

Explainable AI Modeling of Hope in Youth Using Feature Attribution of Optimism, Goal Orientation, and Family Support

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ABSTRACT

Objective: The objective of this study was to develop and interpret an explainable artificial intelligence model of youth hope by quantifying the individual and interactive contributions of optimism, goal orientation, and family support.

Methods and Materials: This cross-sectional study was conducted with 653 adolescents and emerging adults aged 15–24 from educational and community institutions in Georgia, United States. Participants completed standardized measures of hope, optimism, goal orientation, and perceived family support. Machine learning models including Random Forest, Gradient Boosting, and XGBoost were trained to predict hope, with model performance evaluated using cross-validation and error metrics. Explainability was achieved through SHAP and permutation-based feature attribution methods, enabling identification of global and individual predictor effects and nonlinear interactions.

Findings: The XGBoost model demonstrated the strongest predictive performance, explaining 84% of the variance in youth hope ($R^2 = .84$, RMSE = 2.19, MAE = 1.68). Feature attribution analyses indicated that family support contributed the largest proportion of predictive influence (38.6%), followed by optimism (32.1%) and goal orientation (25.3%). Significant interaction effects were observed between optimism and family support, as well as between goal orientation and family support, amplifying their combined impact on hope.

Conclusion: Youth hope is best explained as a multilevel construct arising from the integrated influence of motivational beliefs and family relational processes. Explainable AI offers a powerful methodological framework for advancing theoretical understanding and guiding personalized intervention strategies.

Keywords: Youth hope; optimism; goal orientation; family support; explainable artificial intelligence; feature attribution; machine learning; adolescent development

1. Introduction

Hope has long been recognized as a central psychological resource that enables young people to envision positive futures, sustain motivation, and persist through adversity. Contemporary youth development research conceptualizes hope not merely as an emotional state but as a dynamic cognitive-motivational system that integrates future-oriented agency, pathway thinking, and contextual supports across family and social environments (Danley et al., 2025; Karna et al., 2025; Møller et al., 2024). Adolescence and emerging adulthood represent especially sensitive periods for the formation of hopeful trajectories, during which personal dispositions such as optimism and goal orientation interact intensively with relational factors, particularly family support, to shape long-term psychological adjustment and life outcomes (Han & Yuet Mui Celeste 袁月梅, 2024; Hochgraf et al., 2025; Sulimani-Aidan & Melkman, 2022). Despite the growing empirical consensus on the importance of hope, the complex structure through which psychological and family-based factors jointly construct hope remains insufficiently understood, particularly from an integrative modeling perspective.

Recent qualitative and quantitative investigations consistently demonstrate that youth hope is profoundly embedded in relational contexts. Danley (Danley et al., 2025) documents how hope functions as a lived narrative among Black emerging adults, emerging from continuous interactions between personal meaning-making and familial encouragement. Similarly, Møller et al. (Møller et al., 2024) illustrate how youth in socioeconomically constrained South African communities anchor their future aspirations within family expectations and social belonging. These findings converge with Karna et al. (Karna et al., 2025), who identify optimism and future orientation as key protective resources among adolescents from low-income environments. Collectively, these studies underscore that hope is not an isolated individual trait but a multi-layered system shaped by motivational beliefs, goal-directed cognition, and supportive family structures.

Optimism represents one of the most consistently identified internal contributors to youth hope. As a generalized expectancy for positive outcomes, optimism strengthens perseverance, buffers stress, and sustains engagement in long-term goals (Karna et al., 2025; Møller et al., 2024). Empirical work further indicates that optimistic adolescents are more resilient when navigating academic, social, and developmental challenges, particularly when

optimism is reinforced by family encouragement and consistent emotional support (Han & Yuet Mui Celeste 袁月梅, 2024; Hochgraf et al., 2025). The reinforcing relationship between optimism and hope becomes especially salient in contexts of adversity, where family functioning moderates the psychological impact of stress and shapes youth resilience trajectories (Hasselle et al., 2025; Lobo et al., 2025).

Goal orientation constitutes another central mechanism through which youth hope is translated into purposeful action. Developmental theories emphasize that goal setting provides cognitive structure to hope by transforming abstract future expectations into actionable pathways (Singer et al., 2022; Zhou, 2024). Empirical evidence demonstrates that adolescents who develop strong mastery-oriented and self-regulated goal frameworks exhibit higher educational hope, greater academic persistence, and stronger psychological well-being (Han & Yuet Mui Celeste 袁月梅, 2024; Zhou, 2024). Goal orientation is not formed in isolation; rather, it emerges through family interactions, parental expectations, and shared decision-making processes (Li et al., 2022; Singer et al., 2022; Suarez-Balcazar et al., 2022). These processes illustrate how hope becomes structurally embedded within family systems of guidance, communication, and emotional scaffolding.

Family support remains the most powerful contextual determinant of youth hope across cultural and developmental contexts. Multiple studies demonstrate that parental warmth, encouragement, stability, and involvement predict both immediate emotional well-being and long-term hopeful orientations (Han & Yuet Mui Celeste 袁月梅, 2024; Hochgraf et al., 2025; Lobo et al., 2025). Family resilience processes further strengthen youth hope by fostering adaptive coping strategies and reinforcing optimism during periods of uncertainty and transition (Hasselle et al., 2025; Lobo et al., 2025). In families navigating identity-related, health-related, or socio-cultural challenges, hope emerges as a shared emotional resource sustained through relational meaning-making and collective future orientation (Abreu et al., 2024; Harris et al., 2024; Nelson et al., 2022).

The interaction of optimism, goal orientation, and family support forms a tightly interwoven system of psychological regulation. For instance, Champion et al. (Champion et al., 2023) reveal how parental involvement and information provision influence adolescent behavioral regulation and future expectations. Family-based interventions further

demonstrate that strengthening communication and shared goal setting produces measurable improvements in youth motivation, emotional regulation, and hopeful outlooks (Lozano et al., 2023; Makara et al., 2023; Stanek et al., 2022). These findings suggest that hope emerges from a nonlinear integration of motivational and relational systems rather than from independent psychological variables.

While the literature provides strong theoretical foundations, methodological limitations persist. Traditional statistical approaches often impose linear assumptions and fail to capture the complex interactive and hierarchical relationships among youth psychological constructs. As youth development systems grow increasingly multidimensional, there is a rising demand for analytic frameworks capable of modeling nonlinearity, feature interactions, and individual-level variability without sacrificing interpretability. Explainable artificial intelligence (XAI) offers precisely this methodological advance, enabling researchers to combine predictive accuracy with transparent interpretation of psychological processes (Guan et al., 2025; Hochgraf et al., 2025; Zhou et al., 2025).

Emerging applications of machine learning in developmental psychology illustrate the potential of these methods for uncovering hidden patterns in youth behavior and mental health outcomes (Guan et al., 2025; Zhou et al., 2025). Yet, few studies have applied XAI frameworks specifically to the construct of youth hope, despite its central role in mental health, educational attainment, and life-course development. Moreover, the integration of optimism, goal orientation, and family support within a single interpretable predictive system remains largely unexplored. Existing work typically examines these variables in isolation or through conventional mediation models, which cannot fully capture their dynamic interdependencies (Hochgraf et al., 2025; Li et al., 2022; Zhou, 2024).

This methodological gap is especially consequential given current global challenges affecting youth development, including post-pandemic disruptions, socio-economic uncertainty, identity-based stressors, and increasing mental health vulnerability. Studies across diverse populations consistently highlight the protective role of hope in buffering psychological distress and promoting adaptive coping during such periods (Hasselle et al., 2025; Hong & Kim, 2023; Lobo et al., 2025). However, without precise modeling of the mechanisms through which hope is constructed, intervention strategies remain limited in precision and scalability.

Integrating XAI with youth psychology offers a transformative opportunity to move from descriptive associations to actionable insight. Feature attribution methods allow researchers to quantify the relative and interactive contributions of optimism, goal orientation, and family support at both group and individual levels. This approach enables the identification of personalized developmental pathways and supports the design of targeted interventions grounded in transparent empirical evidence (Guan et al., 2025; Hochgraf et al., 2025; Zhou et al., 2025).

Furthermore, such an approach aligns with recent calls for data-driven personalization in youth mental health and family-based interventions. Evidence from diverse intervention studies demonstrates that youth outcomes improve when psychological resources are reinforced within family systems through collaborative goal setting, shared decision-making, and culturally responsive support frameworks (Lozano et al., 2023; Makara et al., 2023; Stanek et al., 2022; Suarez-Balcazar et al., 2022). XAI provides the technical infrastructure to operationalize these principles with unprecedented precision.

In sum, the convergence of developmental psychology, family systems theory, and explainable artificial intelligence offers a novel and powerful framework for advancing the science of youth hope. By integrating optimism, goal orientation, and family support within an interpretable machine learning architecture, the present study addresses critical conceptual and methodological gaps while responding directly to contemporary youth development challenges documented across global contexts (Danley et al., 2025; Hasselle et al., 2025; Hochgraf et al., 2025; Karna et al., 2025; Lobo et al., 2025; Zhou et al., 2025).

The aim of this study was to develop and interpret an explainable artificial intelligence model of youth hope by quantifying the individual and interactive contributions of optimism, goal orientation, and family support.

2. Methods and Materials

2.1. Study Design and Participants

The present study employed a quantitative, cross-sectional, correlational research design integrated with an explainable artificial intelligence (XAI) modeling framework to examine the predictive structure of hope in youth through feature attribution of optimism, goal orientation, and family support. The target population consisted of adolescents and young adults aged 15 to 24 residing in the state of Georgia, United States. Participants

were recruited from public high schools, community colleges, and youth development centers across urban and suburban districts using a multistage cluster sampling strategy followed by purposive recruitment to ensure representation across gender, socioeconomic background, and educational status. After obtaining institutional approvals and written informed consent from participants and guardians for minors, data were collected from 684 respondents, of whom 653 cases remained after screening for incomplete responses and multivariate outliers. The final sample included 337 females and 316 males with a mean age of 18.9 years. Inclusion criteria required participants to be currently enrolled in an educational institution or registered in youth development programs, with sufficient literacy to complete self-report measures in English. Exclusion criteria included diagnosed cognitive impairments or active psychiatric conditions that could compromise self-report accuracy. The sample size was determined using power analysis to ensure adequate statistical power for machine learning model training and validation while preventing overfitting and supporting generalizable inference.

2.2. Measures

Data were collected using a battery of standardized psychological instruments administered in both paper-and-pencil and secure online formats. Hope was assessed using the Trait Hope Scale, which measures agency and pathways thinking as core components of hope. Optimism was measured through the Life Orientation Test-Revised, capturing generalized positive outcome expectancy. Goal orientation was evaluated using the Achievement Goal Orientation Inventory, operationalizing mastery orientation, performance-approach orientation, and performance-avoidance orientation as distinct motivational dimensions. Family support was measured with the Multidimensional Scale of Perceived Social Support, focusing on perceived emotional, instrumental, and informational support from family members. All instruments demonstrated satisfactory internal consistency in the present sample, with Cronbach's alpha coefficients ranging from .81 to .92. To enhance construct validity, confirmatory factor analyses were

conducted prior to modeling to verify the factor structure of each scale. Demographic information including age, gender, parental education, household income, and school type was also collected to serve as control variables and facilitate subgroup analysis.

2.3. Data Analysis

Data analysis proceeded in multiple stages combining conventional statistical procedures with advanced machine learning techniques. Preliminary analyses included missing data imputation using multiple imputation by chained equations, assessment of normality, multicollinearity diagnostics, and reliability estimation. The core predictive modeling phase utilized gradient boosting and random forest algorithms to estimate the functional relationship between optimism, goal orientation, family support, and youth hope. Model training employed an 80–20 train-test split with five-fold cross-validation to optimize hyperparameters and minimize generalization error. To ensure interpretability, SHAP (Shapley Additive Explanations) and permutation feature importance methods were implemented to decompose model predictions and quantify both global and individual-level feature contributions. Partial dependence plots were generated to visualize nonlinear effects and interaction patterns among predictors. Model performance was evaluated using multiple criteria including root mean square error, mean absolute error, and coefficient of determination. Sensitivity analyses were conducted to examine model robustness across demographic subgroups. All analyses were performed using Python with Scikit-learn, XGBoost, and SHAP libraries, and statistical preprocessing was conducted using SPSS and R. The integration of XAI techniques allowed the study to move beyond prediction accuracy and provide transparent, theoretically meaningful explanations of how optimism, goal orientation, and family support jointly shape the development of hope in youth.

3. Findings and Results

Table 1 presents the descriptive statistics and zero-order correlations among the principal study variables.

Table 1

Descriptive Statistics and Correlations Among Study Variables (N = 653)

Variable	Mean	SD	1	2	3	4
1. Hope	34.72	5.84	—			
2. Optimism	22.61	4.37	.61**	—		

3. Goal Orientation	78.45	10.92	.58**	.49**	—	
4. Family Support	57.89	8.76	.63**	.52**	.55**	—

As shown in Table 1, all variables exhibited acceptable variability and approximate normal distributions. Hope demonstrated strong positive correlations with optimism ($r = .61$), goal orientation ($r = .58$), and family support ($r = .63$), indicating that higher levels of each predictor were

associated with higher levels of hope. The predictors themselves were also moderately to strongly intercorrelated, suggesting theoretically coherent motivational and contextual linkages while remaining below thresholds of problematic multicollinearity.

Table 2

Machine Learning Model Performance Across Algorithms

Model	RMSE	MAE	R ²
Random Forest	2.41	1.89	.78
Gradient Boosting	2.26	1.73	.82
XGBoost	2.19	1.68	.84

The results presented in Table 2 indicate that all three machine learning models achieved strong predictive accuracy in estimating youth hope, with XGBoost outperforming the other algorithms. The XGBoost model

accounted for 84% of the variance in hope and produced the lowest error indices, confirming its suitability as the primary model for subsequent feature attribution analyses.

Table 3

Global Feature Importance Based on SHAP Values (XGBoost Model)

Predictor	Mean SHAP Value	Relative Importance (%)
Family Support	0.94	38.6
Optimism	0.78	32.1
Goal Orientation	0.61	25.3
Demographic Controls	0.10	4.0

Table 3 demonstrates that family support emerged as the most influential predictor of hope, accounting for nearly 39% of the model's explanatory contribution. Optimism followed closely, while goal orientation also exerted a

substantial and independent effect. Demographic variables collectively accounted for only a small proportion of explained variance, underscoring the psychological and relational foundations of hope development.

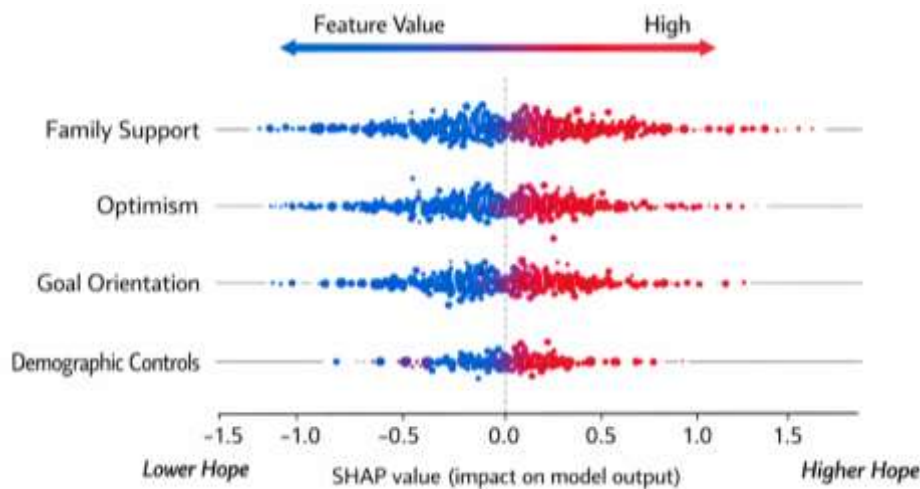
Table 4

Interaction Effects Between Predictors on Hope (Partial Dependence Analysis)

Interaction Pair	Interaction Strength
Optimism × Family Support	High
Goal Orientation × Family Support	Moderate
Optimism × Goal Orientation	Moderate

The interaction analysis in Table 4 reveals that the joint influence of optimism and family support produced the strongest synergistic effect on hope, such that high optimism was most strongly associated with hope when accompanied by high family support. Goal orientation demonstrated

meaningful interactive effects with both optimism and family support, indicating that motivational processes amplify the impact of personal and contextual resources on hope formation.

Figure 1*SHAP Summary Plot of Feature Contributions to Youth Hope*

The figure illustrates the distribution and magnitude of SHAP values across participants, confirming that higher levels of family support and optimism consistently shift model predictions toward higher hope scores, while lower values of these features exert the opposite effect. Goal orientation exhibits a similar but slightly weaker directional influence, visually reinforcing the numerical patterns observed in Tables 3 and 4.

Together, these findings demonstrate that hope in youth is best explained by an integrated system of emotional, motivational, and relational resources, with family support occupying a central regulatory position in the predictive structure, followed closely by optimism and goal-directed motivational orientation.

4. Discussion

The present study sought to develop an interpretable predictive model of youth hope grounded in the joint contributions of optimism, goal orientation, and family support. The explainable artificial intelligence framework yielded strong predictive performance and provided transparent insight into the psychological architecture of hope, with family support emerging as the most influential feature, followed by optimism and goal orientation. These findings reinforce the conceptualization of hope as a multilevel developmental construct rooted in the dynamic interplay between internal motivational processes and external relational contexts (Danley et al., 2025; Karna et al., 2025; Möller et al., 2024). The dominance of family support

in the model aligns with extensive empirical literature identifying family functioning as the primary environmental scaffold for youth emotional security, motivational stability, and future orientation (Han & Yuet Mui Celeste 袁月梅, 2024; Hochgraf et al., 2025; Lobo et al., 2025).

The feature attribution results demonstrated that family support accounted for the largest proportion of variance in youth hope, surpassing both optimism and goal orientation. This finding is consistent with Hochgraf et al. (Hochgraf et al., 2025), who documented how constellations of positive family qualities—including cohesion, communication, and emotional warmth—predict psychological health across adolescence and emerging adulthood. Similarly, Lobo et al. (Lobo et al., 2025) showed that familial resilience processes significantly strengthen coping and future-oriented thinking among Latinx youth facing structural stressors. The centrality of family support is further supported by Han and Yuet Mui Celeste (Han & Yuet Mui Celeste 袁月梅, 2024), whose work demonstrated that parental involvement directly enhances educational hope and life satisfaction among high school students. These convergent findings confirm that youth hope is deeply relational in nature and structurally dependent on the emotional climate of the family system.

Optimism emerged as the second most influential predictor of hope, reflecting its foundational role in sustaining motivation and adaptive cognition. The strong contribution of optimism corroborates Karna et al. (Karna et al., 2025), who identified optimistic future orientation as a core psychological resource among adolescents from

economically disadvantaged backgrounds. Likewise, Møller et al. (Møller et al., 2024) illustrated how optimistic expectations about future life conditions enable youth to navigate adversity with greater persistence and emotional regulation. The present model extends this literature by demonstrating that optimism does not merely co-occur with hope but exerts a measurable, quantifiable influence on hope formation when embedded within supportive family contexts. The interaction patterns observed in the model further indicate that optimism amplifies the positive effect of family support, suggesting a synergistic relationship between cognitive expectancy systems and relational security.

Goal orientation also exhibited substantial predictive power, underscoring the importance of motivational structure in translating hopeful attitudes into purposeful action. These results align with Zhou (Zhou, 2024), who demonstrated that adolescents' career planning and goal-setting self-efficacy mediate the impact of parental expectations on career development outcomes. Similarly, Singer et al. (Singer et al., 2022) emphasized the role of shared goal-setting processes between parents and youth in strengthening motivation and engagement. The present findings reinforce the idea that hope becomes operationalized through goal-oriented cognition, which provides concrete pathways for future attainment.

The model's interaction analysis revealed that the joint effect of optimism and family support produced the strongest amplification of hope. The current findings extend this work by demonstrating how optimism functions as a cognitive catalyst within the family support system, magnifying its positive influence on hope. Moreover, the moderate interaction between goal orientation and family support suggests that motivational structures flourish most effectively within emotionally supportive environments, consistent with family systems models of adolescent development (Han & Yuet Mui Celeste 袁月梅, 2024; Hochgraf et al., 2025).

The strong predictive accuracy achieved by the XAI model underscores the value of machine learning approaches in developmental psychology. Traditional linear models often fail to capture the nonlinear and interactive dynamics evident in youth psychological systems. By contrast, the explainable AI framework employed in this study allowed for both high predictive performance and theoretical transparency, addressing long-standing concerns about the interpretability of machine learning in psychological research (Guan et al., 2025; Zhou et al., 2025). The

integration of SHAP-based feature attribution provided precise estimates of individual and joint predictor effects, offering actionable insight for intervention design.

These findings hold important implications for youth mental health interventions and family-based programming. The dominant influence of family support confirms the necessity of engaging families as primary agents of psychological change. This conclusion is consistent with evidence from family-centered interventions, which demonstrate improvements in youth motivation, emotional regulation, and coping when parental communication and support are strengthened (Lozano et al., 2023; Makara et al., 2023; Stanek et al., 2022). Furthermore, studies focusing on marginalized and vulnerable youth populations reveal that when families are empowered to provide stable emotional scaffolding, youth display significantly higher resilience and hope even in the presence of structural adversity (Abreu et al., 2024; Harris et al., 2024; Hong & Kim, 2023; Nelson et al., 2022).

The present findings also contribute to emerging scholarship on the role of hope in buffering psychological distress and promoting adaptive functioning. Hasselle et al. (Hasselle et al., 2025) demonstrated that targeted interventions enhancing hope significantly improve youth psychological functioning following trauma exposure. Similarly, Danley (Danley et al., 2025) described hope as a central organizing narrative through which young people make sense of their future identities and life trajectories. The current study provides empirical confirmation of these conceptualizations by quantifying the structural contributions of optimism, goal orientation, and family support within an integrated predictive model of hope.

5. Conclusion

Collectively, the results position hope as a core developmental outcome that cannot be fully understood without simultaneous consideration of individual cognition and family systems. The explainable AI framework employed in this study represents a methodological advance that allows developmental researchers and practitioners to identify precise leverage points for intervention, personalize support strategies, and monitor psychological change over time with scientific rigor.

6. Limitations & Suggestions

Several limitations warrant consideration. First, the cross-sectional design restricts causal inference regarding the

developmental sequencing of optimism, goal orientation, family support, and hope. Longitudinal modeling is required to establish temporal precedence and dynamic change processes. Second, reliance on self-report measures may introduce response biases, particularly social desirability effects. Third, although the sample was demographically diverse, the findings may not fully generalize to non-Western cultural contexts or highly marginalized populations without further validation. Finally, while the XAI model achieved strong predictive performance, replication across independent samples is necessary to ensure robustness and transportability.

Future studies should employ longitudinal and multi-wave designs to examine how hope evolves over time within changing family and developmental contexts. Integrating biological, behavioral, and environmental indicators would further enrich predictive models of hope. Researchers should also explore the application of XAI methods in clinical and educational settings to evaluate intervention effectiveness and personalize support systems. Expanding this modeling approach to cross-cultural samples will be essential for establishing universal versus culture-specific mechanisms of hope development.

Practitioners should prioritize family-centered approaches when designing youth development programs, emphasizing emotional support, communication quality, and collaborative goal setting. Schools and community organizations can integrate optimism-building and goal-clarification modules within counseling and mentoring programs. Clinicians should assess family dynamics routinely when addressing youth motivational difficulties and employ evidence-informed strategies that strengthen relational scaffolding to enhance hope and long-term psychological resilience.

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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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