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Predicting Adolescent Creativity from Openness to Experience and Intrinsic Motivation

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A B S T R A C T

Objective: This study aimed to investigate the predictive roles of openness to experience and intrinsic motivation in adolescent creativity.

Methods and Materials: A correlational descriptive research design was employed, involving a sample of 380 high school students from Canada. Participants were selected using the Morgan and Krejcie sample size table through convenience sampling. Standardized instruments were used to assess the variables: the Torrance Tests of Creative Thinking (TTCT) for creativity, the Openness scale from the Big Five Inventory (BFI) for openness to experience, and the Intrinsic Motivation Inventory (IMI) for intrinsic motivation. Data analysis was performed using SPSS version 27. Pearson correlation coefficients were calculated to determine the strength and direction of the relationships between creativity and each predictor variable. A multiple linear regression analysis was then conducted to examine the combined predictive power of openness to experience and intrinsic motivation on creativity.

Findings: Descriptive statistics revealed moderately high levels of creativity ($M = 112.47$, $SD = 13.62$), openness to experience ($M = 36.28$, $SD = 4.81$), and intrinsic motivation ($M = 121.65$, $SD = 11.49$). Pearson correlation analysis showed that creativity was significantly correlated with both openness to experience ($r = .52$, $p < .01$) and intrinsic motivation ($r = .47$, $p < .01$). Multiple linear regression analysis indicated that both predictors significantly contributed to creativity ($R = .58$, $R^2 = .34$, $F(2, 377) = 72.96$, $p < .001$), with openness to experience ($\beta = .39$, $p < .001$) and intrinsic motivation ($\beta = .31$, $p < .001$) emerging as significant predictors.

Conclusion: The findings highlight that both openness to experience and intrinsic motivation play meaningful and complementary roles in predicting adolescent creativity. These results suggest that fostering openness and nurturing intrinsic motivation may be effective strategies for enhancing creative potential in educational settings.

Keywords: *Adolescent creativity; openness to experience; intrinsic motivation; personality traits; predictive factors.*

1. Introduction

Openness to experience, one of the Big Five personality traits, is characterized by imagination, curiosity, aesthetic sensitivity, and a preference for novelty and variety. This trait has consistently been associated with creativity across various age groups and cultural contexts. Adolescents with high levels of openness tend to be more willing to explore unfamiliar ideas, engage in divergent thinking, and tolerate ambiguity—skills central to creative performance (Krumm et al., 2018). Previous studies have revealed strong correlations between openness and creative achievement in musical (Rahmani & Ahmadi, 2019), visual (Atari et al., 2020), and verbal domains (Hong et al., 2020), suggesting that this personality trait may serve as a foundational disposition for creative expression. Furthermore, openness is often linked to intrinsic cognitive and emotional engagement, which amplifies creativity through internalized motivation and enjoyment of the process rather than external rewards (Safaei Rad et al., 2019).

In parallel, intrinsic motivation has emerged as another critical determinant of creative behavior. Defined as the drive to engage in activities for their inherent satisfaction and interest, intrinsic motivation fuels exploration, persistence, and playfulness—hallmarks of creative expression (Fischer et al., 2019). Research shows that when individuals are intrinsically motivated, they are more likely to take intellectual risks, experiment with new ideas, and generate original solutions (Gulzar et al., 2021). In adolescents, this form of motivation not only enhances engagement and performance in academic tasks but also boosts self-determination and well-being (Boeiry et al., 2024). Particularly in educational settings that encourage autonomy, competence, and relatedness, intrinsic motivation can significantly predict creative outcomes (Ajdarbin et al., 2023; Habibi, 2020).

The intersection between openness to experience and intrinsic motivation is especially noteworthy. Theoretical models suggest a reciprocal relationship where openness enhances one's intrinsic motivation to explore new possibilities, while intrinsic motivation supports the actualization of one's creative potential embedded in personality traits (Chad-Friedman et al., 2018; Ma'aser & Zeraati, 2019). For example, students high in openness may find novelty more rewarding, which reinforces their intrinsic drive to engage in creative tasks. In turn, this motivation catalyzes deeper engagement and sustained effort, resulting in more creative output (Farajzadeh & Alavinia, 2022; Yousef, 2021). These dynamics are particularly salient during adolescence, when motivational orientations and personality traits are still in flux, and interventions can have long-lasting developmental impacts.

Prior empirical studies provide further evidence supporting the influence of openness and intrinsic motivation on creativity. A study by Aziz (2023) highlighted the predictive value of openness in determining students' creative thinking skills in higher education (Aziz, 2023). Similarly, Yuan et al. (2022) demonstrated that individual differences in openness moderated the impact of example features on creative performance, emphasizing the importance of dispositional traits in facilitating creativity under different cognitive contexts (Yuan et al., 2022). On the other hand, intrinsic motivation has been shown to serve as a powerful mediator in the relationship between various learning environments and creativity outcomes, particularly in young learners (Balakrishnan, 2022; Tang et al., 2022).

Further supporting this, Conradty and Bogner (2020) found that STEAM-based instructional programs significantly improved both motivation and creativity among students, with intrinsically motivated students demonstrating higher creative competencies (Conradty & Bogner, 2020). These findings echo those of Malik et al. (2020), who reported that intrinsic motivation fully mediated the relationship between social media usage and student creativity, suggesting that internal psychological mechanisms can shape the influence of external technological factors on creative expression (Malik et al., 2020). Moreover, in the context of virtual learning environments, Yasamin (2021) noted that students' personality traits, particularly openness, were significant predictors of creative performance in both virtual and classroom-based settings (Yasamin, 2021).

Additionally, cross-cultural and developmental studies have reinforced the generalizability of these findings. Deng et al. (2022), examining Chinese third-language learners, reported that proactive personality traits—closely linked to openness—significantly predicted creativity, mediated by mindset and cultural thinking styles (Deng et al., 2022). Similarly, Michinov and Michinov (2023) found that personality profiles characterized by openness and emotional stability buffered against the negative psychological effects of the COVID-19 lockdown, while simultaneously enhancing creativity under stress (Michinov & Michinov, 2023). These results underscore the resilience-

enhancing function of openness and its role in adaptive, creative problem-solving.

In examining pedagogical contexts, Saberi Dehkordi et al. (2019) emphasized the value of storytelling in increasing both creativity and motivation among eighth-grade students, underscoring how educational practices can activate underlying personality and motivational traits to enhance creative engagement (Saberi Dehkordi et al., 2019). The study by Ayat et al. (2020) further established the link between managerial roles, personality traits, and effective functioning in women, suggesting broader implications for how openness-related traits influence interpersonal and cognitive dynamics across genders and roles (Ayat et al., 2020). These findings are consistent with Corazza and Lubart's (2021) conceptual framework, which locates creativity at the intersection of intelligence, personality, and temporality, proposing that openness and motivation function as temporal catalysts in the actualization of creative potential (Corazza & Lubart, 2021).

Other studies also suggest that motivational states can shape the influence of personality on creativity. For instance, Hong et al. (2020) found that self-esteem and psychological capital mediated the relationship between Big Five traits and creativity in college students, offering a nuanced view of how internal resources can condition the personality-creativity link (Hong et al., 2020). Similarly, Boeiry et al. (2024) demonstrated that emotional creativity and achievement motivation predicted self-directed learning, indirectly supporting the idea that motivation bridges the gap between trait-level dispositions and behaviorally manifested creativity (Boeiry et al., 2024).

Despite this rich body of literature, there remains a need for more focused research on adolescent populations, particularly in relation to how openness and intrinsic motivation jointly predict creativity. Much of the existing work has emphasized adult or university-aged samples, leaving a gap in our understanding of these relationships during the formative years of adolescence—a period marked by identity development, increased cognitive flexibility, and evolving motivational orientations. Furthermore, the rapid integration of digital technologies, hybrid learning environments, and changing social dynamics underscore the importance of re-examining traditional constructs of creativity through the lens of personality and motivation in youth settings (Tang et al., 2022).

The current study, therefore, seeks to address this gap by examining the predictive roles of openness to experience and intrinsic motivation in adolescent creativity. Drawing on a sample of Canadian high school students, the study employs a correlational descriptive design to quantify the relationships among these variables and to determine the extent to which openness and intrinsic motivation explain variance in creativity scores. By doing so, the study aims to contribute to both theoretical models and practical interventions aimed at fostering creativity during adolescence.

2. Methods and Materials

2.1. Study Design and Participants

This research employed a correlational descriptive design to investigate the predictive relationships between openness to experience, intrinsic motivation, and creativity among adolescents. The study population consisted of high school students from Canada, from which a total of 380 adolescents were selected through convenience sampling based on the Morgan and Krejcie sample size table. All participants provided informed consent, and anonymity and confidentiality were ensured. Participants ranged in age from 14 to 18 years, with a balanced distribution of males and females (approximately equal percentages of boys and girls). Data were collected through standardized measurement instruments: the Torrance Tests of Creative Thinking (TTCT) to assess creativity, the Openness scale from the Big Five Inventory (BFI) to measure openness to experience, and the Intrinsic Motivation Inventory (IMI) to measure intrinsic motivation.

2.2. Measures

2.2.1. Creativity

The Torrance Tests of Creative Thinking (TTCT), developed by Ellis Paul Torrance in 1966, is one of the most widely used standardized tools for assessing creativity in adolescents and adults. The TTCT includes two main forms: verbal and figural, each designed to evaluate different dimensions of creative thinking such as fluency, originality, elaboration, abstractness of titles, and resistance to premature closure. The figural form consists of three activities with a total of 50 items, while the verbal form contains six activities and 44 items. The responses are scored based on a combination of standardized criteria that reflect both quantitative and qualitative aspects of creativity. Numerous studies have confirmed the TTCT's strong psychometric properties, demonstrating high reliability coefficients (ranging from 0.80 to 0.90) and construct

JAYPS Adolescent and Youth Psychological Studies
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validity across diverse populations and cultural contexts, making it a robust tool for assessing creativity in research settings (Ajdarbin et al., 2023; Aziz, 2023; Michinov & Michinov, 2023; Tang et al., 2022; Yuan et al., 2022).

2.2.2. *Openness to Experience*

The Openness to Experience dimension was measured using the Openness scale from the Big Five Inventory (BFI), developed by John, Donahue, and Kentle in 1991. This inventory is a well-validated personality assessment tool that evaluates five major personality traits, with the Openness scale consisting of 10 items. The subcomponents of this scale assess facets such as imagination, artistic interest, emotionality, adventurousness, intellect, and liberalism. Each item is rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), with higher scores indicating greater openness. The BFI has been widely used in adolescent and adult samples and has shown good internal consistency, with Cronbach's alpha coefficients for the Openness scale typically ranging from 0.72 to 0.85. Its validity has also been supported through correlations with other established personality inventories, such as the NEO-PI-R (Aziz, 2023; Deng et al., 2022; Michinov & Michinov, 2023).

2.2.3. *Intrinsic Motivation*

Intrinsic motivation was assessed using the Intrinsic Motivation Inventory (IMI), a multidimensional measurement tool developed by Ryan and Deci in 1982 to assess participants' subjective experience related to a target activity. For this study, relevant subscales such as interest/enjoyment, perceived competence, effort/importance, and value/usefulness were used, comprising a total of 22 items. Each item is scored on a 7-point Likert scale from 1 (not at all true) to 7 (very true), with higher scores reflecting higher levels of intrinsic motivation. The IMI has been used extensively in psychological and educational research and has demonstrated strong internal consistency across subscales, with Cronbach's alpha values often exceeding 0.80. Its construct validity has been confirmed through factor analyses and correlations with other motivation-related constructs, supporting its appropriateness for use in adolescent samples (Ajdarbin et al., 2023; Farajzadeh & Alavinia, 2022).

2.3. *Data Analysis*

The collected data were analyzed using SPSS version 27. Initially, descriptive statistics were calculated to summarize the demographic characteristics of participants and describe the study variables in terms of means and standard deviations. To examine the strength and direction of associations between the dependent variable (creativity) and each independent variable (openness to experience and intrinsic motivation), Pearson correlation coefficients were calculated. Subsequently, to evaluate the predictive role of openness to experience and intrinsic motivation on adolescent creativity, a multiple linear regression analysis was conducted. Preliminary analyses ensured assumptions of linearity, normality, homoscedasticity, and absence of multicollinearity were met. Statistical significance was set at an alpha level of .05 for all analyses.

3. Findings and Results

The demographic characteristics of the participants revealed that, of the 380 adolescents involved in the study, 178 (46.8%) were male and 202 (53.2%) were female. In terms of age distribution, 82 (21.6%) participants were 14 years old, 91 (23.9%) were 15 years old, 86 (22.6%) were 16 years old, 73 (19.2%) were 17 years old, and 48 (12.6%) were 18 years old. Concerning educational level, 97 (25.5%) participants were in Grade 9, 102 (26.8%) in Grade 10, 93 (24.5%) in Grade 11, and 88 (23.2%) were in Grade 12.

Table 1

Descriptive Statistics for Creativity, Openness to Experience, and Intrinsic Motivation

Variable	Mean	Standard Deviation
Creativity	112.47	13.62
Openness to Experience	36.28	4.81
Intrinsic Motivation	121.65	11.49

The descriptive statistics in Table 1 show that the mean score for creativity among adolescents was 112.47 (SD = 13.62), indicating moderately high creative potential in the sample. The mean score for openness to experience was

JAYPS Adolescent and Youth Psychological Studies
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36.28 (SD = 4.81), suggesting a generally high level of openness in the adolescent population. Similarly, the mean score for intrinsic motivation was 121.65 (SD = 11.49), reflecting strong internal motivation to engage in tasks for personal satisfaction.

Prior to conducting the regression analysis, necessary assumptions were assessed and confirmed. Linearity between the dependent variable (creativity) and independent variables (openness to experience and intrinsic motivation) was verified using scatterplots, indicating linear relationships. The assumption of normality was supported by skewness and kurtosis values within the acceptable range (Creativity: skewness = 0.24, kurtosis = -0.38; Openness to Experience: skewness = -0.16, kurtosis = 0.47; Intrinsic Motivation: skewness = 0.11, kurtosis = -0.29). Homoscedasticity was confirmed through visual inspection of residual plots, indicating equal variances across residuals. Additionally, multicollinearity diagnostics indicated no problematic collinearity, with tolerance values greater than 0.10 (Openness to Experience = 0.84; Intrinsic Motivation = 0.84) and variance inflation factor (VIF) values below the threshold of 10 (Openness to Experience = 1.19; Intrinsic Motivation = 1.19).

Table 2

Pearson Correlation Coefficients Between Creativity and Predictor Variables

Variable	1	2	3
1. Creativity	—		
2. Openness to Experience	.52** (p < .01)	—	
3. Intrinsic Motivation	.47** (p < .01)	.43** (p < .01)	—

Table 2 presents the Pearson correlation coefficients among the study variables. Creativity was positively correlated with openness to experience ($r = .52$, $p < .01$) and intrinsic motivation ($r = .47$, $p < .01$), both statistically significant. Additionally, openness to experience was significantly correlated with intrinsic motivation ($r = .43$, $p < .01$), suggesting an interrelated dynamic between personality traits and motivational states.

Table 3

ANOVA Summary of Regression Model Predicting Creativity

Source	Sum of Squares	df	Mean Square	R	R^2	Adjusted R^2	F	p
Regression	6213.84	2	3106.92	.58	.34	.33	72.96	< .001
Residual	12109.63	377	32.12					
Total	18323.47	379						

Table 3 summarizes the ANOVA results of the regression model. The model was statistically significant, $F(2, 377) = 72.96$, $p < .001$, indicating that openness to experience and intrinsic motivation together accounted for a significant proportion of the variance in creativity scores. The R^2 value of .34 suggests that 34% of the variability in creativity can be explained by the two predictor variables, with an adjusted R^2 of .33 to correct for model complexity.

Table 4

Coefficients of Multivariate Regression Predicting Creativity

Predictor	B	Standard Error	β	t	p
Constant	41.23	5.24	—	7.87	< .001
Openness to Experience	1.73	0.21	.39	8.24	< .001
Intrinsic Motivation	0.64	0.15	.31	6.03	< .001

Table 4 displays the multivariate regression coefficients. Openness to experience significantly predicted creativity ($B = 1.73$, $SE = 0.21$, $\beta = .39$, $t = 8.24$, $p < .001$), indicating that for each one-unit increase in openness, creativity increased by 1.73 units. Intrinsic motivation also significantly predicted creativity ($B = 0.64$, $SE = 0.15$, $\beta = .31$, $t = 6.03$, $p < .001$), suggesting that intrinsic motivation contributes independently and meaningfully to creative outcomes.

JAYPS Adolescent and Youth Psychological Studies
E-ISSN: 2981-2526

4. Discussion and Conclusion

The primary objective of this study was to examine the predictive role of openness to experience and intrinsic motivation in adolescent creativity. The findings supported the hypotheses: both openness to experience and intrinsic motivation demonstrated significant positive correlations with creativity. Moreover, results from multiple linear regression analysis indicated that both variables were significant predictors of adolescent creativity, jointly accounting for a substantial proportion of variance in creativity scores. These results reinforce the theoretical assumption that personality and motivation operate as psychological foundations for creative thinking, especially during the formative adolescent years.

The significant positive relationship between openness to experience and creativity is consistent with a wide body of previous research. Individuals high in openness tend to be more imaginative, curious, and receptive to novel ideas—traits that inherently facilitate creative performance. The present findings align with studies demonstrating the role of openness in fostering divergent thinking, cognitive flexibility, and aesthetic engagement (Hong et al., 2020; Krumm et al., 2018; Rahmani & Ahmadi, 2019). In the context of adolescent development, openness may contribute to enhanced creative exploration by allowing young individuals to move beyond rigid structures and engage with complex, ambiguous problems in novel ways (Atari et al., 2020). This personality trait appears to create a cognitive-emotional environment where creativity can flourish naturally, without requiring external validation or constraints.

These findings also resonate with more comprehensive models of personality-creativity interactions. For instance, openness has been linked to increased tolerance for ambiguity, originality, and unconventional thinking—all elements associated with higher creative output (Aziz, 2023; Safaei Rad et al., 2019). Furthermore, Corazza and Lubart (2021) propose that openness plays a key temporal role in activating creativity across the lifespan by enhancing receptiveness to evolving stimuli (Corazza & Lubart, 2021). Adolescents, navigating a period of intense self-discovery and identity formation, may thus benefit from higher openness by channeling internal experiences into creative pursuits that help them better understand themselves and their environment.

The significant contribution of intrinsic motivation to creativity also aligns with theoretical and empirical research in the creativity domain. Intrinsic motivation—defined as the internal desire to engage in an activity for the sake of personal satisfaction—has consistently emerged as a powerful facilitator of creativity (Chad-Friedman et al., 2018; Fischer et al., 2019). The findings of this study support the argument that adolescents who are driven by interest and enjoyment are more likely to invest cognitive and emotional resources into creative tasks. When students are intrinsically motivated, they tend to demonstrate greater engagement, curiosity, and risk-taking—all of which contribute to creative ideation and expression (Gulzar et al., 2021; Yousef, 2021).

This result is also in line with evidence that motivation acts as a psychological enabler, fostering persistence and depth of processing in tasks that require non-linear thinking. For example, Balakrishnan (2022) found that intrinsic motivation played a crucial role in enhancing creative skills among design students by promoting a mindset of exploration and iterative learning (Balakrishnan, 2022). Similarly, Malik et al. (2020) highlighted how intrinsic motivation mediated the relationship between technological engagement and creativity, reinforcing the idea that motivation functions as a bridge between environmental inputs and internal creative expression (Malik et al., 2020).

Notably, the current study's findings support the interactive role of openness and intrinsic motivation. Prior research suggests that personality traits may shape motivational tendencies, and in turn, these motivations mediate the actual expression of creative behavior (Ma'aser & Zeraati, 2019). For example, adolescents with higher levels of openness may naturally be more intrinsically motivated to engage in cognitively stimulating or novel activities, thereby amplifying their creative potential (Ajdarbin et al., 2023). This is consistent with the notion that creativity emerges from a synergy between stable personality dispositions and situational motivational states. Moreover, Yasamin (2021) demonstrated that personality traits, particularly openness, predicted differences in creative performance between virtual and classroom settings, suggesting that personal attributes and contextual factors jointly influence creative outcomes (Yasamin, 2021).

Furthermore, the current study adds to the growing body of cross-cultural literature highlighting these associations in non-Western or diverse educational contexts. For example, Deng et al. (2022) found that Chinese students' proactive personalities—analogous to openness—were significantly associated with creative thinking through motivational mediators (Deng et al., 2022). Similarly, Farajzadeh and

Alavinia (2022) emphasized how motivation and personality jointly influence teacher creativity in the Iranian educational system (Farajzadeh & Alavinia, 2022). These findings demonstrate that the relationship between openness, motivation, and creativity is likely generalizable across diverse cultural settings, reinforcing the relevance of these psychological constructs.

In addition, studies on learning environments and interventions align with the present results. For instance, Conradty and Bogner (2020) reported that students exposed to STEAM-based education showed enhanced creativity and motivation—especially when intrinsic motivation was supported (Conradty & Bogner, 2020). Saberi Dehkordi et al. (2019) found that storytelling increased both motivation and creativity among middle school students, suggesting that experiential learning can activate internal psychological resources (Saberi Dehkordi et al., 2019). Similarly, Boeiry et al. (2024) identified achievement motivation and emotional creativity as key predictors of academic vitality and self-directed learning, supporting the notion that internally driven learners tend to exhibit more creativity and autonomy (Boeiry et al., 2024).

This study also reinforces the importance of designing educational strategies that support both dispositional and motivational aspects of learners. Research by Tang et al. (2022) highlighted that technological tools can enhance creativity only when they are paired with supportive motivational climates (Tang et al., 2022). In this regard, Yousef (2021) demonstrated that augmented reality learning improved creativity and motivation among primary school children, further suggesting that motivational engagement is crucial across age groups (Yousef, 2021). The consistent appearance of intrinsic motivation as a key mediator or predictor in creative development across these studies underlines the need to treat motivation not as a byproduct but as a core driver of creative learning.

Additionally, several studies link openness and motivation to broader psychosocial functioning, thereby expanding the relevance of these constructs beyond creativity. Michinov and Michinov (2023) found that personality traits, particularly openness, moderated the effects of pandemic-related stress on creativity and mental health, implying that openness may confer resilience in addition to cognitive flexibility (Michinov & Michinov, 2023). Ayat et al. (2020) emphasized how personality characteristics inform leadership and managerial effectiveness, suggesting far-reaching implications of openness for career development (Ayat et al., 2020). These broader connections underscore the developmental significance of fostering these traits in adolescence.

Taken together, the findings from this study contribute to a more nuanced understanding of how creativity develops in adolescents. By empirically confirming the roles of openness to experience and intrinsic motivation in creative performance, this research highlights the importance of considering both stable personality traits and dynamic motivational states in models of adolescent creativity. This integrative approach not only aligns with multidimensional theories of creativity but also holds practical implications for educational programming, psychological interventions, and youth development policies.

5. Limitations & Suggestions

Despite its valuable contributions, this study is not without limitations. First, the reliance on self-report instruments may introduce social desirability bias or inaccuracies in participants' perceptions of their own traits and behaviors. Second, the cross-sectional nature of the design limits the ability to draw causal inferences between the variables. While correlations and regression analyses demonstrate associations, they cannot conclusively determine the direction of effects. Third, the sample was drawn exclusively from Canadian adolescents, which, while culturally informative, may limit the generalizability of findings to other regions or age groups. Finally, other potentially influential factors such as emotional intelligence, parental involvement, or classroom climate were not included and may have mediated or moderated the observed relationships.

Future studies should consider employing longitudinal designs to capture the developmental trajectory of creativity in adolescents and to explore how openness and intrinsic motivation interact over time. Including observational or performance-based assessments of creativity could enhance the robustness of findings by triangulating self-report data with behavioral indicators. It would also be valuable to expand the scope of research to include diverse cultural and socioeconomic populations to explore whether contextual variables influence these psychological relationships. Additionally, integrating other personality traits or psychological variables—such as grit, resilience, or goal orientation—could offer a more comprehensive model of adolescent creative development.

In educational practice, fostering an environment that values curiosity, imagination, and self-directed learning can

help cultivate both openness and intrinsic motivation. Teachers and school counselors should be trained to recognize and support individual differences in personality traits, tailoring activities that align with students' interests and cognitive styles. Classroom practices such as inquiry-based learning, creative problem-solving tasks, and open-ended projects can enhance students' engagement and provide space for creative expression. Moreover, allowing students autonomy in how they approach assignments and encouraging intrinsic goals over external rewards may significantly boost both motivation and creativity in adolescent learners.

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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

This article is derived from the first author's doctoral dissertation. All authors equally contributed to this article.

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