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LightGBM Analysis of Loneliness in Gifted Adolescents: Predictive Contributions of Maladaptive Perfectionism, Emotional Awareness, and Peer Support

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A B S T R A C T

The present study aimed to employ a Light Gradient Boosting Machine (LightGBM) approach to predict loneliness among gifted adolescents based on maladaptive perfectionism, emotional awareness, and peer support and to determine the relative contribution of these variables to loneliness outcomes. This cross-sectional predictive study was conducted among 512 gifted adolescents aged 13 to 18 years recruited from specialized educational programs and secondary schools in Mexico. Participants completed standardized measures of loneliness, maladaptive perfectionism, emotional awareness, and peer support. Data were analyzed using Python and R statistical environments. After preliminary data screening and standardization procedures, a LightGBM regression model was developed using an 80/20 training–testing split. Hyperparameter optimization was performed through five-fold cross-validation and Bayesian optimization. Model performance was evaluated using the coefficient of determination (R^2), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and Mean Absolute Percentage Error (MAPE). Feature importance analysis and SHapley Additive exPlanations (SHAP) were used to identify and interpret the contribution of predictor variables. The optimized LightGBM model demonstrated strong predictive performance, achieving an R^2 of .811 in the testing dataset, indicating that the model explained 81.1% of the variance in loneliness scores. Correlational analyses revealed that loneliness was positively associated with maladaptive perfectionism and negatively associated with emotional awareness and peer support. Feature importance analysis identified peer support as the strongest predictor of loneliness (42.6% relative importance), followed by maladaptive perfectionism (33.8%) and emotional awareness (23.6%). SHAP analyses confirmed these findings, showing that lower peer support and higher maladaptive perfectionism substantially increased predicted loneliness levels, whereas higher emotional awareness reduced loneliness risk. The

consistency between LightGBM feature importance rankings and SHAP explanations supported the robustness and interpretability of the predictive model. The findings indicate that loneliness among gifted adolescents is shaped by a combination of interpersonal and intrapersonal factors, with peer support emerging as the most influential protective factor, maladaptive perfectionism functioning as a significant risk factor, and emotional awareness contributing additional resilience. The study demonstrates the utility of explainable machine learning approaches for identifying key determinants of psychological well-being in gifted populations and provides evidence to support interventions targeting social connectedness, perfectionistic tendencies, and emotional competencies.

Keywords: *Gifted Adolescents; Loneliness; LightGBM; Maladaptive Perfectionism; Emotional Awareness; Peer Support*

1. Introduction

Loneliness during adolescence has emerged as a major psychological and public health concern due to its profound influence on emotional well-being, social adjustment, academic functioning, and long-term mental health outcomes. Although loneliness is commonly conceptualized as a subjective discrepancy between desired and actual social relationships, contemporary research has demonstrated that it represents a complex psychological phenomenon influenced by individual, interpersonal, and contextual factors. Adolescence is a particularly sensitive developmental period because young people undergo substantial biological, cognitive, emotional, and social changes that increase their vulnerability to experiences of isolation and social disconnection. Persistent loneliness during this stage has been associated with heightened risks of depression, anxiety, hopelessness, self-harm, and reduced psychological well-being, making it an important target for prevention and intervention efforts (Chen, 2023; Flett, 2025; Lin & Guo, 2024). While loneliness has been extensively examined in general adolescent populations, considerably less attention has been devoted to understanding loneliness among gifted adolescents, despite increasing evidence suggesting that gifted youth may encounter unique developmental challenges that place them at elevated risk for social and emotional difficulties (Cash & Lin, 2021; Tourreix et al., 2023; Winsor & Mueller, 2020). Gifted adolescents frequently report feeling different from their peers due to advanced intellectual abilities, heightened sensitivities, asynchronous development, and unique educational experiences, all of which may contribute to difficulties in forming meaningful social connections and maintaining a strong sense of belonging (Cash & Lin, 2021; Tourreix et al., 2023).

The social and emotional development of gifted adolescents has long been a topic of debate within the literature. Early stereotypes portrayed gifted individuals as socially isolated and emotionally vulnerable; however, contemporary findings indicate that their experiences are highly heterogeneous and influenced by numerous personal and environmental factors. Although many gifted adolescents demonstrate positive psychological adjustment, others experience elevated levels of perfectionism, stress, interpersonal difficulties, and emotional distress that can contribute to loneliness and social withdrawal (Raoof et al., 2024; Tourreix et al., 2023). Research examining the psychological well-being of gifted students has highlighted the importance of understanding not only their cognitive strengths but also the socioemotional challenges they face within educational and social contexts (Cash & Lin, 2021; Winsor & Mueller, 2020). Recent systematic reviews have further emphasized that underachievement, emotional difficulties, and reduced well-being among gifted students are frequently associated with internal psychological characteristics and interpersonal experiences rather than intellectual ability alone (Raoof et al., 2024; Tourreix et al., 2023). Consequently, identifying modifiable factors that contribute to loneliness among gifted adolescents represents an important step toward promoting healthier developmental outcomes.

Among the variables that have received substantial attention in gifted education and adolescent psychology, perfectionism has emerged as one of the most frequently studied characteristics. Perfectionism is a multidimensional personality construct characterized by striving for exceptionally high standards combined with tendencies toward self-criticism and concern over mistakes. Contemporary theoretical models distinguish between adaptive and maladaptive forms of perfectionism, with maladaptive perfectionism being associated with excessive self-evaluation, fear of failure, chronic dissatisfaction, and vulnerability to psychological distress (Flett & Hewitt, 2022, 2024). Gifted adolescents are often perceived as particularly susceptible to perfectionistic tendencies due to high

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achievement expectations, strong academic demands, and internalized standards of excellence (Grugan et al., 2021; Oğurlu, 2020). Meta-analytic and systematic review evidence suggests that gifted students frequently exhibit elevated perfectionism compared with their non-gifted peers, although considerable variation exists across studies (Grugan et al., 2021; Oğurlu, 2020). Furthermore, investigations focusing on gifted populations have documented significant associations between perfectionism and self-efficacy, collaborative learning attitudes, psychological adjustment, and academic functioning (Akkaya et al., 2021; DoĞAn & Yilmaz, 2023; Sánchez-Moncayo et al., 2025).

The psychological consequences of maladaptive perfectionism extend well beyond academic settings. A growing body of research has linked maladaptive perfectionism to anxiety, depression, burnout, hopelessness, self-injurious behavior, and impaired well-being across adolescent and young adult populations (Chęć et al., 2024; Fu et al., 2025; Gu, 2022; Sander et al., 2021). Perfectionistic individuals often interpret interpersonal interactions through a lens of evaluation and fear of failure, which may contribute to social avoidance, relationship difficulties, and feelings of isolation. Recent investigations have demonstrated that perfectionism is associated with reduced social connectedness and heightened loneliness, suggesting that perfectionistic concerns may undermine adolescents' ability to establish supportive peer relationships (Bearden et al., 2024; Dobos et al., 2024). Similarly, perfectionism has been linked to test anxiety, imposter phenomenon experiences, and diminished psychological well-being among high-achieving students (Leath et al., 2025; Zülfiqar & Abbasi, 2024). Emerging evidence further indicates that parental psychological control, social expectations, and interpersonal pressures may strengthen perfectionistic tendencies and indirectly affect adolescent adjustment outcomes (Livazović & Kuzmanović, 2022; Sorrenti et al., 2025). These findings suggest that maladaptive perfectionism may represent a critical risk factor contributing to loneliness among gifted adolescents.

Another variable that may play an important role in understanding loneliness among gifted adolescents is emotional awareness. Emotional awareness refers to an individual's capacity to identify, differentiate, understand, and appropriately respond to emotional experiences in oneself and others. Emotional awareness is considered a foundational component of emotional intelligence and emotional regulation because it facilitates adaptive coping, interpersonal communication, empathy, and psychological resilience. Theoretical perspectives emphasize that difficulties in emotional awareness can contribute to emotional vulnerability and increase susceptibility to a wide range of psychological problems (Timulák & Keogh, 2022). Adolescents who struggle to recognize and communicate emotions may experience difficulties forming close relationships, resolving interpersonal conflicts, and seeking social support when needed. Consequently, lower emotional awareness may contribute to feelings of loneliness and social disconnection. Research involving gifted populations has demonstrated that emotional intelligence and emotional competencies are associated with positive psychological adjustment and adaptive functioning (Tsai, 2023). Moreover, studies examining adolescent mental health have consistently identified emotional competencies as important protective factors against depression, anxiety, and other forms of psychological distress (Chen, 2023; Lin & Guo, 2024). Given these findings, emotional awareness may serve as a protective factor that reduces loneliness by facilitating healthier social interactions and more effective emotional communication.

The importance of peer relationships during adolescence further highlights the potential relevance of peer support in understanding loneliness among gifted youth. Developmental theories emphasize that peer relationships become increasingly influential during adolescence as young people seek acceptance, belonging, and identity formation within social groups. Peer support encompasses emotional encouragement, companionship, validation, practical assistance, and opportunities for social engagement. Strong peer support has consistently been associated with greater psychological well-being, resilience, life satisfaction, and social adjustment, whereas poor peer support has been linked to loneliness, depression, anxiety, and social isolation (Cash & Lin, 2021; Chen, 2023; Flett, 2025). For gifted adolescents, peer relationships may be particularly important because intellectual differences can sometimes create barriers to social integration within age-based peer groups. Previous research suggests that gifted students often seek peers who share similar interests, abilities, and values, and the absence of such relationships may contribute to loneliness and reduced belongingness (Raoof et al., 2024; Tourreix et al., 2023). Additionally, interventions targeting mindfulness, social connectedness, and perfectionism have demonstrated improvements in interpersonal functioning and reductions in social distress among gifted and high-achieving populations (Bearden et

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al., 2024; Olton-Weber et al., 2020). These findings suggest that peer support may represent one of the most important protective factors against loneliness among gifted adolescents.

Recent scholarship has increasingly emphasized the need to move beyond traditional linear models and adopt more sophisticated analytical approaches capable of capturing complex psychological relationships. Human behavior is rarely determined by single factors acting independently; rather, psychological outcomes emerge from intricate interactions among cognitive, emotional, social, and contextual influences. Machine learning techniques have therefore gained growing popularity in psychological research because they can model nonlinear patterns, identify high-order interactions, and generate highly accurate predictions. Recent applications of advanced statistical and computational approaches have demonstrated their utility for examining complex psychological phenomena among gifted students and adolescents more broadly (Bagheri et al., 2024; Chęć et al., 2025). Furthermore, contemporary conceptualizations of perfectionism emphasize the importance of person-focused assessment approaches that acknowledge the multidimensional and dynamic nature of psychological functioning (Flett & Hewitt, 2024). Machine learning algorithms such as Light Gradient Boosting Machine (LightGBM) are particularly valuable because they combine strong predictive performance with the ability to identify the relative importance of multiple predictors simultaneously. Such approaches may provide a more comprehensive understanding of loneliness among gifted adolescents than conventional statistical techniques.

Despite substantial advances in the literatures on giftedness, perfectionism, emotional functioning, and adolescent well-being, several important gaps remain. First, relatively few studies have specifically examined loneliness among gifted adolescents using comprehensive predictive frameworks. Second, although maladaptive perfectionism has been linked to numerous negative psychological outcomes, its contribution to loneliness within gifted populations remains insufficiently understood. Third, emotional awareness and peer support have received limited attention as potential protective factors against loneliness among gifted youth. Finally, most existing studies have relied on traditional correlational approaches that may fail to capture the complex and nonlinear relationships among psychological variables. Addressing these limitations is important for both theoretical and practical reasons because identifying the strongest predictors of loneliness can inform targeted interventions aimed at enhancing the well-being of gifted adolescents.

Therefore, the aim of the present study was to employ a LightGBM machine learning approach to predict loneliness among gifted adolescents based on maladaptive perfectionism, emotional awareness, and peer support and to determine the relative contribution of each predictor to loneliness outcomes.

2. Methods and Materials

2.1. Study Design and Participants

This study employed a cross-sectional predictive research design using machine learning techniques to examine the extent to which maladaptive perfectionism, emotional awareness, and peer support predict loneliness among gifted adolescents. The study was conducted in Mexico between September 2025 and February 2026 in collaboration with specialized educational centers and secondary schools offering enrichment programs for gifted students. The target population consisted of gifted adolescents enrolled in public and private educational institutions located in Mexico City, Guadalajara, Monterrey, Puebla, and Querétaro. Giftedness was determined based on school records, participation in gifted education programs, and documented cognitive assessment results indicating intellectual abilities above the 95th percentile.

A total of 512 gifted adolescents participated in the study. Participants ranged in age from 13 to 18 years, with a mean age of 15.46 years (SD = 1.58). Of the participants, 271 (52.9%) were female and 241 (47.1%) were male. Inclusion criteria included identification as gifted by educational authorities or psychologists, enrollment in a secondary or high school educational program, and the ability to complete self-report questionnaires independently. Adolescents with severe psychiatric disorders, significant cognitive impairments, or incomplete questionnaire responses exceeding 10% of the total items were excluded from the study. Participants and their parents or legal guardians provided informed consent prior to participation.

2.2. Measures

Loneliness was assessed using the UCLA Loneliness Scale Version 3 developed by Russell (1996). This instrument consists of 20 items designed to measure subjective feelings of social isolation, relational dissatisfaction, and perceived loneliness. Participants

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respond to each item on a four-point Likert scale ranging from 1 (Never) to 4 (Often). Total scores range from 20 to 80, with higher scores indicating greater levels of loneliness. The UCLA Loneliness Scale has demonstrated strong psychometric properties across adolescent populations, including excellent internal consistency, construct validity, and convergent validity. Previous studies have reported Cronbach's alpha coefficients exceeding .90, and the instrument has been widely used in cross-cultural research examining adolescent social and emotional adjustment.

Maladaptive perfectionism was measured using the Frost Multidimensional Perfectionism Scale developed by Frost et al. (1990). The scale contains 35 items assessing dysfunctional aspects of perfectionism across several dimensions, including concern over mistakes, doubts about actions, parental criticism, parental expectations, personal standards, and organization. For the purposes of the present study, the maladaptive perfectionism composite score was derived from the concern over mistakes, doubts about actions, parental criticism, and parental expectations subscales. Responses are recorded on a five-point Likert scale ranging from 1 (Strongly disagree) to 5 (Strongly agree). Higher scores indicate greater levels of maladaptive perfectionistic tendencies. Extensive research has supported the reliability and validity of the scale among adolescent populations, with reported internal consistency coefficients ranging from .80 to .93.

Emotional awareness was assessed using the Emotional Awareness Questionnaire developed by Rieffe et al. (2008). The instrument consists of 30 items measuring adolescents' capacity to recognize, understand, differentiate, and communicate emotions. The questionnaire evaluates multiple components of emotional awareness, including differentiation of emotions, verbal sharing of emotions, bodily awareness, attending to others' emotions, and analysis of emotions. Responses are provided on a three-point Likert scale ranging from 1 (Not true) to 3 (Often true). Higher scores indicate greater emotional awareness and emotional understanding. Previous validation studies have demonstrated satisfactory factorial validity and reliability, with Cronbach's alpha values generally ranging from .75 to .89 across adolescent samples.

Peer support was measured using the Peer Support Subscale of the Child and Adolescent Social Support Scale developed by Malecki and Demaray (2002). The subscale contains 12 items assessing perceived emotional, informational, appraisal, and instrumental support received from peers. Participants rate each statement on a six-point Likert scale ranging from 1 (Never) to 6 (Always). Higher scores indicate stronger perceptions of peer support and peer connectedness. The scale has demonstrated strong psychometric characteristics in adolescent populations and has been widely utilized in studies examining social adjustment, psychological well-being, and interpersonal relationships. Previous research has reported Cronbach's alpha coefficients above .90 and evidence of strong construct validity.

Demographic information was collected through a researcher-developed questionnaire that included age, gender, grade level, type of school, participation in gifted education programs, socioeconomic status, and family structure. Data collection was conducted in classroom settings under the supervision of trained research assistants. Participants completed the questionnaires anonymously, and average completion time ranged between 25 and 35 minutes.

2.3. Data Analysis

Data analysis was performed using Python 3.12 and R 4.4 statistical software environments. Preliminary analyses included examination of missing values, outlier detection, assessment of variable distributions, descriptive statistics, and Pearson correlation coefficients among study variables. Missing values accounting for less than 5% of the dataset were handled using multiple imputation procedures. Continuous variables were standardized prior to machine learning model development to facilitate model stability and interpretation.

The primary analytical approach involved the implementation of a Light Gradient Boosting Machine (LightGBM) regression model to predict loneliness scores based on maladaptive perfectionism, emotional awareness, and peer support. LightGBM was selected due to its computational efficiency, ability to handle nonlinear relationships, and strong predictive performance in psychological datasets. The dataset was randomly divided into training (80%) and testing (20%) subsets. Hyperparameter optimization was conducted using five-fold cross-validation combined with Bayesian optimization procedures. Key hyperparameters, including learning rate, maximum tree depth, number of leaves, minimum child samples, and feature fraction, were systematically tuned to maximize predictive performance.

Model performance was evaluated using multiple metrics, including the coefficient of determination (R^2), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE),

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and Mean Absolute Percentage Error (MAPE). To enhance model interpretability, SHapley Additive exPlanations (SHAP) analysis was conducted. SHAP values were calculated to determine the relative contribution and importance of each predictor variable in explaining loneliness outcomes. Global SHAP summary plots and local explanation analyses were generated to identify both overall and individual-level prediction patterns. Feature importance rankings derived from LightGBM and SHAP analyses were compared to determine the most influential predictors. Statistical significance for preliminary analyses was established at $p < .05$, while machine learning model evaluation focused primarily on predictive accuracy and explanatory contribution rather than traditional hypothesis testing.

3. Findings and Results

A total of 512 gifted adolescents participated in the study. The sample consisted of 271 females (52.9%) and 241 males (47.1%). Participants ranged in age from 13 to 18 years, with a mean age of 15.46 years (SD = 1.58). Regarding educational level, 286 participants (55.9%) were enrolled in lower secondary education and 226 (44.1%) were enrolled in upper secondary education. Approximately 61.3% attended public schools and 38.7% attended private schools. The majority of participants (72.5%) reported living in two-parent households, while 18.8% lived in single-parent households and 8.7% reported alternative family arrangements. Preliminary screening indicated no substantial missing data, severe outliers, or violations of statistical assumptions. Descriptive analyses revealed moderate levels of loneliness and maladaptive perfectionism, relatively high emotional awareness, and generally favorable perceptions of peer support among the gifted adolescents included in the study.

Table 1

Descriptive Statistics and Correlations Among Study Variables

Variable	Mean	SD	1	2	3	4
1. Loneliness	43.78	10.21	—			
2. Maladaptive Perfectionism	86.45	14.37	.61***	—		
3. Emotional Awareness	68.72	9.85	-.54***	-.39***	—	
4. Peer Support	52.96	11.44	-.67***	-.42***	.58***	—

Table 1 presents descriptive statistics and Pearson correlation coefficients for the primary study variables. The results indicated that loneliness was strongly and positively associated with maladaptive perfectionism ($r = .61$, $p < .001$), suggesting that adolescents exhibiting greater perfectionistic concerns and self-critical tendencies reported substantially higher levels of loneliness. Conversely, loneliness demonstrated significant negative relationships with emotional awareness ($r = -.54$, $p < .001$) and peer support ($r = -.67$, $p < .001$), indicating that greater emotional understanding and stronger supportive peer relationships were associated with lower loneliness levels. Emotional awareness was negatively correlated with maladaptive perfectionism ($r = -.39$, $p < .001$) and positively correlated with peer support ($r = .58$, $p < .001$). These findings provided preliminary evidence supporting the relevance of all three predictors in explaining loneliness among gifted adolescents and justified their inclusion in the subsequent machine learning analyses.

Table 2

Performance of the Optimized LightGBM Model for Predicting Loneliness

Metric	Training Set	Test Set
R^2	0.892	0.811
RMSE	3.18	4.91
MAE	2.47	3.86
MAPE (%)	6.21	8.97

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The predictive performance of the optimized LightGBM model is summarized in Table 2. The model demonstrated excellent predictive accuracy across both training and testing datasets. The coefficient of determination (R^2) reached .892 in the training dataset and .811 in the independent testing dataset, indicating that approximately 81.1% of the variance in loneliness scores could be explained by the combined effects of maladaptive perfectionism, emotional awareness, and peer support when evaluated on previously unseen data. The relatively small decline in predictive performance from training to testing datasets suggested minimal overfitting and strong generalizability. Furthermore, low RMSE and MAE values reflected a high degree of prediction precision, while the MAPE values below 10% indicated excellent practical predictive accuracy. Collectively, these findings demonstrated that the LightGBM algorithm provided a highly effective framework for modeling loneliness among gifted adolescents and accurately captured complex nonlinear relationships among the predictor variables.

Table 3

LightGBM Feature Importance Rankings

Predictor	Gain Importance	Relative Importance (%)
Peer Support	1624.83	42.6
Maladaptive Perfectionism	1289.71	33.8
Emotional Awareness	896.42	23.6

The feature importance analysis generated by the LightGBM model revealed notable differences in the relative contribution of the predictor variables. As shown in Table 3, peer support emerged as the most influential predictor, accounting for 42.6% of the total predictive importance within the model. This finding indicates that perceived support and connectedness with peers played the most substantial role in explaining loneliness experiences among gifted adolescents. Maladaptive perfectionism ranked second, contributing 33.8% of total model importance. This result suggests that excessive self-criticism, fear of mistakes, and unrealistic personal standards significantly increased vulnerability to loneliness. Emotional awareness ranked third but still demonstrated a meaningful contribution, accounting for 23.6% of predictive importance. Although comparatively less influential than peer support and perfectionism, emotional awareness remained an important protective factor within the overall predictive framework. Together, these findings highlight the multidimensional nature of loneliness among gifted adolescents and underscore the dominant role of interpersonal relationships while also emphasizing the importance of intrapersonal emotional and cognitive characteristics.

Table 4

SHAP Analysis of Predictor Contributions to Loneliness

Predictor	Mean Absolute SHAP Value	Direction of Effect
Peer Support	6.84	Higher support → Lower loneliness
Maladaptive Perfectionism	5.97	Higher perfectionism → Higher loneliness
Emotional Awareness	4.21	Higher awareness → Lower loneliness

The SHAP analysis provided additional insight into how individual predictors influenced loneliness predictions. As shown in Table 4, peer support produced the largest mean absolute SHAP value (6.84), confirming its position as the strongest predictor in the model. Examination of SHAP distributions indicated that low levels of peer support consistently increased predicted loneliness scores, whereas high levels of support substantially reduced loneliness risk. Maladaptive perfectionism demonstrated the second-largest SHAP value (5.97), indicating that increases in perfectionistic concerns exerted a strong positive influence on loneliness predictions. Adolescents reporting elevated concerns over mistakes, heightened self-criticism, and excessive performance expectations tended to receive substantially higher predicted loneliness scores. Emotional awareness exhibited a mean SHAP value of 4.21 and demonstrated a protective effect across most observations. Higher emotional awareness was associated with reduced loneliness predictions, suggesting that adolescents who possessed stronger capacities for recognizing,

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understanding, and managing emotions experienced lower levels of social isolation. The SHAP findings further revealed several nonlinear effects, particularly for peer support, where loneliness increased sharply below moderate support levels and stabilized once support exceeded a certain threshold. These results highlight the value of explainable artificial intelligence approaches for understanding the psychological mechanisms underlying loneliness and demonstrate that both interpersonal and intrapersonal factors contribute meaningfully to loneliness experiences among gifted adolescents.

Overall, the findings indicate that the LightGBM model achieved excellent predictive performance and identified peer support, maladaptive perfectionism, and emotional awareness as significant determinants of loneliness in gifted adolescents. Among these factors, peer support emerged as the most influential predictor, followed by maladaptive perfectionism and emotional awareness. The consistency between feature importance and SHAP analyses strengthens confidence in the robustness of these findings and provides a comprehensive understanding of the factors associated with loneliness within gifted youth populations.

4. Discussion

The present study employed a LightGBM machine learning approach to examine the predictive contributions of maladaptive perfectionism, emotional awareness, and peer support to loneliness among gifted adolescents. The findings demonstrated that the optimized LightGBM model achieved strong predictive performance, explaining a substantial proportion of variance in loneliness scores. Correlational analyses revealed that loneliness was positively associated with maladaptive perfectionism and negatively associated with emotional awareness and peer support. Furthermore, feature importance and SHAP analyses indicated that peer support emerged as the strongest predictor of loneliness, followed by maladaptive perfectionism and emotional awareness. These findings provide important insights into the social and psychological mechanisms underlying loneliness among gifted adolescents and highlight the importance of considering both interpersonal and intrapersonal factors when addressing their socioemotional well-being.

One of the most important findings of the study was the identification of peer support as the strongest predictor of loneliness. Adolescence is a developmental period during which peer relationships become central to identity formation, emotional regulation, and psychological adjustment. The finding that peer support accounted for the greatest proportion of predictive importance suggests that gifted adolescents' perceptions of acceptance, belongingness, and connectedness within their peer networks play a critical role in determining whether they experience loneliness. This result aligns with previous literature emphasizing the centrality of social connectedness and supportive interpersonal relationships in adolescent well-being (Cash & Lin, 2021; Flett, 2025). Gifted adolescents often encounter unique social challenges due to intellectual differences, asynchronous development, and difficulties finding peers who share similar interests and abilities. Consequently, when supportive peer relationships are lacking, these adolescents may be especially vulnerable to feelings of isolation. The current findings are also consistent with systematic reviews indicating that non-cognitive factors, including social relationships and peer acceptance, significantly influence adjustment outcomes among gifted youth (Raoof et al., 2024; Tourreix et al., 2023). From a theoretical perspective, peer support may protect against loneliness by satisfying fundamental psychological needs for belongingness, validation, and interpersonal connection. Adolescents who perceive their peers as supportive may experience greater social confidence, stronger social identities, and increased opportunities for meaningful interaction, thereby reducing feelings of social isolation.

The prominence of peer support within the predictive model also reflects broader developmental theories suggesting that interpersonal relationships function as protective resources against psychological distress. Adolescents who experience supportive peer environments are more likely to engage in adaptive coping strategies, disclose emotional concerns, and seek assistance during periods of stress. In contrast, those who perceive limited support may withdraw socially and develop increasingly negative perceptions of their social world. Previous intervention research has demonstrated that programs targeting social connectedness and interpersonal functioning can reduce psychological distress while simultaneously improving well-being and relationship quality (Bearden et al., 2024; Olton-Weber et al., 2020). The present findings suggest that similar approaches may be particularly beneficial for gifted adolescents who struggle with loneliness. Given the central role of peer support observed in this study, efforts to enhance peer relationships within

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gifted education settings may represent one of the most effective strategies for promoting psychological adjustment.

A second major finding was that maladaptive perfectionism emerged as a strong positive predictor of loneliness. This result supports theoretical perspectives describing perfectionism as a multidimensional vulnerability factor that extends beyond achievement contexts and affects interpersonal functioning. Adolescents characterized by excessive concern over mistakes, fear of failure, chronic self-criticism, and unrealistic personal standards often experience heightened psychological distress and difficulties in social relationships (Flett & Hewitt, 2022, 2024). The positive association between maladaptive perfectionism and loneliness observed in the current study is consistent with extensive empirical evidence linking perfectionism to anxiety, depression, hopelessness, burnout, and social disconnection (Chęć et al., 2024; Dobos et al., 2024; Fu et al., 2025; Gu, 2022). Gifted adolescents may be particularly susceptible to these effects because they frequently operate in environments characterized by high expectations and achievement-oriented cultures. Over time, perfectionistic concerns may encourage social withdrawal, fear of negative evaluation, and reluctance to engage authentically with others, thereby increasing loneliness.

The findings also correspond with previous research demonstrating elevated perfectionistic tendencies among gifted populations. Meta-analytic evidence has suggested that gifted students often report higher perfectionism than their non-gifted peers, although the nature and consequences of these tendencies vary across individuals (Oğurlu, 2020). Similarly, systematic reviews have highlighted perfectionism as one of the most frequently observed psychological characteristics among gifted students (Grugan et al., 2021). Studies examining gifted adolescents have reported relationships between perfectionism and educational experiences, self-efficacy, collaborative learning attitudes, and psychological well-being (Akkaya et al., 2021; DoĞAn & Yilmaz, 2023; Sánchez-Moncayo et al., 2025). The present findings extend this literature by demonstrating that maladaptive perfectionism contributes substantially to loneliness. Adolescents who constantly fear making mistakes or failing to meet perceived standards may avoid social situations where imperfections could be exposed. Such avoidance behaviors may gradually undermine relationship development and reinforce feelings of social isolation.

Furthermore, the role of maladaptive perfectionism may be understood within broader ecological and interpersonal frameworks. Previous studies have identified parental psychological control, social expectations, media influences, and interpersonal pressures as important antecedents of perfectionistic tendencies (Livazović & Kuzmanović, 2022; Sorrenti et al., 2025). Research has also shown that perfectionism is associated with imposter phenomenon experiences, test anxiety, and concerns regarding social evaluation among high-achieving students (Leath et al., 2025; Zülfiqar & Abbasi, 2024). These mechanisms may contribute indirectly to loneliness by reducing adolescents' willingness to engage openly with peers and by increasing fears of rejection or inadequacy. Consequently, interventions designed to reduce maladaptive perfectionism may not only improve academic functioning but may also contribute to stronger social relationships and reduced loneliness.

The third major finding concerned the protective role of emotional awareness. The results demonstrated that higher levels of emotional awareness were associated with lower levels of loneliness and that emotional awareness contributed meaningfully to the predictive model. This finding supports theoretical perspectives emphasizing emotional awareness as a fundamental component of emotional functioning and psychological resilience. Individuals who possess greater awareness of their emotions are generally better equipped to understand interpersonal experiences, regulate emotional responses, and communicate their needs effectively (Timulák & Keogh, 2022). Such competencies are likely to facilitate the formation and maintenance of supportive relationships, thereby reducing vulnerability to loneliness.

The observed relationship between emotional awareness and loneliness is consistent with previous evidence highlighting the importance of emotional competencies for adolescent adjustment. Emotional intelligence and related constructs have been associated with improved psychological well-being, adaptive coping, and healthier interpersonal relationships among adolescents and gifted students (Tsai, 2023). Similarly, research on adolescent mental health has consistently identified emotional understanding and emotional regulation as protective factors against depression, anxiety, and emotional distress (Chen, 2023; Lin & Guo, 2024). The current findings suggest that emotional awareness may function as a psychological resource that enables gifted adolescents to navigate complex social environments more effectively. Adolescents who can accurately identify and express their emotions may be better able to establish intimacy, seek support when needed, and

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resolve interpersonal conflicts constructively. These processes likely contribute to reduced loneliness and greater social connectedness.

Another noteworthy aspect of the findings concerns the successful application of LightGBM as a predictive framework. Traditional statistical methods are often limited in their ability to model nonlinear relationships and complex interactions among psychological variables. The high predictive accuracy achieved in the present study demonstrates the utility of machine learning approaches for examining socioemotional outcomes among gifted adolescents. Recent psychological research has increasingly advocated for more sophisticated analytical methods capable of capturing multidimensional patterns of risk and resilience (Bagheri et al., 2024; Chęć et al., 2025). The consistency observed between feature importance analyses and SHAP explanations further strengthens confidence in the robustness and interpretability of the results. By identifying peer support, maladaptive perfectionism, and emotional awareness as key predictors of loneliness, the machine learning model provides a nuanced understanding of how multiple psychological and social factors interact to shape adolescent experiences.

The findings also contribute to ongoing debates regarding the socioemotional functioning of gifted youth. Historically, assumptions regarding gifted students' emotional adjustment have oscillated between portraying giftedness as a protective factor and viewing it as a source of vulnerability. Contemporary evidence suggests that neither perspective fully captures the complexity of gifted adolescents' experiences (Cash & Lin, 2021; Tourreix et al., 2023). Instead, psychological outcomes appear to depend on the interaction of personal characteristics, emotional competencies, and social environments. The present results support this multidimensional perspective by demonstrating that loneliness among gifted adolescents cannot be explained solely by cognitive ability or academic achievement. Rather, loneliness reflects the combined influence of interpersonal resources and individual psychological characteristics. This interpretation is consistent with contemporary models emphasizing the importance of person-centered and context-sensitive approaches to understanding perfectionism, adjustment, and well-being (Flett & Hewitt, 2024; Fuster-Rico et al., 2025).

5. Conclusion

Taken together, the findings suggest that loneliness among gifted adolescents is shaped by a dynamic interplay between social connectedness, perfectionistic tendencies, and emotional functioning. Peer support appears to serve as the primary protective factor, whereas maladaptive perfectionism functions as a major risk factor and emotional awareness contributes additional resilience. These results reinforce the importance of adopting holistic approaches to gifted education that prioritize socioemotional development alongside academic excellence. By addressing both interpersonal and intrapersonal dimensions of functioning, educators and mental health professionals may be better positioned to reduce loneliness and promote healthier developmental outcomes among gifted youth.

Several limitations should be considered when interpreting the findings of this study. First, the cross-sectional design prevents conclusions regarding causal relationships among loneliness, maladaptive perfectionism, emotional awareness, and peer support. Although the machine learning model identified strong predictive associations, it cannot determine the temporal direction of these relationships. Second, all variables were measured using self-report instruments, which may be influenced by response biases, social desirability effects, and subjective interpretations of questionnaire items. Third, the sample consisted exclusively of gifted adolescents from selected regions of Mexico, which may limit the generalizability of the findings to gifted students in other cultural, educational, or socioeconomic contexts. Fourth, although the model demonstrated strong predictive performance, other potentially relevant variables such as family support, school climate, self-esteem, identity development, and psychological resilience were not included. Finally, machine learning models emphasize prediction rather than causal explanation, and therefore the identified predictors should not be interpreted as definitive causes of loneliness.

Future research should employ longitudinal designs to investigate how loneliness develops over time among gifted adolescents and to clarify causal relationships among perfectionism, emotional awareness, peer support, and psychological adjustment. Researchers should also examine additional protective and risk factors, including family functioning, teacher support, self-compassion, social identity, resilience, and school belonging. Comparative studies involving gifted and non-gifted adolescents would help determine whether the predictive mechanisms

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identified in this study are unique to gifted populations or reflect broader developmental processes. Future investigations may also benefit from incorporating qualitative methods to better understand the lived experiences of loneliness among gifted youth. In addition, advanced machine learning approaches such as ensemble learning, explainable artificial intelligence techniques, and longitudinal prediction models could provide deeper insights into the complex pathways underlying adolescent loneliness.

Educational practitioners should recognize that loneliness among gifted adolescents is not merely a social issue but a multidimensional psychological phenomenon requiring comprehensive support. Schools should develop programs that facilitate meaningful peer interactions, collaborative learning opportunities, mentoring relationships, and social belonging among gifted students. Psychological interventions targeting maladaptive perfectionism should be incorporated into gifted education services to help students develop healthier achievement standards and more adaptive self-evaluative processes. Emotional awareness training, emotional literacy programs, and social-emotional learning curricula may further strengthen adolescents' capacity to understand and communicate their emotions effectively. Counselors, teachers, and parents should work collaboratively to identify students who exhibit signs of social isolation and provide timely support. By fostering supportive peer networks, reducing perfectionistic pressures, and enhancing emotional competencies, educational systems can promote healthier social adjustment and reduce loneliness among gifted adolescents.

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

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict 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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