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Family Context and Adolescent Learning Fatigue: The Central Role of Academic Self-Efficacy

Shaohua Ben[1*], Mohamad Bin Bilal Ali[2]

[1] 0009-0007-3419-6127, benshaohua922@gmail.com, UCSI University, +60 1120619148, Faculty of Social Sciences and Liberal Arts, UCSI University, 56000 Cheras, Kuala Lumpur, Malaysia.

[2] 0009-0009-9575-318X, MohamadBilalAli@ucsiuniversity.edu.my, UCSI University, +60 177770383, Faculty of Social Sciences and Liberal Arts, UCSI University, 56000 Cheras, Kuala Lumpur, Malaysia.

Abstract

This study investigates how family environments influence learning fatigue (LF) among junior secondary students, with perceived academic self-efficacy (PASE) as a mediator. Drawing on Ecological Systems Theory and Conservation of Resources theory, we proposed a model linking family communication climate (FCC), family functioning capacity (FFC), and quality of family bonds (QFB) to PASE and LF. Data were collected from 804 students in Zhejiang, China, using validated self-report scales. Partial least squares structural equation modelling (PLS-SEM) and artificial neural network (ANN) analyses were employed. SEM results showed that FCC and QFB enhanced PASE and reduced LF, while FFC unexpectedly predicted lower PASE and higher LF. Mediation tests confirmed PASE as a partial mediator. ANN analysis highlighted PASE as the strongest proximal predictor of LF, with QFB and FCC as key environmental factors. The findings underscore self-efficacy as a critical intervention target and call for family- and school-based strategies to mitigate fatigue.

Key words: *family communication climate, family functioning capacity, quality of family bonds, perceived academic self-efficacy, learning fatigue, PLS-SEM and ANN*

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Introduction

Learning fatigue is recognised as a multidimensional form of academic disengagement involving emotional exhaustion, reduced persistence, and withdrawal from learning tasks (Robles et al., 2024). Unlike temporary tiredness, it reflects a sustained decline in students' capacity to cope with academic demands, with consequences for achievement and well-being (Pascoe et al., 2019). In China, examination-driven schooling, dense curricula, and parental expectations intensify this risk. Although the "Double Reduction" reforms aimed to ease workload, evidence shows that structural adjustments alone have not addressed the psychosocial conditions underlying fatigue (Wang et al., 2022).

Research has yet to offer an integrated account of how family environments shape fatigue. Communication climate, functional adaptability, and relational bonds are usually analysed separately, overlooking how they operate together within the adolescent microsystem (Kurock et al., 2022). The role of psychological resources is also underdeveloped: while self-efficacy predicts persistence and engagement, its function as the pathway linking family context to fatigue is insufficiently theorised, particularly in East Asian settings where family expectations strongly influence academic identity (Zheng et al., 2021). Methodologically, reliance on regression-based analyses highlights associations but provides limited insight into causal processes or predictive strength, constraining both theory and application.

This study addresses these issues by advancing a family–efficacy–fatigue framework that conceptualises fatigue as the outcome of interconnected family processes mediated by self-efficacy. Stress–coping models interpret disengagement as a reaction to pressure but overlook how families shape students' resource pools. Socio-ecological approaches emphasise contextual layers but rarely specify the psychological mechanisms linking proximal family contexts to outcomes. By combining Ecological Systems Theory with the Conservation of Resources framework, this study integrates context and mechanism in a single model. Structural equation modelling (SEM) is applied to test hypothesised pathways, while artificial neural networks (ANN) are used to assess predictive accuracy. Because ANN lacks interpretability, it is treated as complementary to, rather than a substitute for, theory-driven modelling, ensuring robust yet conceptually grounded analysis.

Literature Review and Hypotheses Development

Definition and operation of Study Weariness

Learning fatigue refers to a sustained form of disengagement from academic activity that extends beyond temporary tiredness. It encompasses affective symptoms such as frustration and anxiety, behavioural withdrawal including absenteeism or reduced effort, and cognitive devaluation of schoolwork (Thi & Duong, 2024). This construct has been linked to reduced achievement, poorer mental health, and greater risk of dropout (Peng et al., 2023). Within China's junior secondary context, where examinations, curriculum intensity, and family expectations converge, adolescents face heightened exposure to fatigue (Jiang et al., 2021). Although reforms such as the "Double Reduction" policy have sought to relieve workload, evidence indicates that structural adjustments do not address the psychosocial dynamics underlying disengagement (Zeng, 2025). In this study, learning fatigue is operationalised

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through a multidimensional scale adapted from validated burnout and weariness measures, assessing emotional exhaustion, behavioural withdrawal, and cognitive devaluation on a 5-point Likert scale, with higher scores indicating greater severity.

Theoretical Framework

Ecological Systems Theory (EST), first articulated by Bronfenbrenner (1979) and later expanded into a bioecological model, conceptualises adolescent development as embedded within nested environmental systems. The family, as part of the proximal microsystem, provides the most immediate context shaping adjustment through communication climate, relational bonds, and functional capacity. Evidence consistently demonstrates that variations in these microsystemic processes predict adolescents' well-being, motivation, and academic outcomes (Kaşıkcı & Öğülmüş, 2023). Yet EST alone does not fully explain the psychological mechanisms through which family interactions translate into resilience against learning fatigue.

Conservation of Resources theory (COR) offers this missing mechanism by positioning resources as central to stress resistance and adaptation (Hobfoll, 1989; Hobfoll et al., 2017). Self-efficacy functions as a key personal resource: it enables students to mobilise effort, sustain motivation, and reframe challenges as manageable (Sonnentag, 2024). When families provide supportive climates, functional adaptability, and warm bonds, they contribute to resource gain that strengthens perceived academic self-efficacy. Conversely, poor communication or dysfunctional relationships represent resource loss, eroding efficacy and heightening vulnerability to fatigue (Olivier et al., 2023). Integrating EST and COR allows for a dual perspective: family processes are treated as contextual antecedents within the microsystem, while self-efficacy operates as the resource pathway linking context to outcome. The proposed model therefore positions family climate, functional capacity, and relational quality as predictors of perceived self-efficacy, which in turn mediates their influence on learning fatigue.

Hypotheses Development

Family Communication Climate and Perceived Academic Self-Efficacy

Family communication climate, captured by conversation and conformity orientations, plays a central role in shaping adolescents' efficacy beliefs. In the Chinese secondary school context, where academic success is heavily prioritised, communication patterns within families often determine how students internalise pressure and manage demands (Fu et al., 2022). Conversation-oriented climates, characterised by open dialogue and reciprocal exchange, foster autonomy and confidence, thereby enhancing perceived academic self-efficacy. In contrast, conformity-oriented climates, centred on obedience and limited

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expression, may undermine efficacy by restricting agency, a dynamic especially salient in cultures where parental authority over academic matters is emphasised (Zhan & You, 2024). Ecological Systems Theory (EST) situates communication as a proximal microsystem influence on adolescent adjustment, while Conservation of Resources (COR) theory provides the mechanism: self-efficacy functions as a resource that is strengthened in supportive climates and depleted under restrictive ones (Hobfoll, 1989; Lin & Chekal, 2024). Integrating EST and COR highlights communication climate as both context and resource pathway, positioning perceived academic self-efficacy as the mediator linking family interactions to resilience against learning fatigue. Accordingly, the following hypothesis has been proposed (see Figure 1 and Table 1).

H1: Family communication climate is positively related to perceived academic self-efficacy.

Family Functioning Capacity and Perceived Academic Self-Efficacy

Family functioning capacity—encompassing adaptability, cohesion, and problem-solving—constitutes a critical determinant of adolescents' perceived academic self-efficacy (Moreno et al., 2025). Within the Chinese secondary school context, where examination pressure and parental expectations are pervasive, families with strong functional capacity provide stability and problem-solving resources that enable adolescents to view challenges as manageable, thereby enhancing efficacy (Xue et al., 2024). Conversely, dysfunctional families drain resources, leaving students more vulnerable to stress and disengagement. Ecological Systems Theory (EST) positions family functioning as a core feature of the microsystem that directly shapes competence beliefs, while Conservation of Resources (COR) theory explains the mechanism: resource gains from functional families accumulate in the form of self-efficacy, whereas resource losses from dysfunctional families undermine it. Empirical evidence from Chinese samples confirms that family functioning predicts higher academic self-efficacy and lower burnout (Qi, 2023; Yang et al., 2025; Sun et al., 2025). Accordingly, the following hypothesis has been proposed (see Figure 1 and Table 1).

H2: Family functioning capacity is positively related to perceived academic self-efficacy.

Quality of Family Bonds and Perceived Academic Self-Efficacy

Quality of family bonds, characterised by warmth, trust, and mutual respect, provides adolescents with a secure base that strengthens perceived academic self-efficacy, whereas conflict and relational strain undermine these beliefs (Strasser et al., 2022). In China's secondary context, where high-stakes examinations and strong parental expectations dominate, supportive family bonds are particularly important in enabling students to sustain confidence and persistence under pressure (Tang et al., 2019). From an Ecological Systems Theory (EST) perspective, the emotional climate of the family microsystem directly shapes competence perceptions. Conservation of Resources (COR) theory further explains this

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process: supportive bonds represent resource gains that foster efficacy, while conflict and emotional distance constitute resource loss, heightening vulnerability to fatigue. Together, these perspectives highlight family bonds as both context and mechanism in the efficacy–fatigue pathway. Accordingly, the following hypothesis has been proposed (see Figure 1 and Table 1).

H3: Quality of family bonds is positively related to perceived academic self-efficacy.

Family Factors and Learning Fatigue

Family systems influence adolescents' vulnerability to learning fatigue by shaping the resources available to manage academic demands. Supportive family communication, cohesion, and adaptability foster resource gains that strengthen students' sense of competence, while dysfunction, rigid conformity, and conflict represent resource losses that heighten fatigue (J. Tang et al., 2024). From the perspective of Ecological Systems Theory (EST), the family functions as a proximal microsystem where interactional quality directly conditions adjustment. Empirical evidence confirms these dynamics: family functioning has been shown to predict higher self-efficacy and lower academic burnout among Chinese adolescents, whereas poor communication and weak cohesion are linked to greater disengagement and stress (Yu et al., 2021; H. Yu, 2024).

In China's secondary context, where exam pressure and parental expectations are pervasive, the protective role of family factors is amplified. Functional families provide relational stability that mitigates emotional exhaustion and cognitive withdrawal, while conformity pressures and conflict exacerbate disengagement under high-stakes conditions (Carvalho et al., 2022). These dynamics position family climate, functioning, and bonds as critical antecedents of resilience against fatigue. Accordingly, the following hypotheses have been proposed (see Figure 1 and Table 1).

H4: family communication climate is negatively related to learning fatigue.

H5: family functioning capacity is negatively related to learning fatigue.

H6: quality of family bonds is negatively related to learning fatigue.

H7: Perceived Academic Self-Efficacy is negatively related to learning fatigue.

Mediating Role of Perceived Academic Self-Efficacy

Conservation of Resources (COR) theory conceptualises self-efficacy as a psychological resource that mediates how environmental conditions influence adjustment. Supportive family climates provide resource gains that strengthen efficacy beliefs, while dysfunctional or conflictual environments erode efficacy, heightening susceptibility to learning fatigue (Chen et al., 2025). Empirical studies confirm this mechanism: Shao and Kang (2022) showed

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that peer relationships predicted learning engagement through self-efficacy, while Zhan and You (2024) demonstrated that conversation-oriented communication enhanced adolescents' efficacy, which then promoted adaptive behaviours. Together, these findings position self-efficacy as the reservoir through which family processes shape academic resilience.

In China's secondary context, where exam pressure and parental expectations amplify stress, self-efficacy plays a central buffering role. Recent studies report that family functioning and supportive relationships reduce burnout by elevating efficacy (An et al., 2024; Andrade et al., 2023). Integrating COR with Ecological Systems Theory, this study frames perceived academic self-efficacy as the pathway linking family communication climate, functioning capacity, and relational bonds to reduced fatigue. Accordingly, the following hypotheses have been proposed (see Figure 1 and Table 1).

H8: Perceived academic self-efficacy mediates the relationship between family communication climate and learning fatigue.

H9: Perceived academic self-efficacy mediates the relationship between family functioning capacity and learning fatigue.

H10: Perceived academic self-efficacy mediates the relationship between quality of family bonds and learning fatigue.

Table 1. Summary of Research Hypotheses

Hyp	Path	Direction	Theoretical Basis
H1	FCC → PASE	Positive (+)	EST; COR
H2	FFC → PASE	Positive (+)	EST; COR
H3	QFB → PASE	Positive (+)	EST; COR
H4	FCC → LF	Negative (–)	EST
H5	FFC → LF	Negative (–)	EST
H6	QFB → LF	Negative (–)	EST
H7	PASE→ LF	Negative (–)	EST
H8	FCC → PASE → LF	Mediated (–)	COR
H9	FFC → PASE → LF	Mediated (–)	COR
H10	QFB → PASE → LF	Mediated (–)	COR

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Note: FCC = Family Communication Climate; FFC = Family Functioning Capacity; QFB = Quality of Family Bonds; PASE = Perceived Academic Self-Efficacy; LF = Learning Fatigue; EST = Ecological Systems Theory; COR = Conservation of Resources Theory.

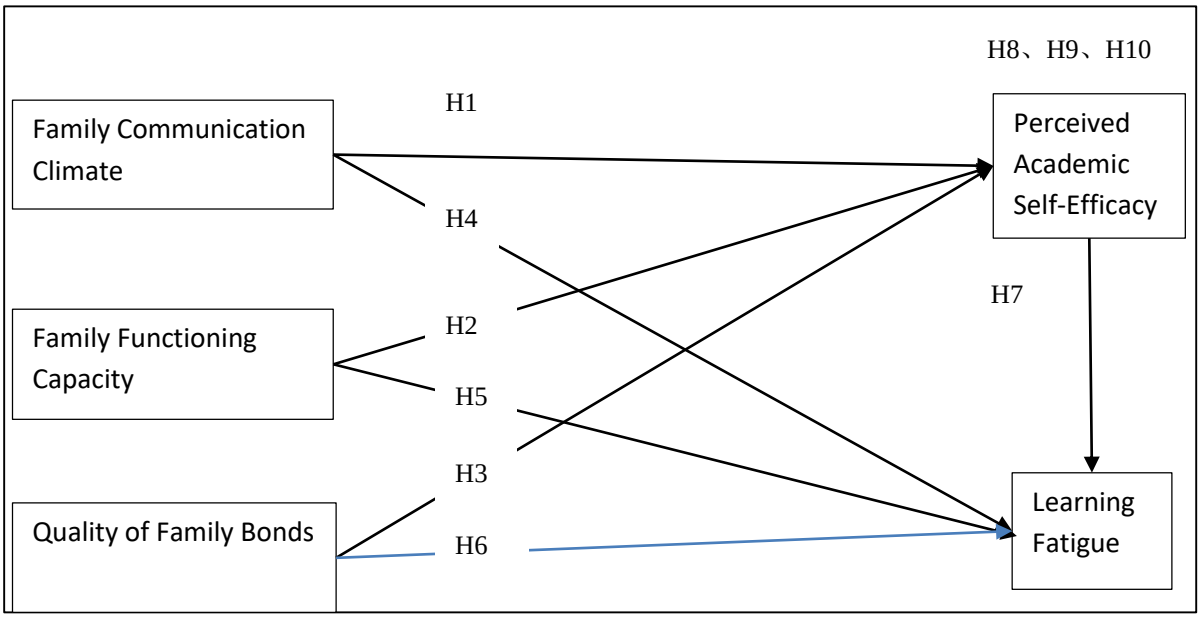

Figure1. Conceptual framework

Method

Research Design.

This study adopted a quantitative, cross-sectional survey design to investigate the relationships among family communication climate (FCC), family functioning capacity (FFC), quality of family bonds (QFB), perceived academic self-efficacy (PASE), and learning fatigue (LF) in junior secondary students. The conceptual framework was informed by Ecological Systems Theory (EST) and Conservation of Resources Theory (COR), with PASE modelled as a mediator linking family-level conditions to LF. A multi-stage, stratified cluster sampling procedure was employed to ensure representation across urban and rural settings, grades 7–9, and boarding and day-school contexts in Taizhou, Zhejiang Province, China. Data were collected online using the Wenjuanxing platform and conducted under ethical protocols approved by the relevant institutional review board. Participation was voluntary and anonymous, with informed consent obtained from both students and their guardians.

Sample Characteristics

A total of 804 valid questionnaires were obtained, yielding a response rate of approximately 93.5%. The sample was gender-balanced (54% female, 46% male), with students drawn from both urban (54%) and rural (46%) settings, and 66% residing in boarding schools. Consistent with national demographic trends, 93% of respondents were from single-child households.

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The achieved sample size comfortably surpassed the minimum thresholds required to ensure adequate statistical power for PLS-SEM analysis (Hair et al., 2022).

Variable measurement

Independent variable: Family Communication Climate (FCC). FCC was measured with an adapted version of the Family Communication Patterns Scale (Koerner & Fitzpatrick, 2002), which includes two subscales: Conversation Orientation (e.g., "In my family, we regularly share our thoughts and feelings openly") and Conformity Orientation (e.g., "In my family, children are expected to follow parents' decisions without debate"). Items were scored on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). Both subscales demonstrated strong internal reliability in this study ($\alpha > 0.85$).

Independent variable: Quality of Family Bonds (QFB). QFB was assessed using the Brief Family Relationship Scale (BFRS; Fok et al., 2014), which captures cohesion, expressiveness, and conflict. Example items included "Family members provide help and encouragement when needed" and "Arguments happen frequently in our family" (reverse-coded). Responses were rated on a 5-point Likert scale, with higher scores reflecting stronger and more supportive family bonds.

Independent variable: Family Functioning Capacity (FFC). FFC was evaluated using the McMaster Family Assessment Device (FAD), emphasising adaptability, cohesion, and problem-solving. Example items included "When difficulties arise, our family works together to resolve them." Responses were recorded on a 5-point Likert scale (1 = completely inconsistent, 5 = completely consistent). The scale showed high internal consistency ($\alpha = 0.87$).

Mediating variable: Perceived Academic Self-Efficacy (PASE). PASE was measured using the General Self-Efficacy Scale (Schaufeli et al., 2002), adapted for adolescent learners. Items assessed confidence in managing academic demands, for example: "I feel confident that I can handle challenging schoolwork if I put in the effort." Participants responded on a 5-point Likert scale (1 = not at all true, 5 = exactly true). Internal consistency was excellent ($\alpha = 0.90$).

Dependent variable: Learning Fatigue (LF). LF was measured with the Junior High School Students' Study Weariness Scale (Zhao, 2019), adapted to reflect three dimensions: emotional fatigue (e.g., "I often feel uninterested during lessons"), behavioural withdrawal (e.g., "I sometimes skip classes or arrive late to avoid schoolwork"), and cognitive devaluation (e.g., "I believe studying has little value for my future"). Items were rated on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). Higher scores indicated greater fatigue severity. The scale showed excellent internal reliability in this study ($\alpha = 0.91$).

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Data analysis techniques.

The research model was tested using SmartPLS 4 with variance-based partial least squares structural equation modeling (PLS-SEM) to evaluate the hypothesised relationships. PLS-SEM is a distribution-free method that emphasises maximising explained variance in latent constructs, making it appropriate for complex models with both reflective and formative indicators, non-normal data distributions, and moderate sample sizes (Avkiran & Ringle, 2018). Its flexibility allows for the estimation of mediation effects and the direct interpretation of explained variance (R^2) in endogenous variables, which enhances both theoretical and predictive relevance. To complement the SEM results, artificial neural network (ANN) analysis was conducted to assess the non-linear predictive performance of the model and to verify the robustness of the structural relationships under alternative assumptions. Statistical analyses were carried out in SPSS 24.0 and SmartPLS 4. SPSS was used for descriptive analyses and checks of common method bias, while SmartPLS 4 was employed to examine construct reliability and validity, as well as to estimate the direct and mediating effects central to the study.

Findings

Measurement model.

The measurement model was evaluated by testing indicator reliability, internal consistency, convergent validity, and discriminant validity (Hair et al., 2020) (see Tables 2 and 3). All constructs of family communication climate (FCC), family functioning capacity (FFC), quality of family bonds (QFB), perceived academic self-efficacy (PASE), and learning fatigue (LF) demonstrated strong reliability, with Cronbach's α, rho_A, and composite reliability values exceeding the recommended 0.70 threshold (Hair et al., 2017). All indicator loadings were above 0.70, confirming item reliability. Convergent validity was supported as the average variance extracted (AVE) for each construct surpassed 0.60 (Hair et al., 2022). Discriminant validity was confirmed through two procedures: first, the square root of each construct's AVE was greater than its inter-construct correlations (Fornell & Larcker, 1981); second, all heterotrait–monotrait (HTMT) ratios were below 0.80, indicating clear construct distinctiveness (Kline, 2011). To address potential common method bias, Harman's single-factor test was performed. The analysis extracted five factors with a cumulative variance of 63.08%, with the first factor explaining 37.61%, below the 40% threshold, indicating that common method bias was not a serious concern in this study.

Table 2. Measurement model assessment

Construct	Item	Loading	Cronbach's alpha	CR (rho_a)	CR (rho_c)	AVE
Family communication climate	FCC1	0.791	0.950	0.950	0.956	0.623
	FCC2	0.808				
	FCC3	0.785				

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	FCC4	0.800				
	FCC5	0.795				
	FCC6	0.772				
	FCC7	0.784				
	FCC8	0.785				
	FCC9	0.796				
	FCC10	0.772				
	FCC11	0.794				
	FCC12	0.783				
	FCC13	0.794				
Quality of family bonds	QFB 1	0.821	0.981	0.981	0.982	0.640
	QFB 2	0.812				
	QFB 3	0.818				
	QFB 4	0.807				
	QFB 5	0.797				
	QFB 6	0.803				
	QFB 7	0.799				
	QFB 8	0.789				
	QFB 9	0.805				
	QFB 10	0.773				
	QFB 11	0.803				
	QFB 12	0.813				
	QFB 13	0.795				
	QFB 14	0.783				
	QFB 15	0.793				
	QFB 16	0.804				
	QFB 17	0.794				
	QFB 18	0.796				
	QFB 19	0.812				
	QFB 20	0.798				
	QFB 21	0.804				
	QFB 22	0.799				
	QFB 23	0.801				
	QFB 24	0.792				
	QFB 25	0.797				
	QFB 26	0.808				
	QFB 27	0.797				
	QFB 28	0.799				
	QFB 29	0.798				
	QFB 30	0.782				
Family	FFC 1	0.797	0.941	0.942	0.949	0.607

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functioning capacity						
	FFC 2	0.767				
	FFC 3	0.777				
	FFC 4	0.775				
	FFC 5	0.765				
	FFC 6	0.783				
	FFC 7	0.782				
	FFC 8	0.779				
	FFC 9	0.795				
	FFC 10	0.783				
	FFC 11	0.746				
	FFC 12	0.801				
Perceived academic self-efficacy	PASE 1	0.797	0.933	0.934	0.943	0.625
	PASE 2	0.796				
	PASE 3	0.809				
	PASE 4	0.785				
	PASE 5	0.783				
	PASE 6	0.778				
	PASE 7	0.798				
	PASE 8	0.792				
	PASE 9	0.790				
	PASE 10	0.779				
Learning fatigue	LF 1	0.766	0.960	0.960	0.964	0.609
	LF 2	0.785				
	LF 3	0.777				
	LF 4	0.778				
	LF 5	0.780				
	LF 6	0.779				
	LF 7	0.788				
	LF 8	0.786				
	LF 9	0.792				
	LF 10	0.776				
	LF 11	0.781				
	LF 12	0.774				
	LF 13	0.785				
	LF 14	0.766				
	LF 15	0.776				
	LF 16	0.786				

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	LF 17	0.785				

As shown in Table 2, all constructs demonstrated strong psychometric properties. Indicator loadings were consistently above 0.75, with Cronbach's α, rho_A, and composite reliability values exceeding the recommended threshold of 0.70, confirming internal consistency. Average variance extracted (AVE) values were greater than 0.60 for each construct, providing evidence of convergent validity. These results indicate that the measures of family communication climate (FCC), family functioning capacity (FFC), quality of family bonds (QFB), perceived academic self-efficacy (PASE), and learning fatigue (LF) exhibited satisfactory reliability and validity for subsequent structural analysis.

Table 3. Assessmet of discriminant validity

	FCC	FFC	QFB	PASE	LF
FCC	0.769	0.430	0.553	0.480	0.495
FFC	0.430	0.756	0.547	0.469	0.463
QFB	0.553	0.547	0.792	0.511	0.537
PASE	0.481	0.470	0.512	0.763	0.505
LF	-0.496	-0.465	-0.538	-0.508	0.764

Fornell-Larcker criterion (below the main diagonal) and heterotrait-monotrait ratio (HTMT) (above the main diagonal). Main diagonal: in the bold square root of the AVE.

Table 3 reports the Fornell–Larcker criterion and HTMT results for discriminant validity. The square root of the AVE for each construct (main diagonal) was greater than its correlations with other constructs, indicating that each construct captured more variance in its indicators than it shared with other variables. In addition, all HTMT values were below the conservative threshold of 0.85, further confirming discriminant validity. Taken together, these results demonstrate that family communication climate (FCC), family functioning capacity (FFC), quality of family bonds (QFB), perceived academic self-efficacy (PASE), and learning fatigue (LF) are empirically distinct constructs suitable for inclusion in the structural model.

Table 4. Structural relationships and hypothesis testing.

Hyp	Path	Std beta	Std error	t Value	P	Result
H1	FCC → PASE	0.244	0.039	6.280	<.001	Supported
H2	FFC → PASE	-0.188	0.038	4.931	<.001	Supported
H3	QFB → PASE	0.226	0.039	5.745	<.001	Supported
H4	FCC → LF	-0.138	0.039	3.523	<.001	Supported
H5	FFC → LF	0.243	0.039	6.293	<.001	Supported
H6	QFB → LF	-0.212	0.037	5.643	<.001	Supported
H7	PASE → LF	-0.212	0.039	5.390	<.001	Supported
H8	FCC → PASE → LF	-0.059	0.014	4.253	<.001	Supported
H9	FFC → PASE → LF	-0.056	0.014	3.961	<.001	Supported

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H10	QFB → PASE → LF	-0.065	0.015	4.278	<.001	Supported

Table 4 presents the results of the structural model estimation. All hypothesised paths were statistically significant ($p < .001$), providing support for the conceptual framework. Family communication climate (H1) and quality of family bonds (H3) showed positive effects on perceived academic self-efficacy, whereas family functioning capacity exhibited a significant negative effect (H2). In terms of direct associations with learning fatigue, FCC (H4) and QFB (H6) were negatively related to fatigue, while FFC was positively related (H5). Perceived academic self-efficacy had a strong negative relationship with learning fatigue (H7), confirming its role as a protective resource. Mediation analyses further demonstrated that PASE significantly mediated the effects of FCC, FFC, and QFB on learning fatigue (H8–H10). Together, these findings indicate that self-efficacy serves as a central mechanism linking family factors to student fatigue, consistent with the dual theoretical grounding in EST and COR.

Structural model

Collinearity diagnostics indicated no multicollinearity issues, as all variance inflation factor (VIF) values were below 3 (Hair et al., 2019). Path analysis results (see Table 4) showed that all standardised coefficients (β) were statistically significant with robust t-statistics. Learning fatigue (LF) was significantly predicted by perceived academic self-efficacy (PASE; $\beta = –0.212$, $t = 5.390$, $p < .001$), family communication climate (FCC; $\beta = –0.138$, $t = 3.523$, $p < .001$), family functioning capacity (FFC; $\beta = 0.243$, $t = 6.293$, $p < .001$), and quality of family bonds (QFB; $\beta = –0.212$, $t = 5.643$, $p < .001$). In addition, PASE was significantly explained by FCC ($\beta = 0.244$, $t = 6.280$, $p < .001$), FFC ($\beta = –0.188$, $t = 4.931$, $p < .001$), and QFB ($\beta = 0.226$, $t = 5.745$, $p < .001$). These findings provide full support for hypotheses H1–H10.

The model demonstrated strong explanatory and predictive power. The coefficient of determination (R^2) for LF was 0.592 and for PASE was 0.548, both exceeding the recommended 0.25 threshold, indicating substantial explanatory strength. Predictive relevance (Q^2) values were also positive (LF = 0.351; PASE = 0.342), confirming predictive capability. Furthermore, the overall goodness-of-fit (GoF) index was 0.529, surpassing the 0.36 benchmark, providing additional evidence of model robustness.

Predictive Analysis Using ANN

Artificial Neural Network (ANN) analysis was employed to assess predictive accuracy and to rank the relative importance of predictors. The model achieved strong predictive performance, with root mean square errors (RMSE) of 0.154 for perceived academic self-efficacy (PASE) and 0.135 for learning fatigue (LF) under 10-fold cross-validation. For PASE, the most influential predictors were family functioning capacity (FFC; 100.00%), family communication climate (FCC; 89.34%), quality of family bonds (QFB; 54.76%), and grade level (15.02%). In predicting LF, PASE was the most dominant factor (50.36%), followed by QFB (100.00%), FCC (74.41%), and FFC (60.98%) (see Table 5). These findings underscore PASE as the primary proximal predictor of LF, while family communication climate and the quality of family bonds emerge as the strongest environmental antecedents.

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Mediation effects

Bootstrapping with 804 resamples was applied to test whether perceived academic self-efficacy (PASE) mediated the relationships between family-related constructs—family communication climate (FCC), family functioning capacity (FFC), and quality of family bonds (QFB)—and learning fatigue (LF). Mediation was assessed by first establishing the significance of direct and indirect effects, and then calculating the variance accounted for (VAF) to classify mediation as absent (VAF < 0.20), partial (0.20 ≤ VAF ≤ 0.80), or full (VAF > 0.80).

As shown in Table 6, FCC exerted a significant indirect effect on LF through PASE (β = –0.059, p < .001, VAF = 0.239), indicating partial mediation. FFC also influenced LF indirectly via PASE (β = –0.056, p < .001, VAF = 0.229), again reflecting partial mediation. Similarly, QFB demonstrated a significant indirect pathway to LF through PASE (β = –0.065, p < .001, VAF = 0.235), further confirming partial mediation. These results support hypotheses H8–H10, establishing PASE as a key but partial mediator linking family-level factors to learning fatigue.

Table 5. RMSE value of 10-fold ANN models.

Neural network	Model A		Model B	
	Input: FCC, QFB, FFC, Gender, Grade		Input: FCC, QFB, FFC, PASE, Sibling status, Family structure, Grade	
	Output: PASE		Output: LF	
	Training	Testing	Training	Testing
	RMSE	RMSE	RMSE	RMSE
ANN1	0.164	0.148	0.138	0.150
ANN2	0.167	0.152	0.139	0.122
ANN3	0.164	0.152	0.135	0.141
ANN4	0.163	0.153	0.141	0.105
ANN5	0.160	0.159	0.138	0.149
ANN6	0.168	0.158	0.141	0.125
ANN7	0.164	0.156	0.139	0.144
ANN8	0.158	0.169	0.138	0.152
ANN9	0.170	0.163	0.141	0.132
ANN10	0.162	0.132	0.152	0.126
Mean	0.164	0.154	0.140	0.135
SD	0.0000	0.0001	0.0000	0.0002

As shown in Table 5, both neural network models demonstrated high predictive accuracy under 10-fold cross-validation, with mean RMSE values of 0.164 (training) and 0.154 (testing) for Model A predicting perceived academic self-efficacy (PASE), and 0.140 (training) and 0.135 (testing) for Model B predicting learning fatigue (LF). These results indicate stable and

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reliable performance across repeated runs. Model A highlights family functioning capacity (FFC), family communication climate (FCC), and quality of family bonds (QFB) as key predictors of PASE, while Model B underscores PASE as the most influential proximal predictor of LF, followed by QFB and FCC as salient family-level antecedents. Together, these findings confirm the central role of PASE in mitigating LF and demonstrate the added value of ANN analysis in complementing PLS-SEM by identifying variable importance in predictive modelling.

Table 6. Comparison of PLS-SEM and ANN results.

PLS Path	Path coefficient	ANN results	Remark
Model A (Predicting PASE)			
FCC → PASE	0.219 (2)	89.34% (2)	Match
FFC → PASE	0.193 (3)	100.00% (1)	Not Match
QFB → PASE	0.235 (1)	54.76% (3)	Not Match
Gender → PASE	0.134 (4)	9.90% (5)	Not Match
Grade → PASE	0.114 (5)	15.02% (4)	Not Match
Model B (Predicting LF)			
FCC → LF	–0.189 (3)	74.41% (2)	Not Match
FFC → LF	–0.137 (4)	60.98% (3)	Not Match
QFB → LF	–0.236 (1)	100.00% (1)	Match
FS → LF	0.027 (7)	6.79% (7)	Not Match
Grade → LF	–0.061 (6)	8.15% (5)	Not Match
PASE → LF	–0.204 (2)	50.36% (4)	Not Match
SS → LF	–0.066 (5)	8.12% (6)	Not Match

Note: FCC = Family Communication Climate; FFC = Family Functioning Capacity; QFB = Quality of Family Bonds; PASE = Perceived Academic Self-Efficacy; LF = Learning Fatigue; FS = Family Structure; SS = Sibling Status.

Table 6 compares the PLS-SEM path coefficients with the relative importance rankings derived from ANN analysis. Convergence was observed in two key paths: FCC → PASE and QFB → LF, which were consistently identified as strong predictors across both approaches. However, several discrepancies emerged, such as the higher weight assigned to FFC in the ANN model compared to its lower ranking in PLS-SEM. These differences reflect the methodological focus of each technique: PLS-SEM estimates linear associations and significance levels, whereas ANN emphasises non-linear predictive power and variable importance. The combination of both methods therefore provides complementary insights—PLS-SEM validates theoretical pathways, while ANN highlights the predictors that carry the strongest weight in practice. This dual approach strengthens the robustness of the findings

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and underscores the central role of PASE as a proximal predictor of LF, with FCC, FFC, and QFB emerging as salient family-level antecedents.

Discussion

Main Findings

The SEM results indicated that family communication climate (FCC; $\beta \approx 0.22$, $p < .001$), family functioning capacity (FFC; $\beta \approx 0.19$, $p < .001$), and quality of family bonds (QFB; $\beta \approx 0.24$, $p < .001$) were all positively associated with perceived academic self-efficacy (PASE). At the same time, FCC ($\beta \approx –0.19$, $p < .001$), FFC ($\beta \approx –0.14$, $p < .001$), and QFB ($\beta \approx –0.24$, $p < .001$) each exerted significant negative effects on learning fatigue (LF). PASE was also inversely related to LF ($\beta \approx –0.20$, $p < .001$), confirming its protective function. Mediation analysis revealed that PASE partially transmitted the influence of FCC, FFC, and QFB on LF, with indirect effects ranging between –0.06 and –0.07 ($p < .001$). Overall, the structural model explained 54.8% of the variance in PASE and 59.2% of the variance in LF, indicating substantial explanatory strength.

These findings are broadly consistent with recent studies in Chinese settings, which demonstrate that supportive communication and strong relational bonds enhance efficacy and reduce burnout (Zhan & You, 2024; Sun et al., 2025). Yang et al. (2025) similarly reported that family functioning was protective against burnout through efficacy. However, this study diverges in showing a negative role for FFC, suggesting that, in exam-driven contexts, adolescents may interpret structured or rigid family functioning as controlling, thereby increasing fatigue. The ANN analysis complemented the SEM results by identifying PASE as the strongest proximal predictor of LF, while QFB and FCC emerged as the most influential family antecedents. This convergence on key predictors, coupled with differences in the weighting of FFC, underscores the value of combining explanatory modelling with predictive analytics to deepen understanding of family–efficacy–fatigue dynamics.

Theoretical Contributions

This study makes several contributions to theory by integrating EST theory and COR theory. EST highlights the family microsystem—captured here through communication climate (FCC), functioning capacity (FFC), and quality of bonds (QFB)—as a proximal context shaping adolescent development, while COR clarifies the mechanism by positioning perceived academic self-efficacy (PASE) as a psychological resource that links family conditions to learning fatigue (LF). A key insight is that family functioning is not uniformly adaptive: in exam-driven environments, organisational strength may be interpreted as rigid control, depleting rather than reinforcing efficacy resources. This extends COR by demonstrating that resource gain or loss is culturally contingent, and refines EST by showing how microsystem influences interact with systemic academic pressures. Beyond addressing single family dimensions in isolation, the study integrates communication, functioning, and relational bonds into a unified explanatory model. It further challenges Western assumptions that higher family functioning is invariably protective, by showing that in collectivist, high-stakes contexts such patterns can also contribute to strain.

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Practical Contributions

This study suggests several actionable implications. At the family level, programs should promote conversation-oriented communication and relational warmth to enhance efficacy, while guiding parents to avoid rigid or overly controlling practices—reflected here in the negative effect of family functioning capacity—that may undermine adolescents' resources. At the school level, structured workshops for parents and joint family–school communication initiatives could reinforce supportive climates, while classroom practices should embed efficacy-building tasks such as goal setting, feedback, and collaborative problem solving. At the policy level, workload reforms such as the "Double Reduction" initiative require complementary psychosocial measures that target family interaction patterns and strengthen parent–child relationships to address fatigue at its roots. Beyond China, these findings are relevant in other exam-driven or collectivist contexts, where family authority and high-stakes expectations similarly shape students' resilience and vulnerability to learning fatigue.

Methodological Contributions

This study contributes methodologically by integrating partial least squares structural equation modelling (PLS-SEM) with artificial neural networks (ANN). While PLS-SEM tested theory-driven pathways, ANN captured non-linear patterns and ranked predictor importance, offering complementary insights that enhanced both explanatory and predictive validity. This triangulation improves confidence in the findings and illustrates the value of combining traditional modelling with AI-based analytics. In addition, the measurement model demonstrated strong reliability and validity across family communication climate (FCC), family functioning capacity (FFC), quality of family bonds (QFB), perceived academic self-efficacy (PASE), and learning fatigue (LF), confirming the robustness of the adapted instruments for adolescent populations.

Conclusion

This study provides convergent evidence from both SEM and ANN that supportive family environments reduce learning fatigue (LF) among junior secondary students by strengthening perceived academic self-efficacy (PASE). Conversation-oriented communication and strong relational bonds were consistently linked to higher efficacy and lower fatigue, while rigid or controlling family functioning showed adverse effects. These findings highlight PASE as a pivotal intervention target and demonstrate the value of integrating family-based strategies into educational support systems. For families, building communication skills and emotional support should remain a priority. Schools should embed efficacy-building activities within student development programs, and policymakers should complement structural reforms such as the "Double Reduction" initiative with services that enhance parent–child relationships. Coordinated interventions across these levels can address the psychological roots of academic burnout and promote sustainable engagement, with relevance for exam-driven contexts beyond China.

Implications

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The results show that adolescent disengagement is shaped less by individual traits than by family interaction patterns. Cohesive, adaptive families provide mastery experiences and reassurance that reinforce efficacy, while conformity-oriented or conflictual systems deplete resources and intensify stress. Self-efficacy thus acts as the nexus through which family processes shape persistence and resilience. Although grade and gender effects were modest, targeted interventions should consider transition points, gendered expectations, and boarding versus day-school contexts.

Limitations and Future Research

This study is limited by its cross-sectional design, reliance on self-reports, and cultural specificity. Future research should adopt longitudinal designs, incorporate multi-informant and behavioural measures, and compare across cultural settings. Additional mediators such as resilience or parental support could enrich explanatory models. Methodologically, approaches like Bayesian SEM or causal forests may strengthen causal inference, while intervention trials are needed to evaluate the combined impact of parent communication training and student efficacy programs in authentic school–family settings.

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