

Artificial Neural Network Prediction of Psychological Well-Being Among Adolescents Using Family, Peer, School, and Individual Factors

Elena. Stojanovska¹, Ryan. MacDonald^{2*}, Tendai. Chikore³

¹ Department of Educational Psychology, Ss. Cyril and Methodius University, Skopje, North Macedonia

² Department of Sports Psychology, Acadia University, Wolfville, Canada

³ Department of Applied Psychology, University of Zimbabwe, Harare, Zimbabwe

* Corresponding author email address: ryan.macdonald@acadiau.ca

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ABSTRACT

Objective: This study aimed to develop and evaluate an artificial neural network model for predicting psychological well-being among adolescents using family, peer, school, and individual factors.

Methods and Materials: This cross-sectional predictive study was conducted among 612 adolescents aged 13–18 years enrolled in secondary schools in Ontario, Canada, during the 2025–2026 academic year. Participants were selected using multistage sampling. Psychological well-being was assessed using the Warwick–Edinburgh Mental Well-Being Scale. Family-related predictors included family cohesion and family support; peer-related predictors included peer support and friendship quality; school-related predictors included school connectedness, academic engagement, and academic standing; and individual predictors included self-esteem, resilience, emotion regulation difficulties, perceived stress, and selected demographic characteristics. An artificial neural network based on a multilayer perceptron architecture was developed using 70% of the sample for training, 15% for validation, and 15% for independent testing. Model performance was evaluated using mean squared error, root mean squared error, mean absolute error, correlation coefficients, and coefficient of determination. Permutation-based feature importance was used to rank predictors.

Findings: The artificial neural network demonstrated strong predictive performance, with R^2 values of .83, .76, and .74 in the training, validation, and test samples, respectively. In the independent test sample, the model achieved $R = .86$, $RMSE = 4.44$, $MAE = 3.52$, and $MSE = 19.74$. Perceived stress was the most influential predictor, followed by self-esteem, resilience, emotion regulation difficulties, family support, and school connectedness.

Conclusion: Psychological well-being among adolescents can be predicted with substantial accuracy using a multidimensional artificial neural network model, with individual psychological resources and stress-related factors contributing most strongly while family and school contexts also providing meaningful predictive value.

Keywords: adolescents; psychological well-being; artificial neural network; perceived stress; self-esteem; resilience; family support; school connectedness

1. Introduction

Adolescence is a critical developmental period characterized by rapid biological maturation, cognitive restructuring, emotional differentiation, identity formation, and increasingly complex social relationships. During this stage, young people encounter expanding expectations from family members, peers, schools, and wider social environments while simultaneously developing greater autonomy and personal responsibility. These transitions create substantial opportunities for growth, but they may also increase vulnerability to emotional distress, social disconnection, maladjustment, and mental health difficulties. Psychological well-being therefore represents a central indicator of healthy adolescent development because it extends beyond the absence of psychiatric symptoms and encompasses positive affect, adaptive functioning, perceived competence, meaningful relationships, coping capacity, and a sense of purpose and connectedness. Contemporary perspectives on child and adolescent mental health increasingly emphasize the importance of strengthening positive psychological functioning rather than focusing exclusively on the prevention or treatment of psychopathology (Subramanyam et al., 2024). Understanding the factors that contribute to psychological well-being during adolescence is therefore an important priority for developmental psychology, school mental health, public health, and preventive intervention research.

Adolescent well-being develops within multiple interdependent ecological systems rather than as a consequence of isolated individual characteristics. Family relationships, peer experiences, school environments, and personal psychological resources may simultaneously function as risk or protective factors, and their effects can accumulate, interact, or compensate for one another. Research on multiple developmental domains has demonstrated that combinations of family, school, peer, and individual factors can be more informative than examining any single domain separately (Kristjánsson et al., 2025). This multidimensional perspective is especially relevant during adolescence because young people spend substantial portions of their daily lives moving between family, classroom, friendship, and broader social contexts. Consequently, psychological well-being is likely to reflect not only adolescents' internal capacities but also the quality, stability, and responsiveness of the environments in which these capacities are expressed.

The family remains one of the most influential developmental contexts throughout adolescence, even as relationships outside the home become increasingly salient. Family cohesion, emotional availability, support, communication, attachment, and parental involvement can provide adolescents with a secure relational base from which to negotiate developmental challenges. Research has shown that family functioning is meaningfully associated with adolescent behavioral and emotional outcomes, and dysfunctional family processes may contribute to maladaptive adjustment (Chronopoulou et al., 2025). Secure attachment and positive childhood experiences may also influence the quality of family relationships and adolescents' vulnerability to adverse peer experiences such as bullying (Çiçek et al., 2025). Perceived support from parents and other family members can foster emotional security, self-worth, resilience, and adaptive coping, whereas low support, conflict, inconsistency, or psychological distress within the family may undermine these processes. The significance of family care has also been demonstrated in relation to children's perceived security, particularly when family support operates together with supportive school environments (Li et al., 2025).

Parental involvement may additionally influence adolescent well-being indirectly through school-related processes. Family participation in young people's academic and socioemotional development has been associated with stronger engagement in school, which may in turn support social-emotional functioning (Martinez-Yarza et al., 2024). Similarly, parenting practices and parental self-efficacy may shape the way adolescents experience and respond to the school environment, suggesting that family and school influences are often mutually reinforcing rather than independent (Varner et al., 2025). Family processes may also interact with broader structural and cultural contexts. For example, research examining academic development among African American youth has emphasized the importance of parental socialization and the interaction between family-level processes and the built and social environments surrounding young people (Murry et al., 2023). These findings collectively indicate that family support should not be considered merely as a background characteristic but as an active developmental resource with potential direct and indirect implications for psychological well-being.

At the same time, peers become increasingly important during adolescence as young people devote greater attention to belonging, acceptance, friendship, interpersonal

comparison, and social identity. Supportive friendships may provide companionship, emotional validation, practical assistance, and opportunities for self-disclosure, all of which may contribute to positive psychological functioning. Perceived social support has been associated with attachment-related characteristics and prosocial interpersonal orientations among high school students, underscoring the importance of relational security in adolescent social development (Yıldız & Eldeleklioglu, 2024). Social support also contributes to the satisfaction of fundamental psychological needs and may reduce disengagement from educational settings, particularly among adolescents facing structural disadvantages (Jia, 2025). However, peer relationships can also function as sources of stress, exclusion, victimization, and emotional harm, making the peer domain particularly complex.

Peer victimization and bullying are among the most consistently documented social threats to adolescent mental health. Bullying can occur in traditional face-to-face settings as well as through digital environments, and repeated exposure may be associated with anxiety, depression, social withdrawal, low self-esteem, and reduced psychological well-being. Recent work has highlighted the need to understand bullying as a multidimensional developmental and mental health concern rather than as a narrowly disciplinary problem (Harsono & Febriyana, 2026). Attachment to parents, including relationships with fathers, may affect adolescents' experiences of peer bullying, further illustrating the interaction between family and peer systems (Sezgin, 2026). Longitudinal evidence has also shown that peer victimization and social support are closely intertwined with mental health during early adolescence, suggesting that supportive relationships may buffer some of the consequences of negative peer experiences (Martínez et al., 2024).

Cyberbullying represents another increasingly important component of adolescent peer functioning. Patterns of cyberbullying may evolve over time and are associated with the quality of adolescents' social relationships, indicating that digitally mediated aggression should be understood within the broader relational context of adolescence (Park & Choi, 2025). Studies comparing psychosocial determinants of bullying and cyberbullying have similarly found that these behaviors share some risk factors while also reflecting distinct social and psychological processes (Malinowska-Ciešlik et al., 2023). Bullying victimization may be especially harmful among adolescents exposed to other sources of disadvantage. For instance, victimization has

been linked to mental health problems among left-behind children, highlighting the cumulative burden that social adversity can impose on psychological adjustment (Feng et al., 2024). Parents' perceptions of school relationships may also vary according to youths' experiences of peer victimization, demonstrating that peer difficulties can shape family interpretations of the school environment and potentially influence family-school interactions (Fu et al., 2025).

The school environment represents another major developmental context because adolescents spend a substantial proportion of their daily lives within educational settings. School climate, connectedness, teacher support, fairness, safety, peer norms, and academic engagement may influence psychological functioning by shaping adolescents' sense of belonging, competence, predictability, and social inclusion. School connectedness generally refers to the extent to which students perceive that adults and peers within the school care about them, value their participation, and provide a safe and supportive environment. A growing body of literature identifies school connectedness as a protective factor associated with numerous psychological and behavioral outcomes (Peng & Patterson, 2025). School connectedness may also moderate or mediate the influence of adverse childhood experiences on bullying-related outcomes, suggesting that supportive educational environments can serve as developmentally meaningful spaces of resilience (Su et al., 2025).

School climate may influence more than immediate emotional adjustment. Evidence from large developmental cohorts suggests that educational contexts may be associated with broader aspects of adolescent development, including processes linked to brain development (Thompson et al., 2026). Such findings reinforce the view that schools are not merely academic institutions but complex developmental environments capable of influencing psychological, social, and neurodevelopmental trajectories. Positive school climate has also been associated with prosocial behavior through mechanisms involving perceived social support and resilience (Hornsby et al., 2023). Furthermore, dimensions of school climate, together with personality and family relationships, have been shown to predict dispositional characteristics such as forgiveness in adolescence (Lampropoulou et al., 2023). These findings suggest that school experiences may affect well-being both directly and indirectly by strengthening interpersonal resources, resilience, and adaptive social tendencies.

School adjustment and educational engagement are also influenced by contextual characteristics that differ across educational systems and school types. School culture may predict variation in students' adjustment, indicating that institutional norms, expectations, and relationships can shape adolescents' functioning in distinct ways (Wang et al., 2025). Broader educational research likewise emphasizes the importance of continuity across educational systems and developmental stages when constructing supportive learning environments (Kearney et al., 2024). Adolescents' experiences of school support may be particularly consequential when other sources of social support are limited. For young people experiencing separation from parents, migration-related stress, or sociocultural marginalization, positive school relationships may partially compensate for vulnerabilities arising elsewhere in their developmental ecology.

The wider sociocultural context must therefore also be considered when evaluating adolescent psychological well-being. Adolescents from immigrant, minority, rural, or otherwise marginalized backgrounds may encounter contextual stressors that alter the meaning and availability of social support. Negative perceptions of the social context of reception, for example, have been associated with mental health among Hispanic and Somali adolescents, while sociocultural resources may function as important protective factors (Guan et al., 2023). Similarly, positive youth development among left-behind adolescents has been conceptualized as a multidimensional process involving relational, personal, and environmental resources (Wang & Kubo, 2025). These findings demonstrate that the same protective factors may operate differently depending on social context and that prediction models should ideally incorporate variables from several ecological levels.

Within these broader contexts, individual psychological resources remain especially important. Self-esteem, resilience, emotion regulation, and perceived stress may directly influence how adolescents interpret and respond to social experiences. Self-esteem contributes to positive self-evaluation and may reduce vulnerability to interpersonal rejection or academic difficulties. Resilience reflects the capacity to adapt, recover, and sustain functioning in the face of stressors or adversity. Qualitative research incorporating students' own perspectives has shown that resilience is understood as a multifaceted process shaped by personal strengths, relationships, and supportive environments (Ganotz-Steinborn & Schwab, 2025). Resilience should therefore not be conceptualized solely as an individual trait;

rather, it may emerge through dynamic interactions between adolescents and their social environments.

Emotion regulation is similarly central to psychological well-being because adolescents must increasingly manage complex emotional experiences while navigating academic demands, changing family relationships, peer evaluation, and identity-related challenges. Difficulty identifying, accepting, or regulating negative emotions can intensify the impact of stress and interpersonal adversity. Conversely, adaptive regulation may support persistence, social competence, and recovery following stressful events. Perceived stress captures the extent to which adolescents experience their lives as unpredictable, overwhelming, or beyond their coping resources and is therefore likely to be strongly associated with well-being. These individual factors may interact with contextual factors in nonlinear ways; for example, high resilience may offset some negative effects of stress, while strong family or school support may be especially beneficial for adolescents with lower self-esteem or greater emotion regulation difficulties.

Social and psychological functioning may also influence health-related behaviors and vice versa. Longitudinal evidence on disordered eating suggests that adolescent social health can be disrupted across time and relationships, illustrating how individual behavioral difficulties may reverberate through interpersonal systems (Otmar, 2026). Such findings are important because they demonstrate that psychological well-being cannot always be understood through simple linear pathways in which one isolated risk factor produces one outcome. Rather, adolescent development involves reciprocal and potentially nonlinear associations among individual characteristics, social relationships, and environmental conditions.

This complexity poses methodological challenges. Much of the existing literature has relied on correlation, regression, mediation, moderation, or structural equation modeling. These approaches are highly useful for testing theoretically specified relationships, but they generally assume relatively simple functional forms and may be less efficient when prediction depends on complex interactions or nonlinear combinations among numerous variables. Adolescent psychological well-being is especially likely to involve threshold effects, compensatory relationships, and interaction patterns that are difficult to capture using traditional linear models. A certain level of school connectedness, for example, may be particularly protective only when family support is low; similarly, resilience may become increasingly important at higher levels of perceived

stress. The predictive contribution of peers may also differ according to attachment security, family functioning, or the presence of victimization.

Artificial neural networks offer a useful complementary approach for addressing this complexity. As data-driven machine-learning models, neural networks can approximate nonlinear functions and identify patterns across multiple predictors without requiring the researcher to predefine every interaction term. In the context of adolescent well-being, this allows simultaneous modeling of family, peer, school, and individual factors while preserving the possibility that their relationships with psychological well-being are nonlinear or interdependent. Neural networks are therefore particularly suited to predictive questions in which the central objective is not merely to estimate whether one variable is statistically significant but to determine how accurately an outcome can be predicted from a multidimensional configuration of characteristics.

The use of machine-learning approaches is also consistent with the broader movement toward more individualized and prevention-oriented models of adolescent mental health. If well-being can be predicted with reasonable accuracy using accessible psychosocial indicators, schools, families, and mental health professionals may be better positioned to identify combinations of vulnerability and protection before severe difficulties emerge. However, prediction must remain interpretable. Determining which variables contribute most strongly to model performance is essential if machine-learning findings are to inform practical intervention. Feature-importance methods can help identify whether psychological well-being is most strongly associated with perceived stress, self-esteem, resilience, family support, peer relationships, school connectedness, or other characteristics. This is particularly important because contemporary developmental research repeatedly indicates that adolescent outcomes arise through multiple interconnected systems rather than a single dominant determinant (Kristjánsson et al., 2025).

Taken together, the literature suggests that positive adolescent development reflects a complex configuration of relational and individual resources. Supportive family functioning can strengthen security and adaptation; positive peer relationships can provide belonging and emotional support; school connectedness and climate can reinforce social inclusion and resilience; and individual resources such as self-esteem, resilience, and emotion regulation can shape how adolescents respond to stress. Conversely, family dysfunction, bullying, peer victimization, weak school

attachment, poor social support, and elevated stress may accumulate across developmental contexts. Existing evidence has established the importance of many of these factors separately, but fewer studies have integrated family, peer, school, and individual predictors within a unified nonlinear predictive framework. This gap is particularly relevant because adolescents' real-life experiences are inherently multidimensional and because the predictive value of one factor may depend on the presence or absence of others.

Accordingly, the aim of this study was to develop and evaluate an artificial neural network model for predicting psychological well-being among Canadian adolescents using family, peer, school, and individual factors.

2. Methods and Materials

2.1. Study Design and Participants

This study employed a cross-sectional predictive design to develop and evaluate an artificial neural network model for predicting psychological well-being among adolescents based on family, peer, school, and individual factors. The study population consisted of adolescents enrolled in public secondary schools in Canada during the 2025–2026 academic year. A total of 612 adolescents participated in the study. Participants were recruited from secondary schools located in urban and suburban communities across Ontario, Canada, using a multistage sampling procedure intended to obtain adequate variability in demographic, family, interpersonal, and educational characteristics. In the first stage, participating schools were selected from different school districts; in the second stage, classes were selected from eligible grade levels; and in the final stage, students meeting the inclusion criteria were invited to participate. The relatively large sample was selected because artificial neural network models require sufficient observations for model training, validation, and testing and because the study incorporated predictors from several psychosocial domains.

Eligible participants were adolescents between 13 and 18 years of age who were currently enrolled in grades 8 through 12, were able to read and understand English, and provided assent to participate in the study. For participants younger than the age at which independent consent was permitted under the applicable institutional requirements, written informed consent was additionally obtained from a parent or legal guardian. Adolescents were excluded when they had a documented cognitive or developmental condition that substantially interfered with their ability to understand or

independently complete the questionnaires, when they submitted questionnaires with substantial missing information, or when they withdrew from participation before completion of the assessment. Participation was voluntary, and students were informed that they could discontinue participation at any stage without academic or personal consequences. Questionnaires were completed anonymously, and no identifying information was included in the analytical dataset. The study was conducted in accordance with the ethical principles governing research involving human participants and adolescents, including confidentiality, voluntary participation, informed consent or assent, and protection of participants' privacy.

2.2. Measures

Psychological well-being, which constituted the outcome variable of the artificial neural network model, was assessed using the Warwick–Edinburgh Mental Well-Being Scale. This instrument consists of 14 positively worded items designed to evaluate positive psychological functioning, including optimism, positive affect, effective coping, interpersonal connectedness, clear thinking, autonomy, and perceived ability to deal with problems. Participants rated each item on a five-point Likert scale ranging from 1, indicating "none of the time," to 5, indicating "all of the time." Item scores were summed to obtain a total psychological well-being score, with higher scores indicating greater psychological well-being. The scale was selected because it provides a broad assessment of positive mental functioning rather than focusing exclusively on psychological symptoms or psychopathology and has been extensively applied in adolescent and population-based research.

Family-related predictors were assessed using the Family Adaptability and Cohesion Evaluation Scale IV and the Multidimensional Scale of Perceived Social Support. The Family Adaptability and Cohesion Evaluation Scale IV was used to assess the quality of family functioning, particularly family cohesion and flexibility. Items measure adolescents' perceptions of emotional bonding, communication, family organization, adaptability, and the capacity of family members to respond to changing demands. Higher balanced cohesion and flexibility scores reflect healthier family functioning. The family subscale of the Multidimensional Scale of Perceived Social Support was additionally used to assess adolescents' perceived availability of emotional and

instrumental support from family members. Responses were recorded on the standard Likert-type response format, with higher scores representing stronger perceived family support. Together, these measures allowed the family domain to represent both structural-relational family functioning and adolescents' subjective perceptions of support received from family members.

Peer-related factors were measured using the peer component of the Multidimensional Scale of Perceived Social Support and the Friendship Quality Scale. Perceived peer support reflected the extent to which adolescents believed that friends were available to provide emotional assistance, understanding, companionship, and help during difficult situations. Friendship quality was assessed in terms of companionship, closeness, emotional security, help, conflict management, and perceived acceptance within important peer relationships. Higher scores represented more supportive and higher-quality peer relationships. Because relationships with peers represent a central developmental context during adolescence, both perceived social support and the qualitative characteristics of friendships were included as inputs in the predictive model.

School-related predictors were assessed using measures of school connectedness and academic engagement. School connectedness was evaluated using items adapted from established school connectedness measures assessing students' feelings of belonging, acceptance, safety, respect, and interpersonal connection within the school environment. Participants indicated the extent to which they felt close to people at their school, perceived teachers as supportive, believed that they were treated fairly, and experienced a sense of belonging to their school community. Academic engagement was assessed across behavioral and emotional dimensions, including participation in classroom activities, persistence with academic tasks, attention during instruction, interest in learning, and positive attitudes toward school. Higher scores reflected stronger school connectedness and greater engagement. Academic performance was additionally represented by participants' self-reported overall academic standing during the most recent grading period, providing a complementary indicator of their functioning in the educational environment.

Individual-level predictors included self-esteem, resilience, emotion regulation, perceived stress, and demographic characteristics. Self-esteem was assessed using the Rosenberg Self-Esteem Scale, a 10-item measure of global self-worth containing positively and negatively worded statements. Items were rated on a four-point Likert

scale, and negatively phrased items were reverse-scored so that higher total scores represented more positive self-esteem. Resilience was measured using the 10-item Connor–Davidson Resilience Scale, which evaluates perceived capacity to adapt to stress, recover from difficult experiences, remain persistent when facing challenges, and manage adverse circumstances. Higher scores indicated greater psychological resilience. Emotion regulation difficulties were assessed using the Difficulties in Emotion Regulation Scale–Short Form, which measures problems involving emotional awareness and clarity, acceptance of negative emotions, impulse control, goal-directed behavior during emotional distress, and access to effective emotion-regulation strategies. Higher scores reflected greater difficulties in emotion regulation.

Perceived stress was assessed using the 10-item Perceived Stress Scale, which evaluates the extent to which individuals perceive their lives as unpredictable, uncontrollable, and overloaded during the preceding month. Responses were rated on a five-point frequency scale, with positively phrased items reverse-scored before calculation of the total score. Higher scores indicated greater perceived stress. Demographic information was collected using a researcher-developed questionnaire covering age, gender, school grade, household composition, parental educational level, perceived family socioeconomic status, and other basic background characteristics considered relevant to adolescent psychological well-being. Before statistical modeling, the internal consistency of each multi-item scale was examined using Cronbach's alpha, and scale scores were calculated according to the recommended scoring procedures for each instrument.

2.3. Data Analysis

Data analysis was conducted using IBM SPSS Statistics and Python-based machine-learning libraries. Prior to analysis, the dataset was examined for data-entry errors, missing observations, implausible values, and outliers. Descriptive statistics, including frequency, percentage, mean, standard deviation, minimum, and maximum values, were calculated to characterize the sample and study variables. The distributions of continuous variables were examined using indices of skewness and kurtosis as well as graphical inspection. The internal consistency of the multi-item instruments was evaluated using Cronbach's alpha coefficients. Bivariate Pearson correlation coefficients were initially calculated to examine relationships between

psychological well-being and the continuous family, peer, school, and individual variables. These conventional statistical analyses were performed primarily to describe the data and provide an interpretable overview of associations before implementation of the nonlinear predictive model.

An artificial neural network based on a multilayer perceptron architecture was developed to predict adolescents' psychological well-being scores. The input layer contained the selected family, peer, school, individual, and demographic predictor variables, whereas psychological well-being constituted the continuous output variable. Continuous predictors were standardized before model development to prevent variables with larger numerical ranges from disproportionately influencing the optimization procedure. Categorical predictors were transformed into appropriate numerical representations before their inclusion in the network. The complete sample of 612 adolescents was randomly divided into training, validation, and testing subsets, with 70% of cases allocated to the training set, 15% to the validation set, and 15% to the independent testing set. Accordingly, 428 participants were used for model training, 92 for validation, and 92 for final testing. The training dataset was used to estimate network weights, the validation dataset was used to optimize model configuration and monitor generalization performance, and the test dataset was retained until the final stage to provide an unbiased assessment of predictive accuracy.

The network consisted of an input layer, two hidden layers, and a single output neuron representing predicted psychological well-being. Rectified linear unit activation functions were applied to the hidden layers because of their computational efficiency and capacity to model nonlinear relationships, whereas a linear activation function was used in the output layer because the outcome variable was continuous. Model weights were optimized using the Adam optimization algorithm, and mean squared error was used as the loss function. The number of neurons in the hidden layers, learning rate, batch size, and other hyperparameters were optimized according to performance on the validation dataset. Early stopping was implemented to terminate training when validation loss ceased to improve, thereby reducing the likelihood of overfitting. Dropout regularization was additionally incorporated into the hidden layers to improve model generalizability. The final network configuration was selected on the basis of the lowest validation error and stable performance across the training and validation datasets.

The predictive performance of the final artificial neural network was evaluated in the independent test sample using the coefficient of determination, mean absolute error, root mean squared error, and mean squared error. The coefficient of determination was used to indicate the proportion of variability in psychological well-being explained by the model, whereas mean absolute error and root mean squared error quantified the magnitude of prediction error, with lower values representing better predictive accuracy. Agreement between observed and predicted psychological well-being scores was additionally examined through the correlation between actual and model-predicted values. To determine the relative contribution of predictor variables, permutation-based feature importance was calculated by measuring the deterioration in model performance following random permutation of each predictor while the remaining predictors were held unchanged. This procedure enabled predictors from family, peer, school, and individual domains to be ranked according to their contribution to prediction. Where appropriate, partial dependence and feature-attribution analyses were also used to facilitate interpretation of nonlinear relationships between the most influential predictors and psychological well-being. All conventional statistical tests were evaluated using a two-tailed significance level of $p < .05$, while assessment of the neural network emphasized out-of-sample predictive performance rather than statistical significance alone.

3. Findings and Results

A total of 612 adolescents participated in the study and were included in the final analysis. The participants ranged in age from 13 to 18 years, with a mean age of 15.47 years ($SD = 1.52$). Of the total sample, 307 participants (50.16%) identified as female, 294 (48.04%) identified as male, and 11 (1.80%) identified with another gender identity or preferred not to specify. Regarding school grade, 86 participants (14.05%) were in Grade 8, 111 (18.14%) were in Grade 9, 123 (20.10%) were in Grade 10, 139 (22.71%) were in Grade 11, and 153 (25.00%) were in Grade 12. In terms of family structure, 454 adolescents (74.18%) lived with two parents or guardians, 129 (21.08%) lived in a single-parent household, and 29 (4.74%) reported other household arrangements. With respect to perceived socioeconomic status, 96 participants (15.69%) described their family socioeconomic status as below average, 379 (61.93%) as average, and 137 (22.39%) as above average. The majority of participants reported at least one parent with postsecondary education, and most adolescents described their academic standing as average or above average. These characteristics indicated that the sample represented a broad range of adolescent educational, family, and socioeconomic backgrounds and therefore provided sufficient variability for examining multidimensional predictors of psychological well-being.

Table 1

Descriptive Statistics and Zero-Order Correlations Among Psychological Well-Being and Study Predictors

Variable	M	SD	1	2	3	4	5	6	7	8	9	10
1. Psychological well-being	49.86	8.74	—									
2. Family cohesion	28.43	5.62	.49**	—								
3. Family support	21.76	4.31	.52**	.58**	—							
4. Peer support	20.91	4.68	.41**	.34**	.46**	—						
5. Friendship quality	31.58	6.14	.44**	.29**	.39**	.62**	—					
6. School connectedness	24.37	5.19	.47**	.35**	.38**	.33**	.36**	—				
7. Academic engagement	27.94	5.71	.39**	.27**	.29**	.24**	.28**	.55**	—			
8. Self-esteem	28.62	5.36	.64**	.41**	.44**	.38**	.39**	.36**	.31**	—		
9. Resilience	27.88	6.02	.61**	.39**	.42**	.34**	.36**	.40**	.35**	.59**	—	
10. Emotion regulation difficulties	45.17	10.28	-.56**	-.36**	-.39**	-.31**	-.33**	-.32**	-.28**	-.53**	-.48**	—
11. Perceived stress	19.42	6.39	-.67**	-.40**	-.43**	-.35**	-.36**	-.38**	-.32**	-.58**	-.55**	.61**

As shown in Table 1, psychological well-being was significantly associated with all family, peer, school, and individual-level variables in the theoretically expected directions. The strongest positive zero-order association was observed between self-esteem and psychological well-being, $r = .64$, $p < .01$, followed by resilience, $r = .61$, $p < .01$. Family support also demonstrated a substantial positive

relationship with psychological well-being, $r = .52$, $p < .01$, while family cohesion was similarly associated with higher well-being, $r = .49$, $p < .01$. Among school-related factors, school connectedness showed a moderate positive association with psychological well-being, $r = .47$, $p < .01$, whereas academic engagement was associated with well-being at $r = .39$, $p < .01$. Peer support and friendship quality

were both positively related to well-being, with coefficients of $r = .41$ and $r = .44$, respectively. In contrast, perceived stress demonstrated the strongest negative association with psychological well-being, $r = -.67$, $p < .01$, indicating that adolescents reporting greater stress tended to experience substantially lower psychological well-being. Emotion regulation difficulties were also negatively related to psychological well-being, $r = -.56$, $p < .01$. Correlations among predictor variables were generally moderate and remained below levels that would indicate severe

redundancy. Notably, peer support was strongly related to friendship quality, $r = .62$, $p < .01$, and emotion regulation difficulties were positively associated with perceived stress, $r = .61$, $p < .01$. These findings supported the inclusion of all major psychosocial domains in the subsequent artificial neural network analysis because each domain displayed meaningful bivariate relationships with psychological well-being while retaining sufficient distinctiveness to contribute unique predictive information.

Table 2

Artificial Neural Network Model Performance Across Training, Validation, and Test Samples

Dataset	n	MSE	RMSE	MAE	R	R ²
Training	428	14.68	3.83	2.98	.91	.83
Validation	92	18.92	4.35	3.41	.87	.76
Test	92	19.74	4.44	3.52	.86	.74

The performance indices presented in Table 2 indicated that the artificial neural network achieved strong predictive accuracy across the training, validation, and independent test datasets. In the training sample, the model produced a mean squared error of 14.68, a root mean squared error of 3.83, and a mean absolute error of 2.98. The correlation between observed and predicted psychological well-being scores in the training sample was $R = .91$, corresponding to an R^2 value of .83. Thus, approximately 83% of the variability in psychological well-being within the training dataset was accounted for by the neural network. Importantly, model performance remained relatively stable in the validation and test samples, suggesting that the network did not merely memorize patterns within the training data. In the validation sample, RMSE was 4.35 and MAE was 3.41, with an

observed-predicted correlation of $R = .87$ and $R^2 = .76$. In the fully independent test sample, which was not used for network training or hyperparameter selection, RMSE was 4.44, MAE was 3.52, and the correlation between observed and predicted scores remained high at $R = .86$. The test-set R^2 of .74 indicated that the final model explained approximately 74% of out-of-sample variance in adolescents' psychological well-being. The relatively small difference between training and test performance further supported acceptable generalization. Although prediction error increased modestly from the training to the test sample, the magnitude of this change was limited, indicating that the early-stopping and regularization procedures used during model development were effective in controlling overfitting.

Table 3

Relative Importance of Predictors in the Final Artificial Neural Network Model

Rank	Predictor	Permutation Importance	Normalized Importance (%)
1	Perceived stress	0.182	100.00
2	Self-esteem	0.164	90.11
3	Resilience	0.146	80.22
4	Emotion regulation difficulties	0.128	70.33
5	Family support	0.109	59.89
6	School connectedness	0.097	53.30
7	Family cohesion	0.083	45.60
8	Friendship quality	0.071	39.01
9	Peer support	0.064	35.16
10	Academic engagement	0.052	28.57
11	Academic standing	0.037	20.33
12	Perceived socioeconomic status	0.024	13.19

13	Age	0.011	6.04
14	Gender	0.009	4.95

Table 3 presents the relative importance of predictors based on permutation feature importance in the final neural network. Perceived stress emerged as the most influential predictor of adolescent psychological well-being and was therefore assigned a normalized importance value of 100%. Self-esteem was the second most important predictor, with 90.11% normalized importance, followed by resilience at 80.22% and emotion regulation difficulties at 70.33%. These findings indicated that individual psychological functioning played a central role in the model's predictive performance. However, family and school characteristics also made substantial contributions. Family support showed 59.89% normalized importance, while school connectedness contributed 53.30%, demonstrating that psychological well-being was not determined solely by individual characteristics. Family cohesion ranked seventh with

45.60% normalized importance, followed by friendship quality and peer support with 39.01% and 35.16%, respectively. Academic engagement demonstrated a smaller but still meaningful contribution at 28.57%. Demographic characteristics were substantially less influential than psychosocial factors. Academic standing and perceived socioeconomic status had normalized importance values of 20.33% and 13.19%, respectively, while age and gender made only minor contributions. Overall, the pattern of feature importance suggested that the neural network relied primarily on perceived stress, self-esteem, resilience, emotion regulation, family support, and school connectedness when generating predictions. At the same time, the distribution of importance across multiple domains supported the study's multidimensional conceptualization of adolescent psychological well-being.

Table 4

Observed Psychological Well-Being Across Low, Moderate, and High Levels of the Most Important Predictors

Predictor	Level	n	Psychological Well-Being M	SD
Perceived stress	Low	204	57.18	6.24
	Moderate	204	49.72	6.71
	High	204	42.68	7.15
Self-esteem	Low	204	42.91	7.48
	Moderate	204	49.63	6.55
	High	204	57.05	6.34
Resilience	Low	204	43.62	7.36
	Moderate	204	49.88	6.68
	High	204	56.08	6.57
Emotion regulation difficulties	Low	204	56.21	6.43
	Moderate	204	49.91	6.80
	High	204	43.46	7.39
Family support	Low	204	44.83	7.54
	Moderate	204	49.97	6.97
	High	204	54.78	7.01
School connectedness	Low	204	45.37	7.72
	Moderate	204	49.84	6.86
	High	204	54.36	7.12

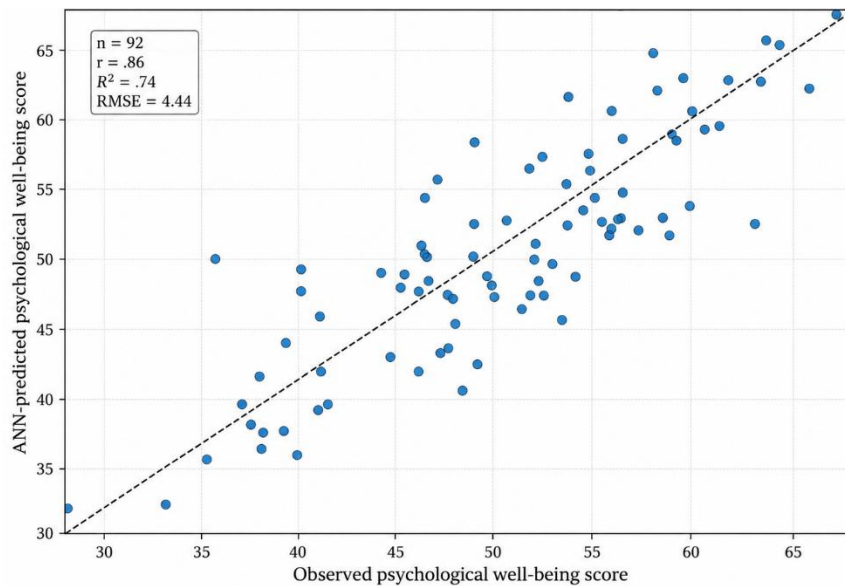
Figure 1*Observed and Artificial Neural Network-Predicted Psychological Well-Being Scores in the Independent Test Sample*

Figure 1 illustrates the correspondence between observed psychological well-being scores and values predicted by the final artificial neural network in the independent test sample. The predicted values closely followed the distribution of observed scores across low, moderate, and high levels of psychological well-being, with most observations located near the line of perfect prediction. This visual pattern was consistent with the test-set correlation of $R = .86$ and the R^2 value of .74 reported in Table 2. Prediction errors were relatively small throughout most of the outcome distribution, although slightly greater dispersion was observed at the lowest and highest ends of psychological well-being. This pattern suggested that the model was most precise for adolescents whose well-being scores fell within the central range and somewhat less precise for participants with extreme scores, which is common in predictive models when fewer observations are available at the tails of the distribution. Nevertheless, there was no substantial systematic pattern indicating persistent overestimation or underestimation across the score range. The close alignment between actual and predicted scores therefore provided additional evidence that the final neural network captured meaningful nonlinear relationships between family, peer, school, and individual characteristics and adolescent psychological well-being and generalized adequately to previously unseen cases.

Taken together, the findings demonstrated that adolescent psychological well-being could be predicted with substantial accuracy using a multidimensional artificial neural network

model. The independent test results indicated that approximately three-quarters of the variance in psychological well-being was predictable from the included family, peer, school, individual, and demographic characteristics. Individual psychological factors were particularly influential, with perceived stress, self-esteem, resilience, and emotion regulation difficulties forming the four strongest predictors. However, family support and school connectedness also showed considerable predictive importance, emphasizing the role of adolescents' broader social environments. Peer relationships and academic engagement contributed additional explanatory information, whereas demographic variables made relatively limited contributions. Overall, these findings supported a multilevel interpretation of adolescent psychological well-being in which internal psychological resources interact with the quality of family relationships, peer experiences, and school connectedness to shape well-being outcomes.

4. Discussion

The present study developed an artificial neural network model to predict psychological well-being among Canadian adolescents using family, peer, school, individual, and selected demographic factors. The findings showed that the model achieved strong predictive performance, with an R^2 of .83 in the training sample, .76 in the validation sample, and .74 in the independent test sample. The relatively small reduction in predictive accuracy from the training to the test phase suggested that the final network generalized

reasonably well to previously unseen cases and that overfitting was adequately controlled. The findings further demonstrated that individual psychological characteristics were the most influential predictors of psychological well-being. Perceived stress ranked first in normalized importance, followed by self-esteem, resilience, and emotion regulation difficulties. Family support and school connectedness also made substantial contributions, while family cohesion, friendship quality, peer support, and academic engagement contributed at moderate levels. In contrast, academic standing, perceived socioeconomic status, age, and gender were comparatively less important. Overall, these results support a multidimensional developmental view in which adolescent psychological well-being is shaped by the interaction of internal psychological resources and the quality of the social environments in which adolescents are embedded.

The strongest predictor in the final neural network was perceived stress. This finding is consistent with the broader understanding of adolescent mental health as highly responsive to cumulative psychological and environmental demands. Adolescence involves simultaneous challenges related to school performance, peer evaluation, family expectations, identity development, and increasing autonomy, and high perceived stress may undermine well-being when these demands exceed adolescents' perceived coping resources. The descriptive results reinforced this interpretation, as adolescents in the low-stress group had substantially higher psychological well-being scores than those in the high-stress group. This pattern is compatible with contemporary approaches that conceptualize adolescent mental health as resulting from the balance between exposure to stressors and access to psychological and contextual resources (Subramanyam et al., 2024). It is also consistent with evidence indicating that exposure to adverse interpersonal experiences, including bullying victimization, can be associated with poorer mental health outcomes among adolescents (Feng et al., 2024; Martínez et al., 2024). The high importance of perceived stress in the present model therefore suggests that adolescents' subjective interpretation of demands may be more informative for psychological well-being than demographic background alone.

Self-esteem emerged as the second most important predictor, and adolescents with higher self-esteem reported markedly higher psychological well-being. This result is theoretically plausible because positive self-evaluation can influence emotional stability, perceived competence, interpersonal confidence, and the ability to interpret

challenges in less threatening ways. Self-esteem may also serve as a psychological resource that buffers the negative effects of social rejection, academic difficulties, and peer conflict. Although several studies in the provided literature focus primarily on social support, attachment, and school functioning rather than self-esteem directly, their findings support the broader proposition that secure and supportive relationships facilitate positive psychological functioning. For example, perceived social support has been associated with adaptive interpersonal functioning among high school students (Yıldız & Eldeleklioğlu, 2024), while secure attachment and positive relational experiences have been linked to healthier family and peer outcomes (Çiçek et al., 2025). These relational experiences may contribute to the development and maintenance of positive self-regard, thereby indirectly supporting psychological well-being.

Resilience was the third most influential predictor and showed a strong positive relationship with psychological well-being. Adolescents with high resilience reported substantially higher levels of well-being than those with low resilience. This finding aligns closely with research emphasizing resilience as a dynamic capacity that enables young people to adapt to stress, maintain functioning under pressure, and recover from adverse experiences. Student-centered qualitative research has shown that resilience is understood not merely as an internal trait but as a capacity that is strengthened by interpersonal and environmental resources (Ganotz-Steinborn & Schwab, 2025). Similarly, research on school climate has demonstrated that resilience can function as an important mechanism linking supportive environments to positive adolescent behavior (Hornsby et al., 2023). The current findings extend this literature by showing that resilience is not only associated with positive outcomes but also possesses substantial predictive importance within a multivariable nonlinear model that simultaneously considers family, peer, school, and individual factors.

Emotion regulation difficulties were also among the strongest predictors and showed an inverse association with psychological well-being. Adolescents reporting greater difficulty understanding, accepting, and regulating their emotional states tended to experience lower well-being. This result is consistent with the developmental demands of adolescence, when emotional reactivity may increase while regulatory capacities are still maturing. Difficulties in emotional regulation can intensify responses to stress, peer conflict, academic setbacks, and family tension, thereby reducing positive functioning. The relevance of emotion

regulation can also be inferred from research showing that interpersonal and behavioral difficulties often unfold across multiple relational contexts. For example, longitudinal research on adolescent social health has shown that individual behavioral problems can contribute to interpersonal disruption over time (Otmar, 2026). The present findings therefore suggest that emotion regulation may operate as a central intrapersonal mechanism through which broader developmental stressors affect psychological well-being.

Family support ranked fifth in normalized importance and was the strongest contextual predictor after the individual psychological variables. Adolescents reporting greater family support also showed substantially higher psychological well-being. This finding is consistent with a large body of developmental evidence emphasizing the family as a foundational source of emotional security, validation, guidance, and instrumental support. Family functioning has been shown to predict adolescent behavioral and psychological outcomes (Chronopoulou et al., 2025), while secure attachment and positive childhood experiences have been linked to healthier family relationships and lower vulnerability to negative peer experiences (Çiçek et al., 2025). Family care has also been associated with greater perceived security among young people, particularly in conjunction with supportive school environments (Li et al., 2025). These findings support the current result by indicating that family support may contribute to well-being not only directly, but also by strengthening adolescents' sense of safety, self-worth, and capacity to manage stress.

Family cohesion also contributed meaningfully to the prediction model, although its importance was lower than that of perceived family support. This distinction is informative because structural or relational qualities of the family may not be identical to adolescents' subjective perceptions of being emotionally supported. A family may be organized and cohesive, yet adolescents may vary in the extent to which they feel understood, encouraged, and emotionally supported. The stronger importance of perceived family support may therefore indicate that subjective relational experience is particularly relevant to psychological well-being. Previous research supports the broader significance of family relationships in adolescent development. Personality, family relationship quality, and school climate have been shown to jointly predict positive dispositional characteristics in adolescence (Lampropoulou et al., 2023), while parental involvement may influence socioemotional development partly through increased

school engagement (Martinez-Yarza et al., 2024). The current findings are therefore consistent with an ecological perspective in which family processes contribute both directly and indirectly to psychological adaptation.

School connectedness emerged as another highly relevant contextual factor. Adolescents who felt more accepted, supported, respected, and connected within their school environment reported higher levels of psychological well-being, and school connectedness demonstrated greater predictive importance than peer support or academic engagement. This result strongly aligns with previous research identifying school connectedness as a major protective factor for psychological and behavioral outcomes (Peng & Patterson, 2025). School connectedness may provide adolescents with a sense of belonging, interpersonal security, institutional trust, and access to supportive adults, all of which may reduce the psychological burden of stress. Evidence also suggests that school connectedness can play a protective role in the context of adverse childhood experiences and bullying (Su et al., 2025). Furthermore, positive school climate has been associated with prosocial behavior through social support and resilience (Hornsby et al., 2023), indicating that supportive school environments may promote well-being through multiple pathways.

The importance of school context is further supported by emerging evidence that educational environments may influence broader developmental processes. Large-scale research has linked school climate to developmental outcomes extending beyond immediate academic functioning, including aspects of adolescent brain development (Thompson et al., 2026). School climate has also been associated with psychological functioning among Black adolescents, with parenting-related factors influencing these associations (Varner et al., 2025). These findings are consistent with the present study because they suggest that school experiences can become psychologically consequential through interactions with family processes and individual coping resources. The higher importance of school connectedness compared with academic standing also indicates that the relational and emotional quality of the school environment may matter more for well-being than objective or perceived academic success alone.

Peer-related factors made meaningful but comparatively smaller contributions to the final model. Friendship quality ranked above general peer support, suggesting that the quality of close peer relationships may be somewhat more important than the broader perception that peers are available for support. This distinction is developmentally

relevant because close friendships provide emotional intimacy, trust, self-disclosure, and validation that may not be captured by more general measures of peer support. Previous studies have shown that social support contributes to psychological need satisfaction and may reduce disengagement from school (Jia, 2025), while attachment and perceived social support are also related to positive interpersonal tendencies among high school students (Yıldız & Eldeleklioğlu, 2024). The present findings therefore support the view that peer relationships contribute to well-being, but they also indicate that their influence may be less substantial than adolescents' internal psychological resources and their experiences of family and school support.

The relatively moderate importance of peer factors may also reflect the dual nature of adolescent peer relationships. Peers can function as sources of support and belonging, but also as sources of victimization, exclusion, bullying, and social comparison. Research has consistently shown that bullying and peer victimization can negatively affect adolescent mental health (Feng et al., 2024; Harsono & Febriyana, 2026). Longitudinal work has also linked peer victimization and social support to mental health outcomes over time (Martínez et al., 2024). Cyberbullying trajectories are likewise associated with the quality of adolescents' social relationships (Park & Choi, 2025), and bullying and cyberbullying share several psychosocial determinants (Malinowska-Ciešlik et al., 2023). Relationships with parents may also shape adolescents' exposure or responses to bullying, including the influence of father attachment (Sezgin, 2026). Thus, the predictive contribution of peer variables in the current study likely reflects both the protective value of supportive friendships and the broader complexity of peer experiences.

Academic engagement contributed to psychological well-being but was less influential than school connectedness. This pattern suggests that feeling emotionally and socially integrated into the school environment may be more important for psychological well-being than participation in academic activities alone. School engagement nevertheless remains relevant because it may function as a pathway through which family and school support influence socioemotional development. Research has shown that family involvement can contribute to social-emotional development through school engagement (Martinez-Yarza et al., 2024). Differences in school culture can also influence students' adjustment across educational contexts (Wang et al., 2025), while broader educational frameworks emphasize

the importance of continuity and integration across educational systems (Kearney et al., 2024). These findings suggest that academic engagement should be interpreted as one component of a broader educational ecology rather than as an isolated predictor.

The comparatively low importance of demographic variables is also noteworthy. Age and gender were among the weakest predictors in the final model, while socioeconomic status and academic standing contributed only modestly. This result suggests that psychosocial experiences may be more informative for predicting adolescent well-being than demographic characteristics alone. Such a finding does not imply that demographic or structural variables are irrelevant, but rather that their effects may operate through more proximal psychosocial mechanisms such as family support, school climate, social stress, or resilience. Research involving adolescents from culturally and socially marginalized backgrounds has shown that perceived context of reception and access to sociocultural resources can affect mental health (Guan et al., 2023). Similarly, positive youth development among socially disadvantaged young people has been conceptualized in terms of multidimensional personal and environmental resources rather than demographic characteristics alone (Wang & Kubo, 2025). The present results therefore reinforce the value of assessing modifiable psychosocial conditions rather than relying primarily on static background variables.

The performance of the artificial neural network itself is an important contribution of the study. The model explained 74% of the variance in psychological well-being in the independent test sample, indicating that a multidimensional set of psychosocial predictors can produce substantial out-of-sample accuracy. The relatively similar performance across the training, validation, and test datasets suggests that the network captured generalizable patterns rather than only sample-specific associations. This finding is particularly meaningful because adolescent psychological well-being is likely to involve nonlinear and interactive processes. For example, resilience may be especially protective under conditions of high stress, while school connectedness may become more important when family support is limited. Conventional linear models may not fully capture such patterns unless interactions are explicitly specified in advance, whereas artificial neural networks can identify more complex functional relationships through model training.

5. Conclusion

The results also support a broader ecological interpretation of adolescent well-being. Risk and protective factors appear to operate across multiple interconnected domains rather than independently. Research on multiple risk and protective domains has similarly shown that adolescent outcomes are best understood through combinations of influences across family, peer, school, and individual contexts (Kristjánsson et al., 2025). School climate, parenting practices, and psychological functioning have also been shown to interact in predicting adolescent outcomes (Varner et al., 2025). Parent perceptions of school relationships may vary according to youths' peer victimization experiences (Fu et al., 2025), further demonstrating that family, school, and peer systems are mutually connected. Thus, the present findings support a model of adolescent well-being in which internal psychological strengths and contextual supports jointly contribute to positive functioning.

6. Limitations & Suggestions

Several limitations should be considered when interpreting the findings. First, the cross-sectional design prevents conclusions about temporal or causal relationships among the predictors and psychological well-being. Although the artificial neural network demonstrated strong predictive accuracy, prediction should not be interpreted as evidence that any particular factor directly causes changes in well-being. Second, most variables were assessed using adolescent self-report measures, which may introduce common-method variance, recall bias, and social desirability effects. Third, although the sample included 612 adolescents and was adequate for model development, participants were recruited from schools in Ontario, Canada, and the findings may not generalize fully to adolescents in other provinces, rural or remote regions, Indigenous communities, or different cultural and socioeconomic contexts. Fourth, the study focused on a selected set of family, peer, school, and individual variables and did not include other potentially relevant predictors such as sleep quality, physical activity, social media use, neighborhood safety, discrimination, chronic health conditions, or exposure to major life events. Finally, although feature-importance analysis improved interpretation of the neural network, artificial neural networks remain less transparent than conventional statistical models, and importance values should not be

interpreted as equivalent to causal effects or standardized regression coefficients.

Future studies should employ longitudinal designs to determine whether the identified predictors prospectively forecast changes in psychological well-being and to clarify reciprocal relationships among stress, resilience, self-esteem, family support, school connectedness, and peer experiences. Replication with larger and more geographically diverse Canadian samples would improve generalizability and permit subgroup analyses across provinces, school systems, socioeconomic groups, cultural backgrounds, and developmental stages. Future research could also compare artificial neural networks with alternative machine-learning algorithms such as random forests, gradient boosting, support vector regression, and ensemble models in order to identify the most accurate and interpretable predictive approach. The inclusion of objective and multi-informant data, including parent reports, teacher assessments, academic records, behavioral indicators, and digital or ecological momentary assessment data, could reduce reliance on self-report measures. Researchers should also examine interaction effects and nonlinear thresholds more explicitly using explainable artificial intelligence methods, such as SHAP values, accumulated local effects, and individual conditional expectation plots. Finally, future models should incorporate additional variables related to sleep, physical health, digital media use, neighborhood conditions, adverse life events, identity-related stress, and access to mental health services to determine whether predictive accuracy can be improved further.

The findings have several implications for schools, families, mental health practitioners, and youth-serving organizations. Prevention programs should prioritize modifiable psychosocial factors rather than relying primarily on demographic risk indicators. In particular, screening and intervention strategies should address perceived stress, self-esteem, resilience, and emotion regulation because these variables were the strongest predictors of psychological well-being. Schools may benefit from implementing universal programs that strengthen coping skills, emotional regulation, stress management, and resilience while simultaneously creating environments characterized by belonging, supportive teacher-student relationships, fairness, safety, and inclusion. Family-based initiatives should emphasize emotional availability, communication, supportive parenting, and adolescents' perceptions of being understood and supported. Peer-focused interventions should promote high-quality friendships, prosocial peer

norms, and effective responses to bullying and cyberbullying. Importantly, interventions should not treat these domains independently. Coordinated approaches that integrate individual skills training with family engagement, peer support, and school-climate improvement are likely to be more responsive to the multidimensional nature of adolescent well-being. Predictive models such as the one developed in this study may also support early identification of adolescents who show combinations of elevated stress and weak protective resources, provided that such tools are used ethically, transparently, and as supplements rather than substitutes for professional judgment.

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Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

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

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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Authors' Contributions

All authors equally contributed to this article.

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