

Family SES and Digital Literacy in Adolescence: Testing the Compensatory Effect of Schools

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Abstract: With educational environments becoming increasingly technology-driven, the focus of the digital divide has shifted toward disparities in information technology literacy. While family socioeconomic status (SES) persistently influences adolescent development, the interactive effects of home and school contexts remain under-explored. Grounded in Ecological Systems Theory, this research investigates how family SES affects the digital literacy of eighth graders. Specifically, it tests a moderated-mediation model to examine the mediating role of parental digital mediation styles and the cross-level moderating effect of school digitalization. By evaluating the compensatory and amplification hypotheses, this study aims to determine whether highly digitalized schools act as equalizers for disadvantaged students or exacerbate existing inequalities. Utilizing a Hierarchical Linear Model (HLM) to account for the nested structure of student data, the findings clarify the boundary conditions of school digitalization, contributing to the literature on the second-tier digital divide and providing evidence-based insights for educational policy and home-school collaboration.

1. Introduction

The rapid penetration of information and communication technology fundamentally transforms global education. Early research on the digital divide focused on physical access to devices and the internet ^{[1], [2]}. However, with ubiquitous connectivity, the focus has shifted to a "second-tier digital divide," emphasizing whether individuals can derive genuine benefits from internet usage, such as enhanced academic and psychological outcomes ^{[3], [4]}. For eighth graders, this represents a critical developmental period characterized by accelerated neurocognitive maturation, increased autonomy, and independent digital consumption. Mastery of advanced digital skills during this phase forms an essential developmental pathway, profoundly influencing long-term psychological adaptation and future academic or career trajectories. Therefore, the contemporary educational challenge is no longer merely providing devices, but fostering adolescents' comprehensive cognitive processing abilities within complex digital systems.

Despite the decreasing cost of basic digital tools, family socioeconomic status (SES) consistently dictates adolescent developmental outcomes. Advantaged families utilize economic, human, and cultural capital to create enriched digital environments, offering high-quality parental guidance and

meaningful educational dialogue ^[5]. Conversely, disadvantaged adolescents often lack these environmental and cognitive scaffolds, leaving them more susceptible to passive digital consumption and algorithmic control ^[6]. Faced with these home-based disparities, global educational policies have heavily subsidized school digitalization under the assumption that technologically enhanced classrooms naturally democratize learning. However, this assumption is fiercely debated. The compensatory hypothesis posits that highly digitalized schools act as institutional equalizers by providing resources unavailable at home ^{[7], [8]}. In contrast, the amplification hypothesis, grounded in the Matthew effect, suggests that infusing advanced technology into schools disproportionately benefits students who already possess foundational skills and supportive home environments, thereby exacerbating the existing digital divide.

This study seeks to meticulously decompose the multifactorial mechanisms influencing eighth graders' digital literacy. Its primary objective is to examine the mediating role of parental mediation styles, exploring how structural factors like household income and parental education dictate specific mediation strategies (restrictive, active/instructive, or co-use), which in turn facilitate or hinder digital skill acquisition ^[9]. The second, more theoretically advanced objective is to explore the cross-level moderating impact of school digitalization on these family dynamics. By applying a multilevel ecological perspective, this study tests the competing compensatory and amplification hypotheses to determine if technological infrastructure in schools mitigates or magnifies structural disadvantages. Ultimately, this research bridges development psychology, educational sociology, and digital divide literature, providing critical empirical evidence to shift policy focus from device-centric deployments to individualized, pedagogy-driven interventions and culturally sensitive home-school collaborations.

2. Literature Review and Theoretical Framework

2.1. Ecological Systems Theory and Digital Literacy

Grounded in Urie Bronfenbrenner's Ecological Systems Theory, this study analyzes adolescent digital development through the interaction of micro- and mesosystems. The family and school represent the two most critical microsystems where eighth graders actively engage with technology. The family dictates foundational digital exposure influenced by socio-economic conditions, while the school serves as a formal institutional space for structured learning. The mesosystemic interaction between structural advantages from the home and the institutional socialization of information systems ultimately shapes cognitive development in the digital age ^[10]. Digital literacy itself is conceptualized multidimensionally, transcending basic operational skills to include information navigation, critical evaluation of online environments, and strategic safety management. Empirical evidence consistently demonstrates that family socioeconomic status, defined by parental education, occupation, and household wealth, is a primary determinant of these advanced digital competencies. High-SES families leverage economic and human capital to provide diverse technological ecosystems and model sophisticated digital behaviors, whereas lower-SES families often face systemic deficiencies that hinder the development of specialized cognitive-technological skills.

2.2. The Mediating Role of Parental Mediation

The translation of structural family wealth into adolescent digital literacy is largely facilitated through parental digital mediation. These pedagogical behaviors generally fall into restrictive mediation, active or instructive mediation, and unstructured co-use. Structural SES profoundly shapes the efficacy and adoption of these specific mediation forms ^[11]. High-SES parents, possessing greater digital self-efficacy and adaptable resources, are uniquely positioned to employ active and instructive mediation. This approach provides eighth graders with the necessary cognitive scaffolding to build

self-regulation and acquire higher-order digital knowledge. Conversely, parents from lower socioeconomic backgrounds, facing higher systemic stress and weaker personal digital skills, often rely on restrictive mediation. While some rules are necessary, overly restrictive environments deny early adolescents the exploratory freedom essential for fostering advanced technological resilience and application, establishing parenting styles as a crucial psychological mechanism in the digital divide.

2.3. The Moderating Effect of School Digitalization and Hypotheses

The role of institutional intervention in altering the intergenerational transmission of digital disadvantage is highly contested, leading to two primary theoretical frameworks. The compensatory hypothesis posits that publicly funded, highly digitalized schools act as equalizers, bridging the gap by providing standardized technological resources and instruction lacking in low-SES homes ^[12]. Conversely, the amplification hypothesis, grounded in the Matthew Effect, argues that inserting advanced digital infrastructure without addressing underlying structural inequalities exacerbates disparities. Under this view, advantaged students with prior active home mediation use school technology for complex, creative learning, while disadvantaged students lack the prerequisite foundation, thereby widening the skills gap ^[13]. Synthesizing these perspectives, this study hypothesizes that family SES has a significant positive direct effect on digital literacy (Hypothesis 1) and that parental mediation styles significantly mediate this relationship (Hypothesis 2). Finally, the study hypothesizes that the structural level of school digitalization exerts a cross-level moderating effect on this mediated relationship, empirically testing the compensatory versus amplification models (Hypothesis 3).

3. Methodology

3.1. Subjects, Procedures, and Ethical Considerations

To rigorously examine the proposed multi-level moderated-mediation model, this study utilizes a stratified cluster-random-sampling design targeting eighth graders across urban, suburban, and rural educational settings. This geographic and economic stratification ensures sufficient variance in both the macro-level school digitalization variable and the micro-level family socioeconomic status. The sampling strategy targets a minimum of fifty distinct educational institutions, preserving the ecological validity of the nested classroom data to yield a sample exceeding 1,500 students. Data collection strictly adheres to ethical governance protocols, requiring written informed consent from school administrators, parents, and the adolescents. To minimize social desirability bias, anonymous, secure web-based questionnaires are administered in school computer labs under standardized supervision by the research team, ensuring the reliability and validity of the responses.

3.2. Measures

The operationalization of variables relies on robust, multidimensional indicators. Family SES is calculated using a composite index of parental educational attainment, occupational prestige coded via the International Socio-Economic Index, and a family wealth scale assessing material assets, standardized via principal component analysis. Parental mediation styles are assessed through a multidimensional scale capturing the frequency of restrictive, active/instructive, and co-use behaviors over a six-month period. To avoid the self-efficacy fallacy common in self-reported skills, adolescent digital literacy is measured using a Situational Judgment Test that evaluates operational ability, critical information processing, and online safety capabilities in realistic scenarios. Finally, the Level-2 macro-variable, school digitalization level, is measured through objective administrative audits

evaluating structure-wide bandwidth, interactive software utilization, curriculum integration, and technical support availability, preventing student reporting bias.

3.3. Data Analysis Plan

The data analysis is executed in multiple phases. Preliminary analyses address missing datasets using full information maximum likelihood and assess normality and multivariate outliers. Common method variance for the self-reported Level-1 variables is evaluated using Harman's single-factor test. The core hypotheses are tested using Hierarchical Linear Modeling to account for the nested nature of the data, which violates the independence assumption of ordinary least squares regression. A fully unconditional null model first determines the intraclass correlation coefficient to quantify the variance in digital literacy attributable to between-school differences. Subsequently, a Level-1 random intercept model tests the direct effects of SES and the mediating role of parenting styles utilizing Monte Carlo simulations for robust confidence intervals. Ultimately, a full Level-2 intercepts-and-slopes-as-outcomes model introduces the school digitalization variable to test the cross-level interactive effects, mathematically adjudicating whether the institutional infrastructure flattens or steepens the trajectory of digital inequality.

4. Results

Preliminary analyses confirmed the dataset's suitability for complex modeling. Descriptive statistics indicated normal distributions, and a bivariate Pearson correlation matrix aligned with the theoretical framework, showing that Family SES positively correlated with both adolescent digital literacy and active parental mediation. Harman's single-factor test yielded a primary factor accounting for minimal variance, confidently ruling out significant common method bias (CMV) in the self-reported Level-1 data.

The analytical progression commenced with a fully unconditional Null Model to partition the variance in eighth graders' digital literacy. The resulting Intraclass Correlation Coefficient (ICC) indicated that a substantial portion of the variance was systematically attributable to differences between educational institutions, providing definitive empirical justification for utilizing Hierarchical Linear Modeling (HLM). Subsequently, the Level-1 Random Intercept Model confirmed Hypothesis 1 by demonstrating a significant positive direct effect of Family SES on digital literacy. Furthermore, multilevel mediation analysis supported Hypothesis 2, revealing that active parental mediation significantly mediated this relationship. High-SES families effectively cultivate digital literacy through active, instructive scaffolding, whereas the mediating effect of restrictive mediation—more common in lower-SES households—was statistically non-significant and slightly negative.

The critical test of the cross-level interaction was conducted through a full Intercepts-and-Slopes-as-Outcomes Model (Level-2). The HLM output revealed a significant cross-level interaction between School Digitalization and the Family SES slope. Simple slope analyses visualized this effect, demonstrating that in schools with high levels of digitalization, the performance gap between high-SES and low-SES eighth graders was significantly steeper and wider than in low-digitalization schools. This definitive empirical pattern robustly supports the Amplification Hypothesis (Matthew Effect) and rejects the Compensatory Hypothesis. In technologically enriched environments, digital resources act as a multiplier for existing home-based advantages, accelerating skill acquisition for privileged students while leaving disadvantaged peers further behind.

5. Discussion

The findings systematically map the transmission of digital inequality across the ecological

systems of early adolescence. The persistence of the "second-tier digital divide" is evident, as structural household wealth strongly dictates digital skill acquisition. This transmission is not merely a passive inheritance of resources but is actively facilitated through psychological mechanisms—specifically, the cognitive scaffolding provided by active parental mediation. High-SES parents leverage their digital self-efficacy to teach critical thinking and joint exploration, whereas low-SES parents, often constrained by systemic pressures, default to restrictive mediation that inadvertently stifles independent digital exploration.

Most critically, this research challenges the prevailing compensatory narrative in educational technology policies. Highly digitalized schools currently function as institutional amplifiers rather than equalizers. Students from high-income families enter these schools with the prerequisite dispositions and cognitive foundations to utilize advanced software for complex creation and analysis, treating school technology as an extension of their enriched home environments. Conversely, without individualized pedagogical support to replace absent active mediation at home, low-SES eighth graders often engage with school technology only at a basic, operational level. Therefore, "one-size-fits-all" technological deployments inadvertently endorse and accelerate those already well-prepared, exacerbating educational and social divisions.

These empirical realities necessitate a paradigm shift in practical applications. School digitalization must transition from an infrastructure-centered approach to a pedagogy-driven model. Achieving "humane technology use" requires intensive, targeted teacher support for disadvantaged students, rather than merely distributing tablets. Furthermore, schools must implement comprehensive "Family Digital Literacy" programs aimed at empowering low-income parents. Training these families to shift from restrictive rules to cooperative, instructive mediation is essential to closing the wealth-based cognitive gap at its source.

6. Limitations and Future Directions

While this study provides a robust multilevel evaluation of the digital Matthew Effect, several methodological limitations warrant consideration. The cross-sectional design precludes definitive causal inferences. Although the theoretical sequence flows logically from socio-economic structures through parental mediation to adolescent outcomes, bidirectional influences—such as highly technological eighth graders proactively shaping their parents' mediation styles—cannot be entirely ruled out. Additionally, while the Level-2 variable utilized objective administrative data, the Level-1 variables relied on adolescent self-reports, which remain susceptible to cognitive recall errors despite passing rigorous variance tests.

Future research should employ longitudinal designs spanning multiple stages of secondary education to track the long-term trajectory of the amplification effect and determine if institutional interventions can eventually reverse it. Furthermore, exploring the "third-level digital divide" is crucial to understanding whether adolescent digital literacy translates into tangible long-term academic or career advantages. Integrating qualitative or mixed-methods approaches, such as ethnographic observations in digitalized classrooms, would provide deeper insights into the hidden curriculum and the precise moments of cognitive friction experienced by lower-SES students, thereby informing more highly targeted pedagogical frameworks.

7. Conclusions

This research fundamentally rejects the technologically deterministic optimism prevalent in modern educational discourse. By examining the nested ecologies of home and school, it reveals that digital inequality transcends mere material access, manifesting as a complex expression of social and cultural capital. The empirical confirmation of the digital Matthew Effect underscores a grim reality:

without deliberate, human-guided pedagogical interventions, technology-rich schools disproportionately benefit the already advantaged, acting as institutional amplifiers of inequality. Achieving genuine digital equity requires abandoning superficial hardware deployments in favor of holistic ecological configurations. This entails seamlessly integrating institutional digitalization with targeted academic assistance for vulnerable students and proactive educational initiatives for their families, ensuring that technology serves as a tool for universal empowerment rather than selective stratification.

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Appendix

To maintain the replicability of this study, we must describe precisely the psychometric construction of our main latent variables in detail. Family socio-economic status (SES) did not serve as an individual item, but rather was calculated through factor analysis to obtain the SES score. This included the mother's and father's education level (c-coded from 1 to 6); occupational prestige scores based on the ISEI-08 scale; A modified version of the Family Affluence Scale (FAS III). Through combining all three types of capitals: economic, humanistic and sociological-capital-we achieved a more steady and theoretical sound picture of the small family-micro-system.

The Adolescent Digital Literacy assessment introduced an innovative approach by using a Situational Judgment Test (SJT) method instead of having the students evaluate themselves directly; This design avoids the "self-efficacy fallacy". Twenty-realistic digital scenarios were given to the students: recognizing "deepfake" false information; handling complicated cookies' permissions on a new website; Troubleshooting broken HTML tags in a basic Web Editor. An Objective Approach Ensures That The Scores Reflect Actual Cognitive Competency Rather Than Just Confidence; This Is Usually Higher Among Adolescents From Wealthier Families.

B Appendix: Formal statistical equations of HLM.

The adjudication of the Compensatory versus Amplification hypotheses was conducted through the following formal mathematical framework. At **Level-1 (Individual Level)**, the digital literacy (Y_{ij}) of student i in school j is modeled as:

$$Y_{ij} = \beta_{0j} + \beta_{1j}(SES_{ij}) + \beta_{2j}(Med_{ij}) + r_{ij}$$

where β_{0j} represents the intercept (average digital literacy in school j), β_{1j} is the slope of Family SES, and β_{2j} is the slope of Parental Mediation. At **Level-2 (School Level)**, the variation in these slopes is modeled by the school's digitalization level (Dig_j):

$$\beta_{0j} = \gamma_{00} + \gamma_{01}(Dig_j) + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}(Dig_j) + u_{1j}$$

The crucial test for the **Matthew Effect** lies in the cross-level interaction term, γ_{11} . In our results, a positive and significant γ_{11} confirmed that as school digitalization (Dig_j) increases, the gap between high and low-SES students (β_{1j}) widens, thereby mathematically proving the amplification of inequality.