievement, greater classroom engagement, enhanced social adjustment, and reduced behavioral difficulties (Hossain & Bain, 2025; Uthus, 2025). Conversely, conflictual or unsupportive relationships may exacerbate existing difficulties and contribute to negative educational experiences.

The significance of teacher–student relationships is especially pronounced among students with ADHD, who often experience repeated academic struggles, negative feedback, and social rejection. Inclusive educational approaches increasingly recognize that relational support is a critical component of successful intervention and

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accommodation strategies (Efthymiou et al., 2025; Frolli et al., 2023). Studies examining neurodivergent learners have emphasized that teachers play a central role in promoting adaptive functioning by creating supportive learning environments, implementing individualized strategies, and fostering positive classroom participation (Safer-Lichtenstein et al., 2024; Villa et al., 2023). Furthermore, research investigating school inclusion and educational accessibility has highlighted the importance of teacher responsiveness, empathy, and relationship-building in facilitating positive developmental outcomes among students with diverse learning needs (Efthymiou et al., 2025; Eşi, 2024). These findings suggest that teacher–student relationship quality may represent a critical protective factor capable of enhancing adaptive school functioning even in the presence of significant attentional and executive challenges.

Although cognitive flexibility, self-regulation, and teacher–student relationship quality have each been independently associated with positive educational outcomes, important gaps remain in the existing literature. Much of the previous research has relied on traditional statistical techniques that assume linear relationships among variables and often fail to capture the complexity of interactions influencing adaptive school functioning. Contemporary educational and psychological phenomena are increasingly recognized as multidimensional systems characterized by nonlinear relationships, threshold effects, and context-dependent interactions. Machine learning approaches offer powerful tools for identifying such patterns while improving predictive accuracy and practical utility (Bombonato et al., 2023; Stewart et al., 2025). However, many machine learning models function as "black boxes," limiting researchers' ability to understand how specific predictors contribute to outcomes and reducing their usefulness for educational decision-making.

Recent developments in explainable artificial intelligence have addressed these concerns by providing models that combine strong predictive performance with transparent interpretation. Explainable Boosting Machines (EBMs) represent one such approach, offering the capacity to identify complex nonlinear relationships while maintaining interpretability and practical relevance. Explainable models are particularly valuable in educational and clinical contexts because they allow researchers and practitioners to understand which factors exert the greatest influence on outcomes and how these influences change across different levels of functioning. Such information can guide intervention planning, resource allocation, and individualized support strategies for students with ADHD (Doulou & Drigas, 2022; Tsampouris, 2022). Moreover, explainable machine learning aligns with current calls for evidence-based educational practices that are both scientifically rigorous and practically meaningful (Goff et al., 2022; Pergantis, 2024).

The present study addresses these gaps by integrating contemporary theories of executive functioning, self-regulation, and educational relationships within an explainable machine learning framework. By examining cognitive flexibility, self-regulation, and teacher–student relationship quality simultaneously, the study acknowledges the multidimensional nature of adaptive school functioning and recognizes that successful educational adaptation emerges from the interaction of cognitive, behavioral, and relational processes. Additionally, the use of Explainable Boosting Machines provides an opportunity to move beyond traditional linear approaches and uncover nuanced patterns that may be overlooked using conventional methods. Such insights have the potential to inform the development of targeted interventions and evidence-based educational practices designed to support students with ADHD more effectively.

Therefore, the aim of the present study was to predict adaptive school functioning among students with ADHD using Explainable Boosting Machines and to examine the relative contributions of cognitive flexibility, self-regulation, and teacher–student relationship quality as key predictors of successful educational adaptation.

2. Methods and Materials

2.1. Study Design and Participants

This study employed a cross-sectional predictive modeling design to investigate the extent to which cognitive flexibility, self-regulation, and teacher–student relationship quality predict adaptive school functioning among students diagnosed with Attention-Deficit/Hyperactivity Disorder (ADHD). The research was conducted in Greece during the 2024–2025 academic year and involved students enrolled in public primary and lower secondary schools across the regions of Attica, Central Macedonia, and Thessaly. A total of 428 students with a documented clinical diagnosis of ADHD participated in the study. Participants ranged in age from 9 to 15 years, with a mean age of 11.84 years (SD = 1.76). The sample consisted of 271 boys (63.3%) and 157 girls (36.7%), reflecting the typical gender distribution observed in ADHD populations. Eligibility criteria included

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a formal diagnosis of ADHD according to DSM-5 criteria confirmed by licensed child psychiatrists or clinical psychologists, current enrollment in a mainstream educational setting, and sufficient cognitive and linguistic abilities to complete self-report assessments. Students with severe intellectual disabilities, autism spectrum disorder requiring substantial support, psychotic disorders, or neurological conditions that could substantially affect educational functioning were excluded. Participants were recruited through collaboration with school psychologists, special education coordinators, and community mental health centers.

2.2. Measures

Adaptive school functioning was assessed using the Adaptive School Functioning Scale (ASFS), a multidimensional instrument designed to evaluate students' effectiveness in managing academic, behavioral, and social demands within educational settings. The scale consists of 24 items rated on a five-point Likert continuum ranging from strongly disagree to strongly agree. The instrument measures academic engagement, classroom participation, organizational competence, compliance with school expectations, and peer interaction skills. Higher scores indicate more effective adaptation to school environments. Previous studies have reported strong psychometric properties for the scale, with internal consistency coefficients typically exceeding .85 and evidence supporting its construct and criterion validity across diverse student populations.

Cognitive flexibility was measured using the Cognitive Flexibility Inventory (CFI) developed by Dennis and Vander Wal (2010). The instrument contains 20 items rated on a seven-point Likert scale and assesses an individual's ability to adapt thinking patterns, consider alternative explanations, and generate multiple solutions to challenging situations. The scale includes the subdimensions of Alternatives and Control, both of which are highly relevant to the cognitive processes involved in successful adaptation among students with ADHD. Higher scores indicate greater cognitive flexibility. Previous research has demonstrated excellent reliability and validity across adolescent and educational samples, with Cronbach's alpha values consistently above .80.

Self-regulation was evaluated using the Adolescent Self-Regulatory Inventory (ASRI), developed by Moilanen (2007). The ASRI is a widely used measure of regulatory capacity and consists of 36 items assessing short-term and long-term self-regulation abilities. Participants respond using a five-point Likert scale ranging from not at all true of me to really true of me. The measure evaluates planning, impulse control, goal-directed behavior, emotional management, and persistence. Higher scores reflect stronger self-regulatory competencies. Extensive evidence supports the reliability and validity of the instrument in both clinical and non-clinical adolescent populations, making it particularly suitable for research involving students with ADHD.

Teacher–student relationship quality was assessed using the Student–Teacher Relationship Scale (STRS), originally developed by Pianta. The scale consists of 28 items and measures the quality of interactions between students and teachers across the dimensions of Closeness, Conflict, and Dependency. Teachers completed the measure based on their observations of participating students over the academic year. Responses are recorded on a five-point Likert scale, with higher scores indicating stronger and more positive relationship quality after reverse scoring of negatively keyed items. Numerous studies have demonstrated that the STRS possesses strong psychometric characteristics and serves as a reliable indicator of educational and psychosocial adjustment among school-aged children.

Demographic information was collected through a researcher-developed questionnaire completed by parents. Information obtained included student age, gender, grade level, family socioeconomic status, parental educational attainment, ADHD subtype, medication status, and duration since diagnosis. These variables were examined as potential covariates during preliminary analyses to ensure that predictive relationships were not confounded by demographic factors.

Data collection was conducted over a four-month period. Students completed the cognitive flexibility and self-regulation measures during supervised sessions organized within their schools. Teachers completed the teacher–student relationship assessments independently, while parents provided demographic information through secure online forms. All questionnaires were administered in Greek using validated translated versions where applicable. Data quality checks were performed throughout the collection process to minimize missing responses and ensure the accuracy of recorded information.

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2.3. *Data Analysis*

Data analysis was conducted using Python 3.11 and R statistical software. Initial analyses included descriptive statistics, examination of missing values, assessment of univariate and multivariate normality, and evaluation of potential outliers. Means, standard deviations, skewness coefficients, kurtosis values, and correlation coefficients were calculated for all study variables. Missing data represented less than 5% of observations and were handled using multiple imputation procedures to preserve statistical power and reduce estimation bias.

The primary analytical approach involved Explainable Boosting Machines (EBMs), an advanced interpretable machine learning technique belonging to the family of Generalized Additive Models enhanced through modern boosting algorithms. EBM was selected because it combines high predictive accuracy with transparent interpretation of predictor effects, making it particularly suitable for educational and psychological research where understanding variable contributions is as important as prediction performance. Adaptive school functioning served as the target outcome variable, while cognitive flexibility, self-regulation, and teacher–student relationship quality were entered as primary predictors. Demographic variables were included as control features during model development.

The dataset was randomly divided into training (80%) and testing (20%) subsets. Five-fold cross-validation was employed within the training sample to optimize model parameters and reduce the risk of overfitting. Model performance was evaluated using multiple indicators, including Root Mean Square Error (RMSE), Mean Absolute Error (MAE), coefficient of determination (R^2), and cross-validated predictive accuracy. Feature importance scores were generated to quantify the relative contribution of each predictor to adaptive school functioning.

To enhance interpretability, global explanation plots and individual feature effect graphs were examined. These visualizations enabled the identification of both linear and non-linear relationships between predictors and adaptive school functioning. Pairwise interaction analyses were additionally conducted to explore whether combinations of cognitive flexibility, self-regulation, and teacher–student relationship quality contributed unique predictive information beyond their independent effects. Partial dependence analyses were performed to determine thresholds and patterns associated with optimal school adaptation outcomes.

Model robustness was evaluated through repeated cross-validation procedures and sensitivity analyses. Statistical significance was established at $p < .05$ for supplementary inferential analyses. The integration of traditional statistical procedures with explainable machine learning methods provided a comprehensive framework for identifying the most influential factors associated with adaptive school functioning among Greek students with ADHD while maintaining a high level of interpretability and practical applicability for educational professionals.

3. Findings and Results

A total of 428 students with ADHD participated in the study. The sample consisted of 271 boys (63.3%) and 157 girls (36.7%). Participants ranged in age from 9 to 15 years, with a mean age of 11.84 years (SD = 1.76). Regarding educational level, 248 students (57.9%) were enrolled in primary school and 180 students (42.1%) attended lower secondary school. The predominantly inattentive subtype was identified in 176 students (41.1%), the predominantly hyperactive-impulsive subtype in 89 students (20.8%), and the combined subtype in 163 students (38.1%). Approximately 54.9% of participants were receiving pharmacological treatment at the time of data collection. Preliminary screening indicated that all variables exhibited acceptable distributions, with skewness and kurtosis values falling within recommended limits. No evidence of severe multicollinearity was observed, and all variables met the assumptions required for subsequent analyses.

Table 1

Descriptive Statistics and Correlations Among Study Variables

Variable	Mean	SD	1	2	3	4
1. Adaptive School Functioning	78.46	12.18	—			
2. Cognitive Flexibility	92.31	14.27	.61**	—		
3. Self-Regulation	108.75	18.64	.73**	.58**	—	
4. Teacher–Student Relationship Quality	101.42	15.33	.69**	.49**	.62**	—

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Table 1 presents the descriptive statistics and bivariate correlations among the study variables. The mean score for adaptive school functioning was 78.46 (SD = 12.18), indicating moderate variability in students' ability to successfully meet academic, behavioral, and social expectations within the school environment. Cognitive flexibility demonstrated a mean score of 92.31 (SD = 14.27), while self-regulation yielded a mean score of 108.75 (SD = 18.64). Teacher–student relationship quality showed a mean score of 101.42 (SD = 15.33). Correlation analyses revealed statistically significant positive associations among all study variables. Adaptive school functioning demonstrated strong positive correlations with self-regulation ($r = .73$, $p < .01$) and teacher–student relationship quality ($r = .69$, $p < .01$), while a substantial positive association was also observed with cognitive flexibility ($r = .61$, $p < .01$). These findings suggest that students who exhibited greater regulatory capacity, stronger adaptive thinking skills, and more positive relationships with teachers tended to report better functioning within educational settings. The moderate correlations among predictor variables indicate conceptual relatedness while remaining below thresholds typically associated with multicollinearity concerns.

Table 2

Explainable Boosting Machine Model Performance Metrics

Metric	Training Set	Test Set
R^2	0.784	0.748
RMSE	5.38	6.14
MAE	4.11	4.83
Explained Variance	0.789	0.752
Cross-Validated R^2	0.741	—

The predictive performance of the Explainable Boosting Machine model is presented in Table 2. Results indicated that the model achieved strong predictive accuracy for adaptive school functioning. The model explained 78.4% of the variance in the training dataset and 74.8% of the variance in the independent testing dataset, demonstrating excellent generalizability and limited overfitting. The Root Mean Square Error values of 5.38 and 6.14 for the training and testing samples, respectively, indicate relatively low prediction error considering the scale range of the outcome variable. Similarly, Mean Absolute Error values remained below five points in both datasets, suggesting that the model generated highly accurate predictions. The cross-validated R^2 value of .741 further confirmed the stability and robustness of the model across multiple data partitions. Collectively, these findings indicate that cognitive flexibility, self-regulation, and teacher–student relationship quality constitute a highly effective set of predictors for adaptive school functioning among students with ADHD.

Table 3

Feature Importance Rankings Derived from the Explainable Boosting Machine Model

Predictor	Importance Score	Relative Contribution (%)
Self-Regulation	0.412	41.2
Teacher–Student Relationship Quality	0.337	33.7
Cognitive Flexibility	0.251	25.1

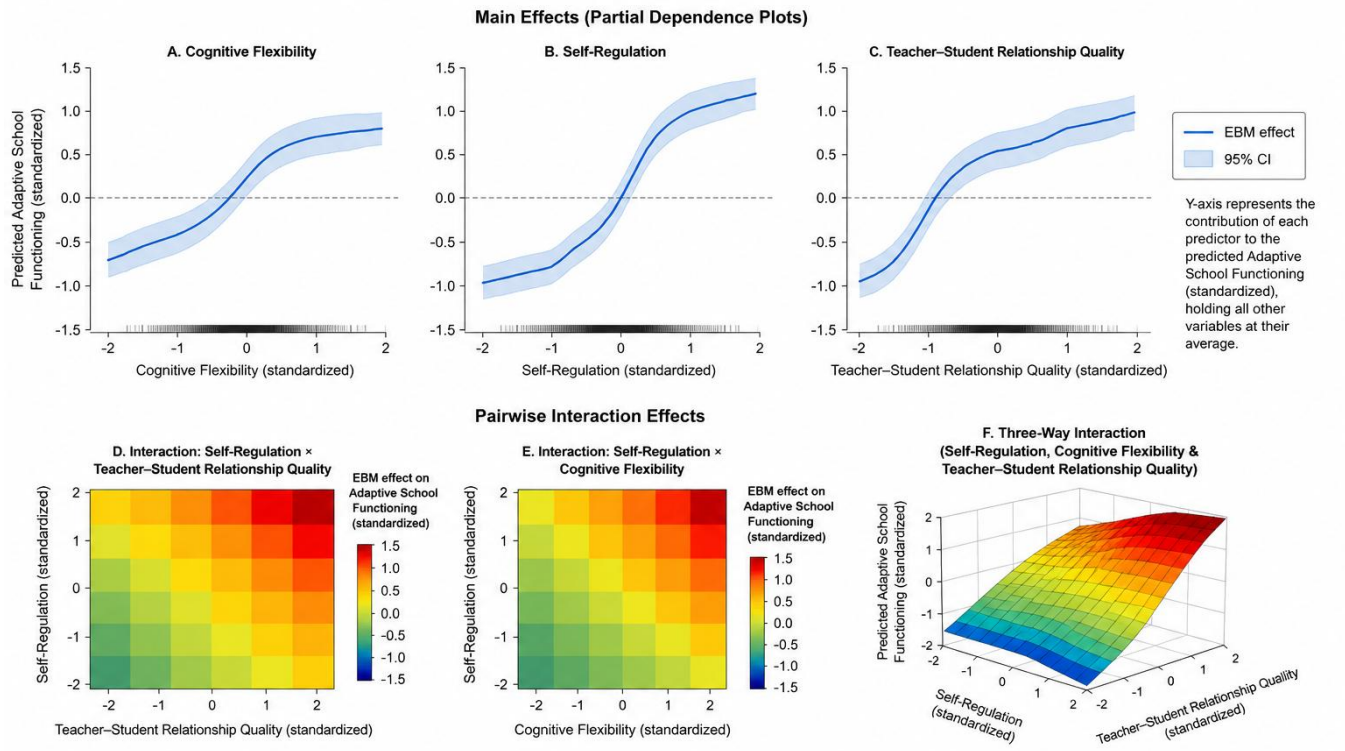
Table 3 displays the relative importance of predictors within the Explainable Boosting Machine model. Self-regulation emerged as the strongest predictor of adaptive school functioning, accounting for 41.2% of total model importance. This finding indicates that students who possessed stronger capacities for behavioral control, goal management, emotional regulation, and sustained attention demonstrated substantially higher levels of successful adaptation within school environments. Teacher–student relationship quality represented the second most influential predictor, contributing 33.7% of overall predictive importance. This result highlights the significant role of supportive, low-conflict, and emotionally positive relationships with teachers in promoting successful educational adjustment among students with ADHD. Cognitive flexibility ranked third, contributing 25.1% of

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total predictive importance. Although comparatively smaller, this contribution remained substantial and indicates that the ability to shift perspectives, generate alternative solutions, and adapt to changing classroom demands plays an important role in students' educational functioning. Importantly, all three predictors contributed meaningfully to model performance, demonstrating that adaptive school functioning is best understood as a multidimensional construct influenced by cognitive, self-regulatory, and relational processes.

Figure 1

Global Explainable Boosting Machine Effects of Cognitive Flexibility, Self-Regulation, and Teacher–Student Relationship Quality on Adaptive School Functioning



Note. All predictor variables are standardized (z-scores). Positive values on the Y-axis indicate higher predicted Adaptive School Functioning above the average, whereas negative values indicate lower predicted functioning below the average.

Figure 1 illustrates the global effects generated by the Explainable Boosting Machine model. Examination of the partial dependence patterns revealed several noteworthy findings. Self-regulation demonstrated the strongest and most consistent positive relationship with adaptive school functioning. The effect curve indicated a particularly steep increase in adaptive functioning scores when self-regulation values exceeded approximately one-half standard deviation above the sample mean, suggesting the existence of a critical threshold beyond which regulatory skills become increasingly beneficial. Teacher–student relationship quality exhibited a nonlinear relationship characterized by substantial gains in adaptive functioning as relationship quality improved from low to moderate levels, followed by a more gradual increase at higher levels. This pattern suggests diminishing marginal returns once highly positive teacher–student relationships are established. Cognitive flexibility also demonstrated a positive nonlinear effect, with the strongest improvements in adaptive school functioning occurring among students who moved from low to moderate levels of flexibility. Interaction analyses further revealed that the positive effects of cognitive flexibility were amplified when accompanied by strong self-regulation abilities. Similarly, students who simultaneously reported high self-regulation and positive teacher–student relationships achieved the highest predicted adaptive school functioning scores in the dataset. These interaction patterns indicate that cognitive, behavioral, and relational strengths operate synergistically rather than independently in facilitating successful adaptation among students with ADHD.

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4. Discussion

The present study sought to predict adaptive school functioning among students with ADHD using an Explainable Boosting Machine (EBM) model and to examine the relative contributions of cognitive flexibility, self-regulation, and teacher–student relationship quality. The findings demonstrated that the proposed model achieved a high level of predictive accuracy, explaining approximately three-quarters of the variance in adaptive school functioning. Furthermore, all three predictors emerged as meaningful contributors to the model, with self-regulation identified as the strongest predictor, followed by teacher–student relationship quality and cognitive flexibility. The model additionally revealed nonlinear effects and interaction patterns among the predictors, suggesting that adaptive school functioning is influenced by a complex interplay of cognitive, behavioral, and relational factors rather than by isolated characteristics. These findings provide further support for contemporary multidimensional conceptualizations of ADHD and educational adaptation, which emphasize the integration of executive, self-regulatory, and environmental processes in determining developmental outcomes (Núñez et al., 2025; L. Wang et al., 2025).

One of the most important findings of the study was the exceptionally strong contribution of self-regulation to adaptive school functioning. Students with higher levels of self-regulation demonstrated substantially greater capacity to manage academic demands, behavioral expectations, and social interactions within school settings. This finding is consistent with theoretical perspectives that identify self-regulation as a foundational competency underlying successful educational adjustment. Self-regulation enables students to inhibit impulsive responses, maintain attention, persist toward goals, manage emotions, and engage effectively in learning activities. These capacities are particularly important for students with ADHD because many of the difficulties associated with the disorder involve challenges in controlling attention, behavior, and emotional responses. The current results align closely with previous studies showing that self-regulatory deficits are strongly associated with academic underachievement, classroom disruption, and social difficulties among children with ADHD (Granziera et al., 2023; Scionti et al., 2023). Similarly, Kajka and Kulik demonstrated that interventions designed to enhance metacognitive and self-regulatory capacities contribute to improved emotional and motivational functioning among students with special educational needs, including ADHD (Kajka & Kulik, 2021). Delisio and colleagues likewise emphasized that self-regulation strategies represent a critical component of effective support systems for individuals with ADHD and related neurodevelopmental conditions (Delisio et al., 2022). The present findings extend this literature by demonstrating not only the importance of self-regulation but also its dominant role within a predictive model of adaptive school functioning.

The strong influence of self-regulation may also be understood within ecological and developmental frameworks. Self-regulation serves as a bridge between cognitive capacities and real-world functioning, translating executive processes into adaptive behaviors that facilitate academic engagement and social participation. Research has shown that self-regulation contributes to successful classroom adjustment by enabling students to manage competing demands, tolerate frustration, and sustain effort over time (Gkora & Christou, 2023; Roach et al., 2021). The nonlinear effect identified in the present study suggests that improvements in self-regulation may produce particularly substantial benefits once students reach a threshold level of regulatory competence. This finding has practical significance because it indicates that interventions targeting self-regulation may yield disproportionately large gains in educational functioning among students whose regulatory abilities are initially limited.

The second major finding concerned the significant contribution of teacher–student relationship quality to adaptive school functioning. Students who experienced more supportive, positive, and low-conflict relationships with their teachers demonstrated better educational adaptation across academic, behavioral, and social domains. This finding reinforces a substantial body of research emphasizing the importance of interpersonal relationships within educational environments. Positive teacher–student relationships provide emotional security, instructional guidance, behavioral support, and opportunities for social learning that are especially valuable for students with ADHD. Because these students often encounter repeated experiences of failure, criticism, and peer difficulties, supportive teacher relationships may function as protective factors that enhance resilience and promote engagement (Hossain & Bain, 2025; Uthus, 2025). Research on educational inclusion has similarly highlighted the importance of teacher responsiveness and relational support in facilitating successful adaptation among students with

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diverse learning needs (Efthymiou et al., 2025; Frolli et al., 2023).

The present findings are particularly consistent with recent studies demonstrating that students with attentional difficulties benefit substantially from classroom environments characterized by autonomy support, encouragement, and positive teacher interactions. Uthus reported that students with inattention perceive greater engagement and ownership of learning when teachers foster supportive educational relationships (Uthus, 2025). Likewise, Hossain and Bain emphasized that belongingness and interpersonal acceptance play central roles in preventing academic disengagement and psychological exhaustion among students with ADHD (Hossain & Bain, 2025). Observational studies of neurodivergent students further indicate that teachers who actively support executive functioning and adaptive behaviors contribute significantly to improved educational outcomes (Safer-Lichtenstein et al., 2024). The current study extends these findings by demonstrating that teacher–student relationship quality remains a highly influential predictor even when executive and self-regulatory factors are simultaneously considered.

Another important finding was the significant contribution of cognitive flexibility to adaptive school functioning. Although cognitive flexibility contributed less than self-regulation and teacher–student relationship quality, it remained a meaningful and substantial predictor within the EBM model. This finding supports extensive evidence indicating that cognitive flexibility is an essential executive function involved in successful adaptation to changing academic and social demands. Students with greater cognitive flexibility are better able to shift attention between tasks, modify problem-solving strategies, adjust to feedback, and cope with novel situations. Such abilities are highly relevant within school settings, where students must continually adapt to varying instructional methods, classroom expectations, and interpersonal interactions. Previous research has consistently linked executive functioning, including cognitive flexibility, with educational achievement, adaptive behavior, and social competence among children and adolescents (Ceruti & Marzocchi, 2025; Herreras, 2025). The association identified in the present study therefore provides further support for the view that executive processes play a fundamental role in educational adaptation.

The current findings are particularly consistent with investigations demonstrating relationships between executive functioning and adaptive behavior across neurodevelopmental populations. Joga-Elvira and colleagues found that executive functioning was strongly associated with adaptive school behavior among girls with Fragile X syndrome, suggesting that executive skills contribute to educational adaptation across diagnostic categories (Joga-Elvira et al., 2021). Similarly, ElAdl reported significant associations between executive functions and social competence among children with and without ADHD, highlighting the broad influence of executive processes on functional outcomes (ElAdl, 2024). Research examining interventions designed to improve executive functioning has further demonstrated positive effects on emotional regulation, academic performance, and behavioral adjustment (Antunes et al., 2025; Y. Wang et al., 2025). Reviews conducted by Bombonato and colleagues as well as Gkora and Drigas similarly concluded that executive-function-focused interventions can produce meaningful improvements in functioning among children with neurodevelopmental disorders (Bombonato et al., 2023; Gkora & Drigas, 2024). The present findings therefore reinforce the importance of cognitive flexibility as a valuable target for educational intervention and support.

A particularly noteworthy aspect of the findings was the identification of interaction effects among the predictors. The EBM analyses indicated that the positive influence of cognitive flexibility was amplified when accompanied by strong self-regulation, while the highest levels of adaptive school functioning were observed among students who simultaneously demonstrated strong self-regulation and positive teacher–student relationships. These findings suggest that adaptive school functioning is best conceptualized as the product of interconnected systems rather than independent variables. Such results are consistent with ecological and systems-based models emphasizing reciprocal interactions among cognitive, emotional, behavioral, and contextual influences (Monteiro, 2021; L. Wang et al., 2025). The findings also support arguments that executive functions achieve their greatest practical value when translated into self-regulated behavior within supportive educational environments. In this regard, cognitive skills alone may be insufficient to ensure successful adaptation unless accompanied by opportunities for positive social engagement and effective behavioral regulation.

The strong predictive performance of the Explainable Boosting Machine model represents another important contribution of the study. Traditional educational and psychological research frequently relies on linear statistical

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models that may overlook nonlinear relationships and interaction effects. By contrast, the present findings demonstrate that explainable machine learning approaches can identify complex patterns while maintaining interpretability. This characteristic is particularly valuable in educational contexts, where practitioners require not only accurate predictions but also understandable explanations regarding the factors influencing student outcomes. The use of EBM therefore contributes to the growing movement toward explainable artificial intelligence in educational and psychological sciences (Doulou & Drigas, 2022; Stewart et al., 2025). Moreover, the model's high level of predictive accuracy suggests that cognitive flexibility, self-regulation, and teacher–student relationship quality collectively capture essential dimensions of adaptive school functioning among students with ADHD.

The findings also support broader contemporary perspectives emphasizing multidimensional intervention approaches. Research investigating ADHD increasingly highlights the limitations of focusing exclusively on symptom reduction and instead advocates for interventions addressing executive skills, emotional functioning, environmental supports, and educational inclusion (Carcelén-Fraile et al., 2025; Martín-Rodríguez et al., 2025). Studies examining educational accommodations, inclusive teaching practices, digital technologies, physical activity interventions, and executive function training similarly suggest that successful outcomes emerge from coordinated efforts targeting multiple domains of functioning (Cabello et al., 2024; Eşi, 2024; Tsampouris, 2022; Villa et al., 2023). The present findings provide empirical support for this multidimensional perspective by demonstrating that adaptive school functioning is simultaneously influenced by cognitive, self-regulatory, and relational factors.

5. Conclusion

The study additionally contributes to ongoing discussions regarding educational equity and inclusion for students with ADHD. Inclusive educational frameworks increasingly emphasize the importance of recognizing neurodiversity and creating learning environments that accommodate diverse strengths and challenges. Research examining giftedness, neurodivergence, executive functioning, and adaptive learning environments has consistently highlighted the need for educational systems that support individualized development rather than focusing exclusively on deficits (Coutinho-Souto & Fleith, 2022; Pergantis, 2024). By identifying modifiable predictors of adaptive school functioning, the current study provides actionable insights that may inform efforts to enhance educational participation and success among students with ADHD.

The present findings should be interpreted in light of several limitations. First, the cross-sectional design precludes conclusions regarding causality and developmental directionality among the study variables. Second, the study relied partially on self-report and teacher-report measures, which may be influenced by response biases and subjective perceptions. Third, the sample was drawn exclusively from Greece, potentially limiting the generalizability of the findings to other cultural and educational contexts. Fourth, although the model explained a substantial proportion of variance in adaptive school functioning, additional variables such as family functioning, peer relationships, socioeconomic factors, and academic support services were not included. Finally, while Explainable Boosting Machines provide greater interpretability than many machine learning approaches, they cannot fully capture all contextual influences that shape students' educational experiences.

Future research should employ longitudinal designs to examine how cognitive flexibility, self-regulation, and teacher–student relationship quality interact over time to influence educational adaptation. Researchers should also investigate additional predictors, including parental involvement, peer support, school climate, emotional well-being, and motivational processes. Cross-cultural studies would help determine whether the observed relationships remain consistent across educational systems and sociocultural environments. Future machine learning investigations may benefit from integrating multimodal data sources, such as behavioral observations, academic records, digital learning analytics, and neuropsychological assessments, to further improve predictive accuracy and theoretical understanding. Intervention studies are also needed to evaluate whether targeted improvements in self-regulation, executive functioning, and teacher–student relationships lead to measurable gains in adaptive school functioning.

The findings have several practical implications for educational professionals, school psychologists, and policymakers. Schools should prioritize interventions that strengthen self-regulatory capacities, including goal-setting, emotional regulation, behavioral monitoring, and executive functioning training. Teacher professional development programs should emphasize relationship-building skills and

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strategies for fostering supportive classroom environments for students with ADHD. Educational planning should adopt a holistic perspective that addresses cognitive, behavioral, and relational dimensions simultaneously rather than focusing solely on symptom management. Screening procedures may benefit from incorporating assessments of self-regulation, cognitive flexibility, and teacher–student relationship quality to identify students at risk for poor school adaptation. Finally, educational policies should promote inclusive environments that recognize the importance of supportive relationships and executive skill development in facilitating successful educational outcomes for students with ADHD.

Authors' Contributions

Authors equally contributed to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

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Declaration of Interest

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Ethics Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

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