Effects of Generative Ai, Digital Leadership, and Teacher Professional Development on Multi-Dimensional Students Development in Xinzheng, China

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Abstract

Generative artificial intelligence (GAI), digital leadership, and teacher professional development affect multi-dimensional student development in Xinzheng, China, senior high schools. Although the level of digital infrastructure investment is high, a large number of inland schools suffer an input-output paradox, in which technological inputs are not enhanced by pedagogy or student performance. This paper develops and analyses a parallel-serial multiple mediation model grounded on I-P-O framework, digital leadership theory, social cognitive theory and UTAUT. An explanatory sequential mixed-methods design was used. Quantitative data were obtained by the administrators (n=40), instructors (n=102) and Grade 11 students (n=458) of 10 public and private schools. The quantitative results were placed within the context of semi-structured interviews with 50 stakeholders. SEM and Bootstrap resampling (5,000 iterations) were used to evaluate direct, indirect and mediation effects. The findings indicate that the use of GAI significantly predicts digital leadership ($\beta = 0.48$, $p < 0.001$) and teacher professional development ($\beta = 0.54$, $p < 0.001$). Digital leadership is a predictor of teacher professional development ($\beta = 0.61$, $p < 0.001$) and multi-dimensional student development ($\beta = 0.21$, $p < 0.001$), with teacher professional development having the strongest direct impact on multi-dimensional student development ($\beta = 0.52$, $p < 0.001$). The mediation analysis shows digital leadership and teacher professional development to be key mediators, and there is a serial mediation path (GAI → digital leadership → teacher professional development → multi-dimensional student development). The model explained 58.6% of the variance of the variance in student development, and fits well ($\chi 2/df = 1.98$, CFI= 0.94, TLI= 0.93, RMSEA= 0.041, SRMR= 0.052) and is invaried between public and private schools. Qualitative results demonstrate that integration of AI is shallow, hardware-based investment, little pedagogical change, and uneven teacher competence in AI-enhanced teaching. Even though students become more successful students, the fear of overuse of AI and lack of critical thinking remains. This work contains an empirically tested model of AI-mediated education change in non-metropolitan settings and practical suggestions to policymakers, school administrations, and teachers to facilitate sustainable and quality digital change.

Keywords: Generative AI, digital leadership, teacher professional development, student multi-dimensional development, educational digital transformation, Xinzheng, China

1. Introduction

The high pace of Industry 4.0 development has boosted the adoption of artificial intelligence (AI), especially generative AI, in the education system across the world. Guidance on Generative AI in Education and Research highlights that such technologies have significant potential to individualize the learning process, improve instructional efficiency, and promote higher-order cognitive growth in students (UNESCO, 2023). In addition to serving as instructional aids, emerging research indicates that generative AI is fundamentally transforming the pedagogical practice, instructional design, and governance frameworks of education (Crompton and Burke, 2022; Moorhouse et al., 2023; Zawodniak et al., 2024). Nevertheless, an increasing empirical data shows that technology innovation is not enough; it must be accompanied by leadership capability, instructions to teachers and students, as well as pedagogical processes that focus on the students (Liu and Hallinger, 2021; Tondeur et al., 2024).

The national education policies in China have placed digital transformation as the main driver of high-quality education development continuously, particularly with the focus on intelligent infrastructure, digital literacy, and the combination of technology and pedagogy. However, there is still a gap in implementation in most county-level and inland senior high schools. Even with the extensive implementation of smart classrooms, online platforms, and AI-assisted technologies, schools often lack the capacity to convert technological inputs into the tangible changes in the quality of teaching and in the growth of students. This dilemma is representative of a larger input output paradox, in which the investment of resources does not necessarily result in effective educational output. Organizational process viewpoints can help to make sense of this phenomenon, which is in line with the input-process-output models, which describe how the technological input should undergo institutional and instructional processes, which can produce meaningful outputs (Ilgen et al., 2005).

The recent global research is becoming more and more focused on the idea that successful digital transformation lies not only in the technological infrastructure but also in the processes of pedagogies including interactive learning and self-regulated learning that directly affect the digital skills and learning achievements of students. As an example, it has been demonstrated that self-regulated learning can greatly contribute to the digital literacy, research skills, and ethical awareness of students, and interactive learning can complement these activities, with synergistic effects on the development of students (Rattanapun et al., 2026; Badger et al., 2026). These results support the theory that multi-dimensional student development in digital space is facilitated by individual mental activities as well as instructional design and not only technology.

Digital leadership and teacher professional development are two mechanisms that have been massively identified to play an enabling role at the organizational level. Leadership defines the institutional environment of technology integration, and teacher capacity defines the quality and depth of classroom application (Voogt et al., 2023; AlAjmi, 2022; Sun and Zhang, 2023). Recent evidence also indicates that management capability and transformational leadership significantly contribute to sustainable development and institutional effectiveness in higher education contexts (Wang et al., 2026). With these developments, the literature available is still scattered, with much concerning individual relations or city situations. Additionally, there is limited literature that has placed generative AI as a fundamental antecedent in a structured analytic framework that encompasses parallel and sequential educational change process.

In order to fill these loopholes, this research paper concentrates on regular high schools in Xinzheng, a typical county-level city in central China. It theorizes the generative AI application as the input that underlies its application, school digital leadership and teacher professional development as the two mediating processes, and student multi-dimensional development as the final outcome. Using a parallel serial mediation model, the current research will elaborate on the how, why, and in what conditions the educational transformation through AI can be successfully implemented to positively impact student development. The results will likely make a contribution to the theoretical development and offer practical implications to policymakers, school heads, and teachers who want to implement digital transformation in a similar educational setting in a sustainable and quality manner.

1.1 Research Questions

1.What extent does generative AI application predict school digital leadership and teacher professional development in county-level senior high schools?

2.How do school digital leadership and teacher professional development individually and jointly predict student multi-dimensional development?

3.What parallel and serial mediating roles do school digital leadership and teacher professional development play in the linkage between generative AI application and student multi-dimensional development?

1.2 Research Objectives

1. To estimate the magnitude and direction of generative AI application's effects on school digital leadership and teacher professional development.

2. To examine the predictive roles of digital leadership and teacher professional development in explaining student multi-dimensional development.

3. To verify the significance of parallel and serial mediation pathways linking AI application to student development.

In Figure 1 shows the variables in conceptual framework. Application of Generative AI → Digital Leadership → Teacher Professional Development → Multi-dimensional Student Development(Including dual parallel mediation and one serial mediation path)

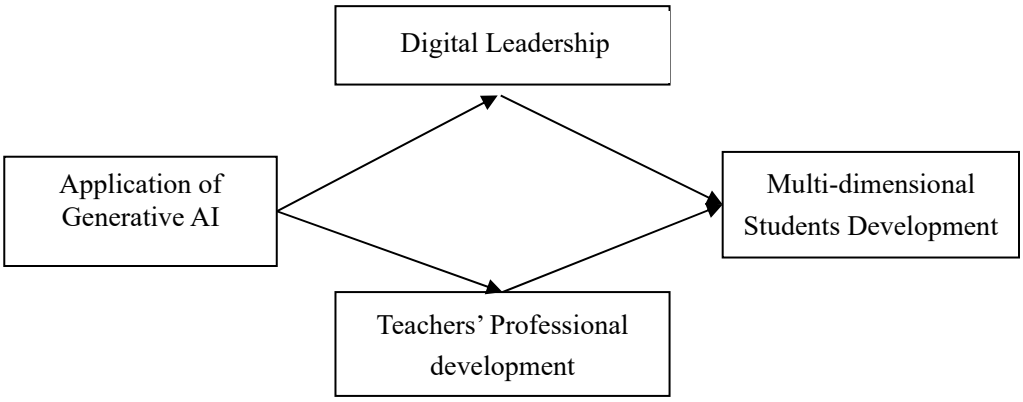

Figure 1. Conceptual Framework

Guided by the I-P-O model, this study positions generative AI application as the input layer; school digital leadership and teacher professional development as dual process variables; and student multi-dimensional development as the output layer. The framework includes direct effects, two parallel mediation paths, and one serial mediation path, forming a logically cohesive and empirically testable system.

2. Literature Review

This paper applies four theoretical perspectives that are complementary to explain how generative AI supports students in educational advancement. To maintain technology integration in technology-intensive settings, first, Digital Educational Leadership Theory focuses on setting the vision, aligning resources, instructional innovation, professional support and data-informed governance (Liu and Hallinger, 2021). Second, the Social Cognitive Theory focuses on dynamic interplay between individual, behavioral, and environmental determinants, which implies that self-efficacy and experiential learning of teachers contribute to the use of technology, the quality of their instruction, and the achievement of students (Bandura, 1986). Third, Unified Theory of Acceptance and Use of Technology (UTAUT) explains that technology adoption requires institutional support, training, and infrastructure to enhance the process of AI integration in schools (Venkatesh et al., 2003). Lastly, the Input- Process-Output (I- P-O) model connects technological inputs (GAI application) to the educational outputs (development of students) based on the digital leadership and teacher professional development. Such frameworks offer a naturalistic framework to research AI-enabled teaching reform mechanisms and directions.

2.1 The Relationship Between Generative Ai Application and School Digital Leadership

As a pivotal technological driving force for educational digital transformation, the deep application of generative AI can promote the upgrading of school governance models, encouraging administrators to build forward-looking digital visions, optimize strategic layouts, and strengthen resource coordination. Existing studies indicate that a mature technological environment and widespread tool adoption push schools to improve digital governance and form systematic digital leadership (UNESCO, 2023; Moorhouse et al., 2023). In the practice of county-level regular senior high schools, the extensive use of generative AI accelerates digital transformation, improves organizational support systems, and further enhances school digital leadership.

H1: Application of generative AI positively impacts digital leadership.

2.2 The Relationship Between Generative Ai Application and Teacher Professional Development

The deep integration of generative AI into teaching practices raises new requirements for teachers' professional competence and serves as a vital external driving force for teacher professional development in the digital era. Research based on the AI-TPACK framework and Social Cognitive Theory shows that the popularization and application of generative AI stimulate teachers' learning motivation, update their teaching beliefs, and encourage them to improve technological application and teaching innovation capabilities (Zawodniak et al., 2024; Mishra et al., 2006). In senior high school education scenarios, generative AI application helps teachers break through the limitations of traditional teaching, conduct intelligent instructional design and personalized guidance, and achieve coordinated

development of professional literacy and teaching competence.

H2: Application of generative AI positively impacts teacher professional development.

2.3 The Relationship Between School Digital Leadership and Teacher Professional Development

Extant empirical studies consistently confirm that school digital leadership exerts a significant positive predictive effect on teacher professional development.

Incorporating digital technology in teaching and learning is associated with the technological pedagogical content knowledge (TPACK) of teachers, their digital teaching competence, and the teachers' self-efficacy in technology integration. Irwanto et al. (2022) have demonstrated that by showing that systematic professional development and supportive institutional environments have a significant influence on teachers' technological pedagogical content knowledge (TPACK), digital teaching competence, and digital integration self-efficacy (Zeng et al. (2022).

Hallinger & Wang (2024) further pointed out that sustained investment and strategic guidance in digital transformation are critical for promoting teachers' acceptance and in-depth use of generative AI. In the Chinese context, Liu & Hallinger (2021) found that digital leadership has a significant positive impact on teacher professional development ($\beta = 0.58$, $p < 0.001$), with resource allocation, professional training, and organizational culture as core transmission paths. Nevertheless, existing research presents obvious limitations: most studies focus on compulsory education or higher education, with insufficient localized evidence for county-level senior high schools; few studies incorporate generative AI into the analytical framework, resulting in limited explanation of mechanisms in technology-embedded contexts.

H3: Digital leadership positively impacts teacher professional development.

2.4 The Relationship Between School Digital Leadership and Student Multi-Dimensional Development

School digital leadership not only affects teachers but also exerts a direct impact on student development. Liu & Hallinger (2021) revealed that digital leadership directly improves student learning outcomes by optimizing learning environments, promoting instructional innovation, and improving evaluation systems. The positive effect of digital leadership on student learning has also been consistently found in previous research, which includes its ability to promote instructional innovation, enhance teachers' digital competency and promote enabling school cultures for ICT-enhanced learning (Liu and Hallinger, 2021; Voogt et al., 2023). Further evidence also indicates that digital leadership can positively impact student learning directly and indirectly by enhancing teacher professional practice and organizational capacity. However, two widely recognized limitations exist: first, the direct effect of digital leadership on student development is generally weaker than the indirect effect, indicating that the internal transmission mechanism remains incompletely explained; second, very few studies have integrated generative AI into the model, making it difficult to explain how emerging technologies reshape influential pathways.

H4: Digital leadership positively impacts multi-dimensional student development.

2.5 The Relationship Between Teacher Professional Development and Student Multi-Dimensional Development

A large body of theoretical and empirical evidence supports the positive effect of teacher professional development on student development. Leithwood et al. (2022) noted that the improvement of teachers' digital teaching ability and innovative strategies can significantly enhance classroom quality and promote students' higher-order thinking and academic performance. Wang et al. (2026) confirmed that teachers' professional growth in AI-integrated teaching exerts a stable predictive effect on students' digital literacy and innovative ability. For Chinese regular senior high schools, In the Chinese educational context, effective instructional leadership and professional development for teachers are found to be effective tools to enhance the quality of teaching and diminish achievement gaps between schools (Liu & Hallinger, 2021). However, most existing studies only focus on direct effects and lack sufficient exploration of the chained mediation mechanism. Under the widespread application of generative AI, the specific pathways through which teacher professional development affects student development still require further empirical verification.

H5: Teacher professional development positively impacts multi-dimensional student development.

2.6 The Mediating Role of School Digital Leadership via Generative Ai Application and Student Multi-Dimensional Development

Based on the Input-Process-Output (I-P-O) model, school digital leadership, as a key organizational mediator, undertakes the transmission function between technological input (generative AI application) and educational output (multi-dimensional student development). Generative AI application enhances school digital leadership by providing technical support for school management modernization, which in turn promotes student development in academic

achievement, digital literacy, cognitive ability, and innovative ability through optimizing digital teaching resources and building a student-centered learning environment (Nguyen & Ng, 2022; Voogt et al., 2023). Empowering technology (such as AI) to enhance learning outcomes rests on the shoulders of digital leadership which has already been shown in previous studies to be a key factor in making technology more impactful. Effective digital leaders define strategic visions, allocate technological and human resources, support continuous professional learning and foster evidence-informing instructional innovation, empowering teachers to incorporate AI into effective classroom practice and improve learning (UNESCO, 2023; Liu & Hallinger, 2021; Voogt et al., 2023). Moreover, in county-level senior high schools, digital leadership can effectively alleviate the imbalance of generative AI application in rural and urban areas, ensuring that technological dividends benefit the multi-dimensional development of all students. However, empirical tests targeting the specific context of county-level senior high schools and the integration of generative AI are still scarce, and the intensity of the mediating effect remains to be further measured by empirical data.

H6: Digital leadership play mediates the relationship between generative AI application and student development.

2.7 The Mediating Role of Teacher Professional Development Between Generative Ai Application and Multi-Dimensional Student Development

Teacher professional development acts as an individual-level mediator connecting technological application (generative AI) and student outcomes (multi-dimensional development), as teachers are the direct implementers of transforming generative AI technology into classroom teaching practice. Generative AI application promotes teacher professional competence in AI integration, digital instructional design and personalized teaching, which further translates into high-quality teaching practices and ultimately improves student multi-dimensional development in academic performance, digital literacy, critical thinking and collaborative ability (Zawodniak et al., 2024). Teacher professional development is the key mechanism through which technological innovations are translated into meaningful educational outcomes, according to Social Cognitive Theory (Bandura, 1986) and Technological Pedagogical Content Knowledge (TPACK) (Mishra & Koehler, 2006). Professional development in AI is systemic, which boosts teachers' digital competence, pedagogical knowledge, and confidence in using AI in teaching, improving student engagement, higher order thinking and innovative problem-solving skills (UNESCO, 2023; Zawodniak et al., 2024). The results indicated that the benefits of generative AI in education are significantly tied to the educators' capacity to use the technologies to empower student-centered pedagogical practices, and less to the technology itself. Moreover, teachers' professional growth in AI-based pedagogy helps to enhance their ability to inspire students to learn independently, self-regulatedly, and think in a higher-order manner, as evidenced by the use of more personalized, interactive, and learner-centered teaching.Additionally, through more personalized, interactive, and learner-centred teaching, teachers' professional growth in AI-supported pedagogy supports students' autonomous learning, self-regulated learning, and higher order thinking in the context of Chinese county-level senior high schools. With increased proficiency in using generative AI to enhance teaching, teachers can more effectively engage students in inquiry-based learning, offer timely formative feedback, and assist with students' knowledge building through independent means. In the final stages, the pedagogical enhancements support students' development in several areas, such as academic success, digital literacy, creativity, collaborative problem-solving, and lifelong learning skills (Bandura, 1986; Mishra & Koehler, 2006; UNESCO, 2023; Badger et al., 2026).

Although relevant paths have been verified in prior studies, the parallel and chained mediation mechanisms in Chinese senior high schools require further confirmation, and the boundary conditions of this mediating effect in the generative AI context also need to be explored in depth.

H7: Teacher professional development mediates the relationship between generative AI application and student development.

3. Method

The research adopted an explanatory sequential mixed-methodology design, where quantitative analysis was done, and then a qualitative inquiry followed to explain and put the statistical findings into perspective. The quantitative stage, which focused on structural equation modeling (SEM), investigated the connections and intermediates between generative AI application, digital leadership, teacher professional development, and student development. The thematic analysis used in the next qualitative phase was necessary to deepen interpretations and increase ecological validity (Creswell and Plano Clark, 2018).

The target population included school administrators, core-subject teachers, and Grade 11 students of 10 senior high schools (five public and five private) in the city of Xinzheng, Henan Province, China. The stratified cluster sampling

method was utilized to make sure that it represents the school types and the stakeholder groups (Cochran, 1960,1977). The number of valid questionnaires received was 600 which consisted of 40 administrators, 102 teachers and 458 students, giving an effective response rate of 78.9%. Also, 50 stakeholders were purposely chosen to take part in semi-structured interviews to give in-depth views (Patton, 2015).

The measurement instrument consisted of four latent constructs adapted from previously validated scales in the literature. Generative AI Application was adapted from UNESCO (2023); School Digital Leadership from Liu and Hallinger (2021); Teacher Professional Development from Tondeur et al. (2024); and Student Multi-dimensional Development from established educational outcome scales. All items were reviewed by three experts to ensure content validity and contextual appropriateness for Chinese senior high schools. A pilot study involving 30 participants confirmed satisfactory reliability before the full survey was conducted. All 36 questionnaire items were scored on a five-point Likert scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree. Higher scores indicated higher construct levels. Reliability analysis demonstrated high internal consistency (Cronbach 0.89 to 0.93) (DeVellis, 2017). The confirmatory factor analysis supported construct validity, with all average variance extracted (AVE) values above the recommended amount of 0.50, a good indicator of convergent validity (Hair et al., 2019).

The SPSS version 26.0 was used to analyze quantitative data in terms of descriptive statistics and initial analysis, and AMOS version 24.0 to conduct structural equation modeling and hypothesis testing. The Bootstrap method with 5,000 resamples was used to measure the effects of mediation by estimating the indirect effects and the confidence intervals (Preacher and Hayes, 2008). Thematic analysis (open, axial and selective coding) was used to analyze the qualitative data in three stages (Braun and Clarke, 2006). The inter-coder reliability was determined by a Cohens Kappa of 0.87 which represented a high degree of coding agreement (Cohen, 1960).

4. Results

4.1 Descriptive Statistics

All core variables scored at relatively high levels (M = 3.58–3.72). Notable weaknesses included shallow AI integration, limited data-driven decision-making, and relatively low student innovative ability.

Table 1. Demographic Characteristics of Participants (n = 600)

Variable	Category	Frequency	Percentage (%)
Role	Administrator	40	6.7
	Teacher	102	17.0
	Student	458	76.3
Gender	Male	312	52.0
	Female	288	48.0
School Type	Public	384	64.0
	Private	216	36.0

The demographic profile of the 600 participants is given in Table 1. Most of them were students (76.3%), teachers (17.0%), and administrators (6.7%), which means that the sample is mostly student-centered. Gender wise, there is a comparatively equal representation of 52.0% of males and 48.0% females. As to school type, majority of the respondents belonged to the public schools (64.0%), with 36.0% belonging to private schools. Within the whole sample, there is a good representation of diversity in terms of roles and school settings, which justifies the external validity of the results.

4.2 Correlation Analysis

All variables were significantly and positively correlated ($r = 0.49–0.68$, $p < 0.01$). The strongest correlation occurred between teacher professional development and student multi-dimensional development ($r = 0.68$).

Table 2. Correlation Matrix of Core Variables (n = 600)

Variable	1. Generative AI Application	2. School Digital Leadership	3. Teacher Professional Development	4. Multi-dimensional Student Development
1. Generative AI Application	1.00	-	-	-
2. School Digital Leadership	0.52**	1.00	-	-
3.Teacher Professional Development	0.58**	0.65**	1.00	-
4.Multi-dimensional Student Development	0.49**	0.57**	0.68**	1.00

**Note: $p < 0.01$ (two-tailed).

4.3 Regression Analysis

Table 3. Hierarchical Regression Analysis of Key Predictors (n = 600)

Dependent Variable	Step	Predictor	β	t	p	R^2	ΔR^2
School Digital Leadership	1	Covariates	–	–	< .01	.08	.08
	2	Generative AI Application	.48	11.25	< .001	.31	.23
Teacher Professional Development	1	Covariates	–	–	< .01	.07	.07
	2	Generative AI Application	.54	13.12	< .001	.38	.31
	3	School Digital Leadership	.61	14.58	< .001	.44	.06
Student Multi-dimensional Development	1	Covariates	–	–	< .05	.04	.04
	2	School Digital Leadership	.53	12.09	< .001	.32	.28
	3	Teacher Professional Development	.38	8.96	< .001	.52	.20

Note. Covariates = school type, participant identity, and age/teaching experience. All reported coefficients are standardized (β).

The hierarchical regression analysis was carried out to consider the predictive impacts of the application of generative AI, school digital leadership, and teacher professional development on the critical outcome variables. With the covariates (school type, participant identity, and age/teaching experience) controlled, generative AI application was a significant predictor of school digital leadership (23-percent more, β =.48, p <.001) and teacher professional development (31-percent more, 2 =.54, p <.001), respectively.

In addition, school digital leadership predicted teacher professional development (β =.61, p <.001) with an extra 6% of explained variance on top of generative AI application. In terms of student multi-dimensional development, school digital leadership had a significant positive influence (28%), with a β =.53, p <.001. In the event that teacher professional development was included in the last step, it continued to be an important predictor (=.38, p <.001) and added value to the explanation of the student outcomes in the vast extent of 52 percent.

In general, the results indicate that the use of generative AI has an indirect effect on student development via organizational (digital leadership), and instructional (teacher professional development) channels, which is preliminary evidence of the hypothesis about the mediation framework.

4.4 Structural Equation Modeling (sem)

4.4.1 Structural Equation Modeling

The proposed parallel mediation model, which connects the application of generative AI with the multi-dimensional development of students by using school digital leadership and teacher professional development, demonstrated a good fit to the observed data. The model fit indices met or exceeded commonly recommended thresholds, indicating satisfactory model adequacy: $\chi^2 = 587.32$, df = 296, $\chi^2/df = 1.98$, CFI = 0.94, TLI = 0.93, RMSEA = 0.041 (90% CI: 0.036–0.046), and SRMR = 0.052. The above findings indicate that the proposed model is highly justified by the presented data.

Also, the model explained a significant portion of the variance in student multi-dimensional development ($R^2 = 0.586$, $p < 0.001$), which is a large portion of the future. This degree of variance explained indicates that the combined effect of the application of generative AI, digital leadership, and teacher professional development has a strong impact on the student outcomes. In general, the results give strong empirical evidence to the suggested mediating framework in the backdrop of the digital transformation in county-based senior high schools.

Table 4. Direct Effects (structural Model Results, N = 600)

Hypothesis	Path	β	p-value	Result
H1	GAI → SDL	0.48	< .001	Supported
H2	GAI → TPD	0.54	< .001	Supported
H3	SDL → TPD	0.61	< .001	Supported
H4	SDL → SD	0.21	< .001	Supported
H5	TPD → SD	0.52	< .001	Supported
–	GAI → SD (Direct)	0.08	> .05	Not significant

Note. GAI = Generative AI Application; SDL = School Digital Leadership; TPD = Teacher Professional Development; SD = Student Development.

Table 5. Mediation Effects (bootstrap = 5,000, N = 600)

Effect Type	Path	Indirect Effect (β)	95% CI	Significance	H	Effect (%)
Total Effect	GAI → SD	0.57	[0.49, 0.65]	Significant	–	100%
Direct Effect	GAI → SD	0.08	[-0.01, 0.17]	Not significant	–	14.04%
Total Indirect Effect	GAI → SDL/TPD → SD	0.49	[0.43, 0.55]	Significant	–	85.96%
Specific Indirect 1	GAI → SDL → SD	0.10	[0.06, 0.14]	Significant	H6	17.54%
Specific Indirect 2	GAI → TPD → SD	0.28	[0.22, 0.34]	Significant	H7	49.12%
Serial Indirect	GAI → SDL → TPD → SD	0.11	[0.07, 0.15]	Significant	–	19.30%

4.4.2 Direct Effects

The results of the structural model show that all the hypothesized direct relationships (H1-H5) are significant ($p < .001$). In particular, the application of generative AI is a significant predictor of school digital leadership ($\beta = 0.48$) and teacher professional development ($\beta = 0.54$). School digital leadership, in turn, has a strong positive influence on teacher development (0.61) and moderate influence on student development (0.21). The direct effect on the development of students is the highest with teacher professional development ($\beta = 0.52$), which underscores its pivotal role in digital transformation into educational outcomes.

Notably, the direct correlation between the application of generative AI to student development is not statistically significant (0.08, $p > .05$), which indicates that AI does not positively affect student performance directly without organizational and teaching mechanisms.

4.4.3 Mediation Effects

The bootstrap analysis (5,000 resamples) proves that overall impact of the application of the generative AI on the development of students is significant (85.96 percent) with 0.57 percent of that impact being mediated via indirect mechanisms. The overall indirect effect is significant ($\beta = 0.49$), and the direct effect is insignificant, which implies that the effect is fully mediated.

The strongest of these mediation pathways are teacher professional development ($\beta = 0.28$, 49.12%), serial pathway

via digital leadership and teacher development (β = 0.11, 19.30%), and pathway via digital leadership (β = 0.10, 17.54%). These results indicate that the effect of generative AI on student development follows the sequential approach, i.e. improving the digital leadership at the school level, which is subsequently strengthening the teacher professional capacity, and eventually, student outcomes.

4.5 Qualitative Findings

Interviewees consistently reported: surface-level AI use dominated daily practice; schools invested heavily in hardware but lacked systematic software mechanisms; teachers possessed basic operational skills but struggled with deep integration; students benefited academically but often over-relied on AI, weakening independent thinking. These qualitative findings are consistent with the statistical patterns of shallow AI integration and uneven capacity revealed in the quantitative results.

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5. Discussion

5.1 Direct Effects

The present study shows that the use of generative artificial intelligence (GAI) is significantly related to school digital leadership and teacher professional development. The results align with recent international studies, which indicate that generative AI is playing a significant role in the digital transformation of education while simultaneously being a technology that is essential to teaching and learning (UNESCO, 2023; Crompton & Burke, 2024; Zawodniak et al., 2024). The findings suggest that schools with greater GAI adoption are more likely to have more robust practices of digital leadership and are more likely to be more active in supporting teachers' professional learning, which fosters an organizational culture that promotes ongoing educational innovation.

The results can be attributed to the Unified Theory of Acceptance and Use of Technology (UTAUT), which suggests that, apart from technology availability, facilitating conditions, institutional support, leadership commitment and the users' expectations of performance improvement are required for the successful adoption of technology (Venkatesh et al., 2003). In this case, GAI is an organizational catalyst that helps school leaders develop strategic digital visions, invest in technological resources, redesign policies, and create professional learning systems. These findings indicate that classroom technology use alone is insufficient to improve educational outcomes. AI is a catalyst for organizational change.

The significant positive relationship between digital leadership and teacher professional development also confirms previous international findings (Liu and Hallinger, 2021; Liu & Hallinger, 2021; Voogt et al., 2023). Effective digital leaders provide an organisation with a positive environment by setting out a clear digital plan, facilitating innovation, offering ongoing professional development and skills training and investing in adequate technological equipment. The leadership practices boost teachers' confidence, digital competencies, and preparedness to use AI in everyday teaching practices. Leadership as an organizational factor is consistent with the previous studies and the present findings indicate that it is one of the most influential factors in the context of education, making education more sustainable through digitalization.

Moreover, teacher professional development had the highest direct impact on multi-dimensional student development. This discovery is in line with the body of educational research that shows teacher quality as the strongest school-based factor affecting student learning outcomes (Leithwood et al., 2022; Tondeur et al., 2024). While generative AI offers significant technological possibilities, the educational impact is entirely reliant on teachers' pedagogical skills. The teachers with a deeper understanding of AI knowledge, digital pedagogical competencies, and creative pedagogical approaches can better leverage technological affordances to create engaging learning experiences that promote students' academic success, digital literacy, creativity, critical thinking, collaboration, and self-directed learning. Thus, technology cannot be the solution to enhancing student outcomes—it is the professional capacity of the teachers that will make the difference in whether or not AI can effectively create quality education.

5.2 Mediation Mechanisms

One of the most significant contributions of this study is the identification of the mechanisms in which generative AI impacts students' development, both organizationally and pedagogically. While there was a significant relationship between GAI and digital leadership, as well as teacher professional development, there was no direct significant relationship between GAI and student multi-dimensional development. Rather, the impact of AI was indirect, and mediated by school digital leadership and teacher professional development. This discovery indicates that adopting AI tools in schools is not enough to guarantee positive learning outcomes.

The results affirm the Input-Process-Output (I-P-O) model (Ilgen et al., 2005), which holds that there is a need to transform the technological inputs through the processes of the organization and the teacher, before meaningful educational outputs can be produced. In the proposed framework, generative AI is the technological input, digital leadership and teacher professional development the organizational and teaching processes, and multi-dimensional development of students the educational output. It is without doubt that technological investments in the absence of these mediating processes are not enough to give better student learning outcomes.

The results also support Social Cognitive Theory (Bandura, 1986) which states that the results of learning are the product of the interaction of environmental factors, actions, and personal abilities. While generative AI presents new learning opportunities, students only benefit when teachers are confident and digitally competent, and have the pedagogical expertise to effectively leverage AI in their classrooms. However, school leaders also shape this process by fostering positive school cultures, collaborative learning and ongoing professional development. Thus, changes in teachers' instructional behaviors are what bring about improvements in student development and not technology.

In the same vein, the results contribute to the explanatory power of UTAUT. In the present study, the authors show that, beyond the technological acceptance, institutional facilitating conditions are still crucial to securing educational outcomes when using technology, namely: visionary digital leadership, organizational support and systematic teacher development. The introduction of AI should therefore be considered an ongoing journey of change within the organization, not merely a piece of technology.

The results of the significant serial mediation pathway (Generative AI → Digital Leadership → Teacher Professional Development → Student Development) further support a progressive model of educational transformation. Leadership and teacher development do not exist in isolation but are done in a sequence. School leaders set the direction, allocate resources and foster supportive digital school cultures, which then allow teachers to build upon their professional skills. Thereafter, better teaching and learning leads to better cognitive, academic, digital and socio-emotional development of students. This sequential mechanism offers a more thorough explanation of how AI is driving the transformation of education than previous research which looked at individual direct relationships between these variables (Crompton and Burke, 2024; Liu and Hallinger, 2021; Zawodniak et al., 2024).

In general, the results of the mediation indicate that the effectiveness of using AI in educational organizations is not only based on the use of technological innovations but also on the ability to build and develop pedagogical innovations that can be applied effectively through leadership and professional learning.

5.3 Integration of Quantitative and Qualitative Findings

The explanatory sequential mixed methods research design allowed qualitative results to compliment and explain the statistical relationships found using the structural equation modeling results. The qualitative findings from the interviews generally confirmed the quantitative findings, and offered greater understanding of the reasons for the indirect effects of generative AI on student development.

First, while the quantitative analysis showed that teacher professional development was the biggest influence on student development, the interview respondents all noted that many teachers were using AI primarily to aid them in lesson planning, creating worksheets, designing presentations, and administrative tasks, with a focus on non-transformative pedagogical applications. The primary uses of AI by few teachers were to support inquiry-based learning, collaborative problem solving, personalized instruction, and higher-order thinking activities. The importance of teacher professional development as a mediator in the structural model in this study can be explained based on these observations. If the programmer is not well-trained, AI cannot be a powerful learning tool.

Secondly, participants often mentioned significant investments in digital infrastructure, such as the installation of smart classrooms, interactive displays, cloud platforms, and AI software. But several respondents noted that organizational policies and practices had not changed as quickly as investments in technology. School leaders recognized that hardware purchases were more likely to be a bigger priority than curriculum revision, mentoring teachers, or innovation. The qualitative results account for the non-statistical significance of the direct effect of GAI on student development. Technology cannot be used to enhance learning without changes to the organization and instruction.

Third, interviews indicated that there is a wide range of teachers' competence with AI. Some teachers showed confidence in the use of AI for instructional design and formative assessment, while some teachers had doubts about prompt engineering, ethical use of AI, personalized learning and classroom management in learning environments supported by AI. The overall pattern of digital competence across teachers provides some justification for the quantitative result that teacher professional development is the most powerful link between the use of AI and student development. Thus, ongoing professional development is crucial to addressing inequities in the implementation of AI

in schools.

In conclusion, students' overall feedback on the use of AI in learning was positive, with a general sense of enhanced efficiency and personalized feedback, and improved information retrieval. However, some participants voiced concerns about the potential impact of AI on independent thinking, creativity, and problem-solving skills. Teachers also highlighted the importance of using AI tools as a complement to tasks that promote critical thinking, collaboration, and true knowledge building. The results of this study support the UNESCO recommendation (2023) to use AI in a responsible way, as it should be used in conjunction with the human judgment, which necessitates technological competences and sound pedagogical practices.

As a whole, the combination of quantitative and qualitative evidence clearly illustrates that sustainable digital transformation is not only about technology. To ensure meaningful contributions of AI to students' all-around development and educational innovation, the development of leadership capacity and teacher competence, organizational culture, and pedagogical innovation should be coordinated.

6. Contribution

6.1 Theoretical Contributions

The present study has several significant theoretical contributions to the growing body of literature about AI and educational digital transformation.

First, it extends Digital Leadership Theory with the evidence that digital leadership is not just a managerial competency, but a key mediational process that can influence the use of AI to enhance learning. Educational research has tended to focus on the direct relationship between leadership and educational outcomes, but the current research suggests that the relationship between leadership and technological innovation is also one of influence on teacher development and students' learning.

Second, in terms of implementation, the study extends the application of UTAUT in educational context. The findings do not only highlight technology acceptance, but show that facilitating conditions are present at various organizational levels such as leadership practices, institutional support, and constant professional learning. This definition takes the UTAUT approach beyond the adoption of technology to the institutional digital transformation.

Third, the findings of this study highlight the three-way interaction between environmental support, leadership behavior, and teacher self-efficacy on the implementation of AI technologies into effective teaching practice, which enriches the framework of SCT. The results demonstrate that the ultimate impact of AI on student outcomes is through changes in teachers' professional competence.

Last but not least, the study builds on the Input–Process–Output (I-P-O) model by testing a parallel-serial mediation model, which empirically suggests that the role of technology in education has a sequential relationship between organizational processes and instruction. This integrated model can explain more fully the transformation of education that has been facilitated by AI than the previous studies which looked at isolated direct effects. Furthermore, this study examines the central China county-level senior high schools, providing valuable contextually relevant data from outside of the metropolitan context that enhances the generalizability to the international digital transformation literature.

6.2 Practical Implications

The implications of the findings are practical for both the policy maker, educator, the educational leader, and the teacher educator.

The policy needs to go along with the infrastructure investment by policymakers and Ministry of Education, to bolster leadership capacity, professional development, curriculum innovation, and ethical governance of AI. The development of human capacities must be emphasized alongside investments in technology in national AI strategies to achieve maximum educational effectiveness.

The school's leadership and head are more than just buyers of AI technologies; they are the ones who must make it successful. It is important for leaders to set clear digital visions, build cooperative learning environments, allocate resources strategically, and create systematic professional learning programs to support teachers' abilities in long-term use of AI.

Professional development and teacher education institutions must shift the focus from how to use AI to how it enhances instruction to foster student success.Teacher education institutions and professional development providers

should shift the focus from the operational use of AI to pedagogical innovation to promote student success. The focus of professional learning programs should be on AI-supported instructional design, personalized learning, formative assessment, ethical use of AI, critical thinking development, and collaboration strategies for learning. Continuous mentoring and communities of practice can also help teachers to apply technological knowledge to innovation in the classroom.

Last, but not least, schools should embrace the balanced use of AI in their implementation, promoting responsible and purposeful technology use. AI should not be seen as a direct substitute for teachers or students' independent thinking, but as a complement to their education that can boost creativity, the spirit of investigation, cooperation, and thinking at a higher level. This in turn will contribute towards sustainable digital transformation and the all-round growth of students in ever more digital educational environments.

7. Limitations and Future Research

First, although the sample is representative of county-level senior high schools in central China, the geographic scope is limited to Xinzheng. Readers should be cautious when generalizing to coastal or western regions with distinct economic and educational contexts. Nevertheless, the sample reflects structural conditions widely shared by inland counties in central and western China, supporting meaningful contextual generalizability.

Second, this study employs a cross-sectional design; despite rigorous SEM modeling, causal inference remains limited. Future longitudinal designs can strengthen causal interpretation.

Consistent with emerging longitudinal designs in international research, future studies may adopt multi-wave data to strengthen causal inference. Cross-regional comparisons would also further contribute to global knowledge production.

8. Conclusion

This mixed-methods study confirms that generative AI application promotes student multi-dimensional development entirely through the mediating pathways of school digital leadership and teacher professional development. Both parallel and serial mediation mechanisms are statistically meaningful, with teacher professional development serving as the primary mediator. Qualitative evidence further illustrates that digital transformation in county-level senior high schools remains constrained by surface-level AI adoption, hardware-dominated investment, and uneven teacher capacity. These findings illuminate the core “black box” of AI-enabled education and provide clear, practical routes for advancing sustainable, high-quality digital transformation in similar basic education systems.

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Authors contributions

ZN: Conceptualization; Methodology; Investigation; Data curation; Formal analysis; Writing - original draft. TD: Supervision; Review & editing. SR: Methodology; Validation; Visualization; Writing – review & editing, All authors have read and approved the final manuscript.

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Disclosure of AI Use

The authors independently developed the study conception, literature review, research design, methodology, data collection, data analysis, interpretation of the findings, discussion, and conclusions. Generative AI tools were used only for minor language editing and grammatical refinement after the manuscript was completed. The authors accept full responsibility for the accuracy, originality, and integrity of this manuscript.

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Data sharing statement

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