

## University digital infrastructure and student-driven innovation: Evidence from higher education institutions in Shandong, China

 Li Xinyu<sup>1\*</sup>,  Wan Nur Tasnim Wan Hussin<sup>2</sup>

<sup>1</sup>Zibo Polytechnic University, Zibo City, Shandong Province, China; lzn1004@163.com (L.X.).

<sup>1,2</sup>Post Graduate Centre, Management and Science University, University Drive, Off Persiaran Olahraga, Section 13,40100, Selangor, Malaysia; wan\_nurtasnim@msu.edu.my (W.N.T.W.H.).

**Abstract:** The rapid advancement of digital transformation in higher education has reshaped innovation ecosystems within universities. However, limited empirical research has examined how university digital infrastructure influences student-driven innovation and through what mechanisms this relationship operates. Drawing on the resource-based view and organizational support theory, this study investigates the direct effect of university digital infrastructure (UDI) on student-driven innovation (SDI) and the mediating role of institutional research support (IRS) within universities in Shandong Province, China. Using survey data collected from university students and employing structural equation modeling (SEM) for hypothesis testing, the results demonstrate that university digital infrastructure significantly and positively affects student-driven innovation. Furthermore, digital infrastructure is found to significantly enhance institutional research support. Most importantly, institutional research support partially mediates the relationship between digital infrastructure and student-driven innovation, indicating that digital platforms foster innovation not only directly but also indirectly through strengthening research support systems. These findings contribute to the literature by extending digital infrastructure research into the higher education innovation context and clarifying the internal mechanism linking digital resources to student innovation outcomes. Practically, the study provides policy implications for universities seeking to enhance innovation capacity through strategic digital infrastructure investment and institutional research support enhancement.

**Keywords:** China, Digital infrastructure, Higher education, Institutional research support, Mediation effect, Shandong Province, Student-driven innovation.

### 1. Introduction

#### 1.1. The Importance of Digital Infrastructure in Universities in the Digital Economy Era

The deepening of the digital economy has shifted organizational value creation logic from "factor input-driven" to "data and platform-driven," making digital transformation a key pathway to enhance organizational adaptability, resource allocation efficiency, and innovation performance [1]. In higher education, digital transformation is no longer limited to upgrading teaching tools but involves systemic transformation that requires coordinated restructuring of technological infrastructure, organizational processes, and governance structures [2, 3]. Consequently, university digital infrastructure (UDI) can be understood as the "digital foundation" supporting teaching, research, and innovation activities, encompassing high-bandwidth networks, cloud and computing resources, digital research platforms, data repositories, and online collaboration systems.

From a management perspective, digital infrastructure not only provides information connectivity but also influences the ways knowledge is acquired and reorganized, thereby reshaping the boundaries and efficiency of the innovation process [2, 3]. Related studies also show that, in the context of China, the construction of digital infrastructure is significantly associated with the allocation of higher

education resources and the evolution of regional disparities, and may support the sustainable development of the higher education system by narrowing the resource gap and improving collaborative efficiency [4]. Furthermore, as an investable, configurable, and upgradable organizational resource, the impact of digital infrastructure on innovation output often needs to be fully manifested through internal support systems and organizational mechanisms [2, 3]. Therefore, identifying "how digital infrastructure translates into innovation output at the student level" becomes a question of significant theoretical and managerial importance.

### *1.2. Shandong Province as a Key Region for Digital Education Transformation*

The Chinese government has elevated "digital education" to a national strategic priority, emphasizing the systematic modernization of the education system and efficient resource allocation through digital platforms and infrastructure development [5]. Meanwhile, the establishment and promotion of foundational platforms like the "National Smart Education Platform (Smart Education of China)" are recognized as key drivers for enhancing public education services and digital resource supply, with international organizations endorsing these efforts [6, 7].

Against this backdrop, Shandong Province, renowned for its large-scale higher education system, comprehensive industrial ecosystem, and robust digital transformation initiatives, has been actively advancing educational informatization and smart campus development in recent years. The provincial government has emphasized accelerating the systematic deployment of digital campuses, digital resources, and educational governance frameworks during the 14th Five-Year Plan period [8]. Official documents reveal that Shandong's education authorities have formulated informatization plans to enhance smart campus construction and digital application systems, creating institutional and resource environments for university digital infrastructure investment and platform-based governance [8, 9]. By focusing on Shandong's higher education institutions as a research case, this study provides a clearer examination of how digital infrastructure drives innovation output within the context of policy incentives and accelerated infrastructure development, while offering managerial insights for regional digital governance in higher education.

### *1.3. Innovation and Entrepreneurship Education and Student-led Innovation Policy Guidance*

Guided by innovation-driven and high-quality development principles, universities now serve not only as knowledge producers but also as institutions tasked with nurturing innovative talent and fostering entrepreneurial ecosystems. Notably, policies supporting student innovation and entrepreneurship have been continuously strengthened, with the State Council of the People's Republic of China [10] emphasizing the need for enhanced institutional safeguards and service support. Within higher education, innovation and entrepreneurship education has evolved from supplementary courses to become an integral component of professional training, playing a pivotal role in talent development and institutional innovation performance [11].

Meanwhile, academic research has increasingly examined how innovation and entrepreneurship education systems shape students' innovative behaviors and capabilities from organizational and institutional perspectives. On one hand, the integration of innovation education with platforms, mentors, competitions, and incubation programs is recognized as significantly influencing students' entrepreneurial intentions and innovative performance [3, 12]. On the other hand, policy and institutional environments also play a crucial role in shaping college students' innovation behaviors. However, existing studies still require more detailed explanations of the "policy objectives, organizational support, student innovation" transmission chain [3, 10]. Based on this, this paper focuses on student-driven innovation (SDI) and introduces institutional research support (IRS) as a key organizational mechanism variable. It aims to reveal how digital infrastructure enhances organizational support systems, thereby promoting student innovation output and better aligning with the dual policy orientations of educational digitalization and innovation education [11, 13].

#### 1.4. Theoretical Issues

##### 1.4.1. Existing Research Gaps

Although digital transformation has become a dominant theme in contemporary management research, the theoretical understanding of how digital infrastructure translates into innovation outcomes remains fragmented. Extant studies primarily conceptualize digitalization as a firm-level strategic transformation process, emphasizing digital capabilities, business model innovation, and performance outcomes [1, 14], updated discussions extended in 2020+ literature. While these studies offer valuable insights into corporate digital strategy, they often assume relatively clear organizational objectives and market-driven innovation logics.

However, universities operate under fundamentally different institutional logics compared to profit-oriented firms. Higher education institutions combine teaching, research, and societal engagement functions, making innovation outcomes multidimensional and less directly market-driven [2]. As a result, existing theoretical frameworks developed in corporate contexts may not be directly transferable to universities without contextual adaptation. This raises an important theoretical question: How does digital infrastructure function as a strategic resource within higher education organizations, and through what internal mechanisms does it influence student-level innovation outcomes?

##### 1.4.2. Predominant Focus on Corporate Digitalization

A substantial portion of recent digital transformation research centers on enterprises, particularly examining how digital technologies enhance firm performance, agility, and competitive advantage [1, 15]. Studies have explored topics such as digital platforms, big data analytics capabilities, artificial intelligence integration, and digital business model innovation. These investigations typically focus on organizational performance metrics, market share growth, or financial outcomes.

While such research advances understanding of digital capability-performance linkages, it leaves limited room for examining non-market innovation contexts such as universities. Moreover, corporate-focused studies often conceptualize digital infrastructure as an operational enabler rather than a broader socio-technical system embedded in institutional settings [3]. In higher education institutions, digital infrastructure not only supports operational efficiency but also shapes knowledge production processes, research collaboration patterns, and innovation cultures. Therefore, a theoretical shift from firm-centric digitalization to institutionally embedded digital infrastructure is necessary.

##### 1.4.3. Limited Attention to University Digital Infrastructure and Student Innovation Behavior

Within higher education literature, digitalization research has predominantly focused on online teaching effectiveness, digital learning adoption, and educational technology acceptance [2]. Although these studies enrich understanding of digital pedagogy, they rarely extend analysis to innovative behaviors initiated by students.

Student-driven innovation (SDI) reflects bottom-up activities, including research participation, entrepreneurial initiatives, technology competitions, and patent development. Existing entrepreneurship education research shows that institutional environments and educational programs influence students' entrepreneurial intentions [11, 12]. However, empirical investigations linking university-level digital infrastructure directly to student innovation behaviors remain scarce.

This gap is theoretically significant because digital infrastructure may influence student innovation not merely through teaching platforms but through broader research ecosystems, including data access, collaborative tools, and innovation incubation systems. Without explicitly examining this relationship, our understanding of how digital transformation reshapes university innovation ecosystems remains incomplete.

##### 1.4.4. Insufficient Exploration of Mediating Mechanisms

Another limitation of current research lies in the insufficient exploration of mediating mechanisms between digital infrastructure and innovation outcomes. Many studies test the direct effects of digital

capability on performance or innovation, but provide limited explanations of the organizational processes that convert digital resources into innovation outputs [15].

From an organizational support perspective, institutional mechanisms, such as research funding allocation, mentorship systems, collaborative culture, and innovation incentives, play a crucial role in translating structural resources into behavioral outcomes [3]. In universities, digital infrastructure alone may not automatically stimulate student innovation unless embedded within a supportive institutional research environment.

Therefore, introducing Institutional Research Support (IRS) as a mediating construct addresses an important theoretical gap. It allows for the examination of how digital infrastructure strengthens internal research support systems, which in turn fosters student-driven innovation. By theorizing and empirically testing this mediation pathway, the present study contributes to a more nuanced understanding of digital infrastructure as an enabling but not self-sufficient strategic resource.

### *1.5. Research Objectives and Contributions*

Building upon the theoretical gaps identified above, this study aims to develop and empirically test a mechanism-based framework explaining how university digital infrastructure influences student-driven innovation within higher education institutions. Specifically, the research focuses on three interrelated objectives.

First, this study seeks to examine whether university digital infrastructure (UDI) directly enhances student-driven innovation (SDI). While digital infrastructure has been widely discussed in corporate digital transformation literature [1], its direct impact on student-level innovation outcomes in higher education remains underexplored. By shifting the unit of analysis from firm performance to student innovation behavior, this study extends digital transformation research into a non-market institutional context.

Second, the study investigates the relationship between digital infrastructure and institutional research support (IRS). Drawing on the resource-based view and organizational support theory, digital infrastructure is conceptualized as a strategic organizational resource that may strengthen internal research support systems, including funding accessibility, mentorship structures, collaborative platforms, and innovation culture. Understanding this relationship clarifies how digital assets reshape internal organizational environments in universities.

Third, and most importantly, this research examines whether institutional research support mediates the relationship between digital infrastructure and student-driven innovation. By introducing IRS as a mediating construct, the study moves beyond simple direct-effect models and provides a process-oriented explanation of how digital resources are translated into innovation outcomes. This mediation perspective addresses a critical limitation in prior digital transformation research, which often overlooks internal organizational mechanisms.

#### *1.5.1. Theoretical Contributions*

This study contributes to management literature in three key ways.

##### *1.5.1.1. Contextual Extension of Digital Transformation Theory*

It extends digital transformation research from corporate settings to higher education institutions, thereby enriching the boundary conditions of digital infrastructure theory.

##### *1.5.1.2. Micro–Macro Linkage in Innovation Research*

By connecting university-level digital infrastructure (macro-level organizational resource) with student-driven innovation (micro-level behavioral outcome), the study provides a multi-level perspective on innovation generation.

### 1.5.1.3. Mechanism-Based Explanation

The introduction of institutional research support as a mediator advances a more nuanced understanding of how digital infrastructure generates innovation outcomes through organizational processes rather than direct technological determinism.

### 1.5.2. Practical Implications

From a managerial perspective, the findings suggest that digital infrastructure investment alone may not be sufficient to stimulate student innovation. Instead, universities should integrate digital infrastructure development with institutional research support mechanisms, including mentorship programs, research funding accessibility, and collaborative innovation platforms. For policymakers in digitally transforming regions such as Shandong Province, the study provides empirical evidence supporting coordinated strategies that align digital infrastructure construction with institutional capability enhancement.

### 1.6. Research Questions

RQ1: Does university digital infrastructure significantly enhance student-driven innovation?

RQ2: Does digital infrastructure improve institutional research support in universities?

RQ3: Does institutional research support mediating the relationship between digital infrastructure and student-driven innovation?

### 1.7. Research Contributions

#### 1.7.1. Theoretical Contributions

This study makes several important theoretical contributions to management and digital transformation literature.

First, it extends digital infrastructure research into the higher education innovation context. Existing digital transformation studies predominantly focus on corporate settings, examining how digital capabilities enhance firm performance, agility, or competitive advantage [1]. By shifting the analytical lens from profit-oriented firms to universities, this study broadens the contextual boundary of digital infrastructure theory. It conceptualizes university digital infrastructure (UDI) as a strategic organizational resource that influences innovation outcomes within a non-market institutional environment. In doing so, the study contributes to a more context-sensitive understanding of digital transformation.

Second, this research develops and empirically validates a mechanism-based framework linking university digital infrastructure to student-driven innovation through institutional research support (UDI → IRS → SDI). Rather than assuming a direct technological determinism effect, the study introduces institutional research support (IRS) as a mediating construct that explains how digital resources are translated into innovation outcomes. This mediation model advances the literature by clarifying the internal organizational processes through which digital infrastructure shapes innovation behaviors. It responds to recent calls for moving beyond direct-effect models toward process-oriented explanations in digital transformation research.

Third, by connecting macro-level organizational resources (digital infrastructure) with micro-level innovation behaviors (student-driven innovation), this study contributes to bridging the micro–macro divide in innovation management research. It demonstrates how institutional-level digital investments influence individual-level innovative outcomes through structured organizational support systems.

#### 1.7.2. Practical Contributions

Beyond theoretical implications, this study offers meaningful managerial and policy insights for higher education administrators and regional policymakers.

First, the findings suggest that digital infrastructure investment alone is insufficient to generate sustainable student innovation outcomes. Universities should integrate digital platform construction

with the strengthening of institutional research support mechanisms, including mentorship systems, research funding accessibility, innovation incentives, and collaborative research platforms. Digital infrastructure must be embedded within supportive organizational systems to fully realize its innovation potential.

Second, for policymakers in Shandong Province and similar regions undergoing digital education transformation, the study provides empirical evidence supporting coordinated digital governance strategies. Specifically, digital campus construction initiatives should be aligned with institutional capacity-building programs that foster an innovation culture and research support structures. Such integrated approaches can enhance the effectiveness of public investment in higher education digitalization.

Third, the study offers an evidence-based framework that university leaders can use to assess whether their digital transformation efforts are generating substantive innovation outcomes or merely technological upgrades without organizational integration.

## 2. Literature Review and Hypotheses Development

### 2.1. Digital Infrastructure in Higher Education (UDI)

Digital infrastructure has increasingly been recognized as the foundational layer of organizational digital transformation. In management research, digital infrastructure refers to the integrated set of technological resources, including network systems, cloud computing platforms, data repositories, digital applications, and collaborative technologies, that enable information processing, knowledge sharing, and innovation activities [1, 16] (extended discussions in recent literature). More recent scholarship emphasizes that digital infrastructure functions not merely as technical support but as a socio-technical architecture shaping organizational capabilities and value creation processes [3, 17].

Within higher education institutions, university digital infrastructure (UDI) includes high-speed campus networks, digital research databases, smart laboratory systems, cloud-based innovation platforms, virtual collaboration tools, and data-driven research management systems [2]. Unlike traditional IT assets, UDI functions as a systemic enabler of teaching, research, and innovation activities. It reduces coordination costs, improves knowledge accessibility, and facilitates interdisciplinary collaboration among students and faculty.

From the perspective of the resource-based view (RBV), digital infrastructure can be conceptualized as a strategic organizational resource that enhances institutional capability development [1, 18]. When embedded within organizational routines and governance structures, digital infrastructure contributes to dynamic capabilities, enabling institutions to sense, seize, and reconfigure opportunities in rapidly changing environments [14] (updated digital capability discussions in 2021+ research). In universities, such capabilities may translate into improved research productivity, stronger collaboration networks, and enhanced innovation ecosystems.

Recent empirical studies suggest that digital transformation in higher education improves organizational agility, research collaboration efficiency, and knowledge integration [2, 3]. However, most of these studies focus on digital learning adoption or institutional digital strategy at an aggregate level. Few studies explicitly examine digital infrastructure as a distinct organizational construct influencing innovation-related behavioral outcomes.

Importantly, digital infrastructure differs from general digital adoption in that it represents the structural foundation upon which innovation ecosystems operate. A robust digital infrastructure enhances data accessibility, lowers experimentation costs, supports open innovation practices, and facilitates knowledge recombination, all of which are central to innovation generation (Nambisan et al., 2022). In the university context, such infrastructure may empower students to access research databases, participate in digital research platforms, collaborate across disciplines, and engage in innovation competitions or entrepreneurial initiatives.

Therefore, conceptualizing UDI as a strategic institutional resource provides a theoretical basis for examining its impact on both organizational-level support mechanisms and individual-level innovation

outcomes. This perspective sets the stage for analyzing how digital infrastructure not only directly influences student-driven innovation but also indirectly shapes innovation through institutional research support systems.

### *2.2. Institutional Research Support (IRS)*

Institutional research support (IRS) refers to the structured organizational mechanisms through which universities provide resources, guidance, and institutional conditions that facilitate research and innovation activities. Unlike general organizational support, IRS specifically emphasizes research-oriented infrastructure, funding systems, mentorship arrangements, innovation incentives, collaborative platforms, and an academic culture conducive to experimentation and knowledge creation.

Recent management research highlights that digital transformation outcomes are contingent upon complementary organizational capabilities and support structures [1, 17]. Digital infrastructure alone does not automatically generate innovation; rather, it requires institutional embedding to become operationally effective. In higher education institutions, such embedding occurs through formal research governance systems, funding allocation processes, interdisciplinary collaboration mechanisms, and innovation-oriented institutional norms [3].

From an organizational support theory perspective, structured institutional support signals resource availability, reduces uncertainty, and enhances individuals' motivation to engage in innovative behaviors. In the university context, IRS may include access to research grants, faculty mentorship, laboratory facilities, digital research databases, incubation centers, and recognition systems for innovative achievements. These elements collectively shape students' perceptions of feasibility and institutional encouragement, which are critical antecedents of innovation engagement [11, 12].

Importantly, the IRS operates at the meso-level between institutional infrastructure and individual behavior. While digital infrastructure (UDI) represents the technological foundation of the university ecosystem, IRS represents the governance and organizational mechanisms that mobilize and coordinate these digital resources. For example, a university may possess advanced digital platforms, but without structured mentorship programs or accessible research funding schemes, students may lack the institutional pathways necessary to translate digital access into innovation outputs.

Furthermore, emerging research on digital ecosystems suggests that innovation performance depends on the alignment between technological architecture and institutional coordination mechanisms [17]. This alignment is particularly salient in higher education institutions, where research activities require cross-functional collaboration, knowledge integration, and administrative facilitation. Institutional research support, therefore, acts as a bridging mechanism that connects structural digital resources to behavioral innovation outcomes.

Conceptualizing IRS as a mediating construct enables a process-oriented understanding of innovation generation within universities. Instead of assuming a direct deterministic relationship between digital infrastructure and student innovation, IRS captures internal organizational processes that transform digital capabilities into actionable research opportunities and innovation engagement.

Thus, the IRS plays a pivotal role in explaining how university digital infrastructure influences student-driven innovation, providing a theoretically grounded mechanism that integrates resource-based and organizational support perspectives.

### *2.3. Hypotheses Development*

Building upon the conceptual foundations outlined above, this study develops a mediation framework linking university digital infrastructure (UDI), institutional research support (IRS), and student-driven innovation (SDI). Drawing on the resource-based view and organizational support theory, digital infrastructure is conceptualized as a strategic organizational resource whose effects on innovation are both direct and indirectly realized through institutional mechanisms.

### 2.3.1. Digital Infrastructure and Student-Driven Innovation

Digital infrastructure provides the technological architecture that enables knowledge access, collaboration, and experimentation. From a resource-based perspective, strategically deployed digital assets enhance organizational capability and create conditions conducive to innovation [1, 17]. In higher education institutions, digital infrastructure reduces information asymmetry, lowers experimentation costs, and facilitates interdisciplinary collaboration through digital platforms, research databases, and online coordination tools.

Innovation at the individual level, particularly student-driven innovation, depends heavily on access to knowledge resources and collaborative networks. Digital research platforms allow students to retrieve real-time academic data, participate in virtual laboratories, and collaborate across institutional boundaries. These capabilities expand opportunity recognition and accelerate the transformation of ideas into tangible innovation outputs [2]. Furthermore, digital tools enhance autonomy and flexibility, empowering students to initiate innovation projects independently of rigid institutional constraints.

Recent research on digital ecosystems suggests that digital infrastructures function as generative platforms enabling distributed innovation activities [17]. In the university context, such generativity may manifest in student-led research initiatives, competition participation, and entrepreneurial experimentation. Therefore, a well-developed digital infrastructure is expected to directly enhance students' capacity and motivation to engage in innovative behaviors.

Accordingly, the following hypothesis is proposed:

*H<sub>1</sub>: University digital infrastructure (UDI) has a positive and significant effect on student-driven innovation (SDI).*

### 2.3.2. Digital Infrastructure and Institutional Research Support

Although digital infrastructure provides technological resources, its organizational impact depends on how it is integrated into institutional systems. Digital platforms improve transparency, streamline administrative procedures, and facilitate coordination across departments, thereby strengthening institutional research governance and support mechanisms [1].

In universities, digital infrastructure enhances research support in several ways. First, digital research management systems improve funding allocation efficiency and project monitoring processes. Second, digital collaboration platforms promote interdisciplinary research and mentorship engagement. Third, data-sharing infrastructures enhance knowledge diffusion and academic interaction. These improvements collectively contribute to a more supportive research environment.

From a capability perspective, digital infrastructure enables institutions to reconfigure internal support processes and enhance responsiveness to innovation demands [17]. Thus, rather than being merely a technical asset, digital infrastructure reshapes organizational routines and strengthens research-oriented institutional mechanisms.

Therefore, universities with more advanced digital infrastructure are likely to exhibit stronger institutional research support systems.

Accordingly, the following hypothesis is proposed:

*H<sub>2</sub>: University digital infrastructure (UDI) positively influences institutional research support (IRS).*

### 2.3.3. The Mediating Role of Institutional Research Support

While digital infrastructure may directly enhance innovation, organizational support theory suggests that structural resources typically influence individual behavior through intermediate institutional mechanisms. Institutional research support reduces uncertainty, provides resource accessibility, and signals institutional endorsement of innovation activities, thereby increasing individuals' engagement in innovative behaviors.

In higher education settings, students' participation in research and innovation activities often depends on access to funding schemes, mentorship guidance, laboratory facilities, and innovation

incentives. Even when digital infrastructure is well developed, the absence of structured institutional support may limit students' ability to transform digital access into innovation outcomes. In this sense, institutional research support functions as a bridging mechanism that converts digital capability into behavioral innovation.

Moreover, recent digital transformation research emphasizes that technological assets must be complemented by organizational alignment to generate sustainable innovation outcomes [1, 17]. This alignment is particularly critical in university ecosystems, where research coordination, mentorship structures, and innovation culture shape students' opportunity recognition and engagement in innovation.

Institutional research support is expected to mediate the relationship between digital infrastructure and student-driven innovation. Specifically, digital infrastructure strengthens institutional research support, which, in turn, promotes student innovation behaviors.

Accordingly, the following hypothesis is proposed:

*H<sub>3</sub>: Institutional research support (IRS) positively mediates the relationship between university digital infrastructure (UDI) and student-driven innovation (SDI).*

#### 2.4. Conceptual Model



**Figure 1.**  
Conceptual Model.

Figure 1 presents the conceptual framework of this study. University digital infrastructure (UDI) is proposed to directly influence student-driven innovation (SDI) (H1) and indirectly influence SDI through institutional research support (IRS) (H3). Additionally, UDI is hypothesized to positively affect IRS (H2), forming a mediation structure (UDI → IRS → SDI).

### 3. Methodology

#### 3.1. Research Design

This study adopts a quantitative research design to empirically examine the relationships among university digital infrastructure (UDI), institutional research support (IRS), and student-driven innovation (SDI). To test a theoretically grounded mediation model, a cross-sectional survey method was used to collect primary data from university students in Shandong Province, China.

A structured questionnaire was developed based on established measurement scales in digital transformation, organizational support, and innovation research, with contextual adaptations to fit the higher education environment. All measurement items were assessed using a Likert-type scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"), ensuring consistency and comparability across constructs.

The research model was tested using covariance-based structural equation modeling (CB-SEM), implemented through SPSS and AMOS. This analytical approach is appropriate because it allows for the simultaneous estimation of measurement and structural models, assessment of construct validity and reliability, and examination of mediation effects within a theoretically specified framework.

Confirmatory factor analysis (CFA) was conducted to validate the measurement model, followed by structural path analysis to test the proposed hypotheses.

Bootstrapping procedures with 5,000 resamples were applied to evaluate the significance of indirect effects, ensuring robust mediation testing. Model fit was assessed using commonly accepted indices, including the chi-square to degrees of freedom ratio ( $\chi^2/df$ ), Comparative Fit Index (CFI), Tucker, Lewis Index (TLI), and Root Mean Square Error of Approximation (RMSEA).

This research design enables rigorous testing of the hypothesized relationships and provides empirical evidence for the proposed UDI  $\rightarrow$  IRS  $\rightarrow$  SDI mediation framework.

### 3.2. Sample and Data Collection

The target population of this study consisted of undergraduate and postgraduate students enrolled in universities located in Shandong Province, China. Shandong was selected as the empirical context due to its active promotion of digital education transformation and substantial investment in university digital infrastructure, making it an appropriate setting for examining the proposed relationships.

A multi-stage sampling strategy was adopted. First, several comprehensive and applied universities representing different institutional types were selected to ensure variability in digital infrastructure development levels. Second, students from different academic disciplines and study levels were invited to participate in the survey to enhance sample representativeness.

Data were collected through an online questionnaire platform over approximately two months. Participation was voluntary and anonymous. Before formal distribution, a pilot test was conducted with a small group of students to ensure clarity and contextual appropriateness of the measurement items. Based on feedback, minor wording adjustments were made.

A total of 678 questionnaires were distributed, of which 598 were returned. After excluding incomplete or invalid responses, 582 valid questionnaires remained for analysis, resulting in an effective response rate of 85.84%. The final sample size meets the recommended minimum for covariance-based structural equation modeling (CB-SEM), which generally requires at least 200 observations for stable parameter estimation.

To reduce common method bias, several procedural remedies were implemented. First, respondents were assured of anonymity to minimize evaluation apprehension. Second, items measuring independent, mediating, and dependent variables were arranged in different sections of the questionnaire to reduce psychological priming effects. Third, Harman's single-factor test was conducted to assess potential common method variance.

Demographically, the sample included students across different academic years and disciplines, providing sufficient variability for hypothesis testing.

### 3.3. Measurement of Variables

All constructs in this study were measured using multi-item scales adapted from established literature to ensure content validity. Given the higher education context of this research, minor wording modifications were made to reflect the university setting while preserving the original conceptual meaning of the items. All items were measured using a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree").

#### 3.3.1. University Digital Infrastructure (UDI)

University digital infrastructure (UDI) was conceptualized as the extent to which universities provide advanced digital platforms, research databases, collaborative tools, and digital innovation systems that support academic and innovation activities. The measurement items were adapted from prior digital infrastructure and digital capability studies [1, 2, 17] with contextual adjustments for higher education institutions.

The scale captures students' perceptions of:  
accessibility of digital research platforms

availability of online collaboration tools  
adequacy of digital laboratories and databases  
overall digital support environment  
UDI was measured using 582 items.

### 3.3.2. Institutional Research Support (IRS)

Institutional research support (IRS) reflects the structured organizational mechanisms that facilitate research and innovation activities within universities. The measurement items were adapted from organizational support and innovation support literature [19] updates in organizational support research [3, 12], emphasizing research funding accessibility, mentorship availability, innovation incentives, and collaborative research culture.

The scale captures perceptions of:  
availability of research funding opportunities  
accessibility of faculty mentorship  
institutional encouragement of innovation  
effectiveness of research management systems  
IRS was measured using 582 items.

### 3.3.3. Student-Driven Innovation (SDI)

Student-driven innovation (SDI) was conceptualized as students' proactive engagement in research-based and innovation-oriented activities, including participation in innovation projects, entrepreneurial initiatives, and interdisciplinary collaborations. Measurement items were adapted from innovation behavior and entrepreneurship education studies [11, 12, 15], modified to capture behavioral manifestations rather than mere innovation intention.

The scale captures:  
participation in innovation or research projects  
engagement in entrepreneurial or technological competitions  
development of innovative ideas or prototypes  
active collaboration in innovation activities  
SDI was measured using 582 items.

#### Translation and Validity Procedures

Since the original measurement scales were developed in English, a translation and back-translation procedure was conducted to ensure linguistic accuracy and conceptual equivalence. Two bilingual researchers independently translated the items into Chinese and then back into English. Discrepancies were discussed and resolved to maintain semantic consistency.

Content validity was assessed during the pilot test phase, and minor adjustments were made based on participant feedback to improve clarity and contextual relevance.

## 4. Results

### 4.1. Descriptive Statistics

**Table 1.**  
Analysis of Descriptions for Each Measurement Item.

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
UDI1	582	1	5	3.655	1.142	-0.749	-0.098
UDI2	582	1	5	3.646	1.113	-0.706	-0.062
UDI3	582	1	5	3.73	1.007	-0.832	0.639
UDI4	582	1	5	3.708	1.142	-0.717	-0.047
UDI5	582	1	5	3.978	0.93	-0.998	1.091
IRS1	582	1	5	3.861	0.918	-0.551	0.084
IRS2	582	1	5	3.696	0.918	-0.341	-0.137
IRS4	582	1	5	3.687	0.972	-0.355	-0.411
IRS3	582	1	5	3.955	1	-0.719	-0.14
IRS5	582	1	5	3.902	0.999	-0.687	-0.203
IRS6	582	1	5	3.911	1.016	-0.681	-0.218
IRS7	582	1	5	3.955	0.958	-0.855	0.346
IRS8	582	1	5	3.985	0.923	-0.76	0.189
SDI1	582	1	5	3.734	1.105	-0.672	-0.239
SDI2	582	1	5	3.557	1.306	-0.51	-0.848
SDI3	582	1	5	3.747	1.182	-0.642	-0.483
SDI4	582	1	5	3.431	1.191	-0.238	-0.884
SDI5	582	1	5	3.627	1.176	-0.644	-0.451
SDI6	582	1	5	3.558	1.259	-0.441	-0.913
SDI7	582	1	5	3.55	1.101	-0.158	-1.042
SDI8	582	1	5	3.519	1.271	-0.373	-0.995

The table shows that all measurement items have absolute skewness values below 2 and absolute kurtosis values below 7. According to Kline [20] criteria, data with absolute skewness  $<3$  and absolute kurtosis  $<10$  are considered to have no significant non-normal distribution. Under stricter standards, a skewness  $<2$  and kurtosis  $<7$  indicate a near-normal distribution. Therefore, the sample data in this study meet the normality assumption at the univariate level.

Furthermore, a normal distribution is a critical prerequisite for parameter estimation in the covariance structure equation model (CB-SEM). Since this study employed AMOS for model estimation, maximum likelihood estimation (MLE) requires data to approximate a normal distribution. The skewness and kurtosis results indicate that none of the observed variables showed significant deviations from normality, making them suitable for subsequent confirmatory factor analysis (CFA) and structural model testing.

The data in this study meet the basic distribution requirements for structural equation modeling (SEM) analysis, providing a statistical foundation for subsequent reliability, validity testing, and path analysis.

#### 4.2. The Rotated Component Matrix

**Table 2.**

The rotated component matrix.

The rotated component matrix <sup>a</sup>			
	Ingredient		
	1	2	3
UDI1			0.672
UDI2			0.680
UDI3			0.743
UDI4			0.784
UDI5			0.764
IRS1	0.682		
IRS2	0.782		
IRS4	0.776		
IRS3	0.710		
IRS5	0.855		
IRS6	0.800		
IRS7	0.833		
IRS8	0.719		
SDI1		0.660	
SDI2		0.746	
SDI3		0.673	
SDI4		0.745	
SDI5		0.763	
SDI6		0.752	
SDI7		0.841	
SDI8		0.784	

The extraction method was principal component analysis.

Rotation method: Caesarean normalization maximum variance method.

a. Rotation converged after 5 iterations.

Table 2 presents the results of the exploratory factor analysis (EFA). Principal component analysis was employed as the extraction method, and varimax rotation with Kaiser normalization was applied to enhance factor interpretability. The rotation converged after five iterations.

The results reveal a clear three-factor structure corresponding to university digital infrastructure (UDI), institutional research support (IRS), and student-driven innovation (SDI). All measurement items loaded strongly on their intended constructs, with factor loadings ranging from 0.660 to 0.855, exceeding the commonly recommended threshold of 0.60 for acceptable construct validity [21].

Specifically, items UDI1–UDI5 loaded highly on the first factor, with loadings between 0.672 and 0.784, indicating strong internal consistency within the digital infrastructure construct. Items IRS1–IRS8 loaded on the second factor, with loadings ranging from 0.682 to 0.855, demonstrating a robust representation of institutional research support. Similarly, items SDI1–SDI8 loaded on the third factor, with factor loadings between 0.660 and 0.841, supporting the structural coherence of the student-driven innovation construct.

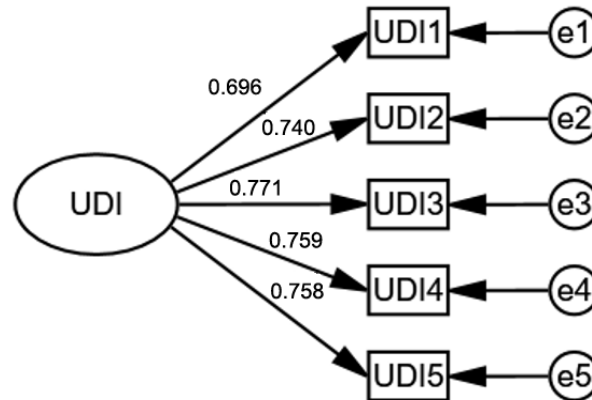
Importantly, no significant cross-loadings were observed, as all items exhibited substantially higher loadings on their respective factors compared to other factors. This result indicates good discriminant validity among the three constructs.

Overall, the EFA results provide preliminary evidence supporting the dimensional structure of UDI, IRS, and SDI, thereby justifying subsequent confirmatory factor analysis (CFA) and structural model testing.

### 4.3. Structural Model

#### 4.3.1. UDI

The study comprised one dimension with five measurement items. After conducting confirmatory factor analysis using AMOS 25.0, the results are presented in the figure and table below.



Chi Square/ DF=1.568  
RMSEA= 0.031  
CFI= 0.998

**Figure 2.**  
Individual Model for UDI.

**Table 3.**  
Fit of confirmatory factor model.

Model fitting index	Optimal standard value	Statistic	Fit
CMIN	—	7.842	—
DF	—	5	—
CMIN/DF	<3	1.568	Good
RMR	<0.08	0.015	Good
GFI	>0.9	0.995	Good
AGFI	>0.9	0.984	Good
NFI	>0.9	0.994	Good
IFI	>0.9	0.998	Good
TLI	>0.9	0.995	Good
CFI	>0.9	0.998	Good
RMSEA	<0.08	0.031	Good

The Table 3 shows that the CMIN/DF ratio is 1.568, below the 3 threshold. All fit indices (GFI, AGFI, NFI, TLI, IFI, CFI) exceed 0.9, with RMR (0.015) and RMSEA (0.031) both below 0.08. These results meet standard research criteria, confirming the model's good fit.

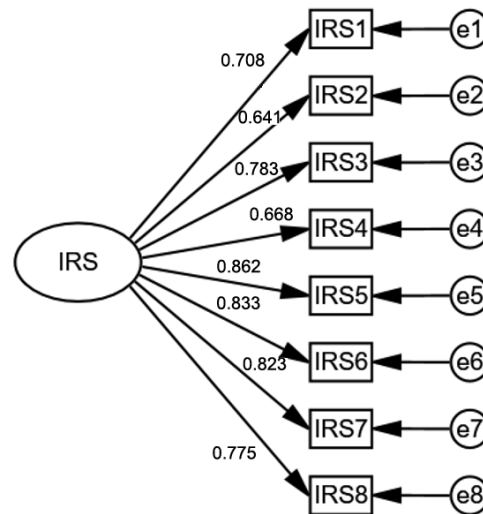
**Table 4.**  
Validating factor analysis results.

Variable	Measurement indicators	Factor loading	CR	AVE
UDI	UDI1	0.696	0.862	0.555
	UDI2	0.74		
	UDI3	0.771		
	UDI4	0.759		
	UDI5	0.758		

As shown in Table 4, all measurement indicators of the variables have standardized factor loadings above 0.6, with composite reliability (CR) exceeding 0.7 and average variance extracted (AVE) greater than 0.5, indicating strong convergent validity.

#### 4.3.2. IRS

The study comprised one dimension with eight measurement items. After conducting confirmatory factor analysis using AMOS 25.0, the results are presented in the figure and table below.



Chi Square/ DF=12.313  
RMSEA= 0.140  
CFI= 0.924

Figure 3.  
Pre-modified confirmatory factor model.

Table 5.  
Optimal standard values for model fitting indicators.

Model fitting index	Optimal standard value	Statistic	Fit
CMIN	—	246.268	—
DF	—	20	—
CMIN/DF	<3	12.313	Bad
RMR	<0.08	0.039	Good
GFI	>0.9	0.901	Good
AGFI	>0.9	0.822	Bad
NFI	>0.9	0.918	Good
IFI	>0.9	0.924	Good
TLI	>0.9	0.893	Bad
CFI	>0.9	0.924	Good
RMSEA	<0.08	0.140	Bad

The table 5 shows that CMIN/DF, AGFI, TLI, and RMSEA all fail to meet the criteria, necessitating model modification. The modification indices indicate that adjusting the model through residual correction reduces the chi-square value. The table below displays the covariance correction

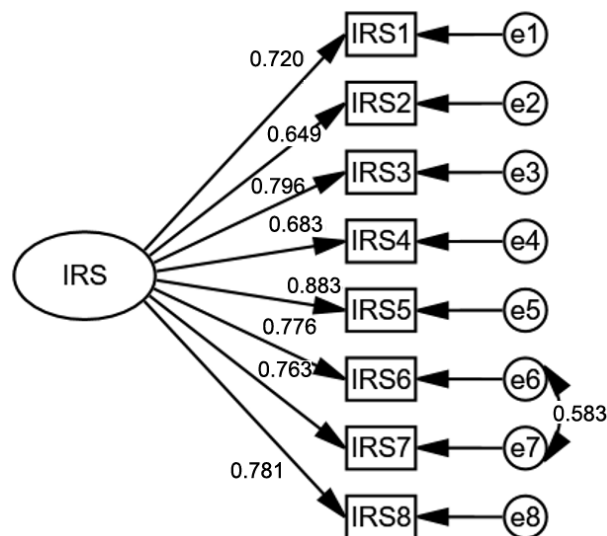
indices between residuals, which quantify how adding a correlation path between two residuals decreases the model's chi-square value.

**Table 6.**

Covariance correction index of residual.

			M.I.	Par Change
e6	<-->	e7	165.620	0.190

Table 6 reports the estimation results of the model residual covariance modification indices, where the modification index (M.I.) and parameter change value (Par Change) are used to identify the residual correlation paths to be optimized in the model. The results show that the modification index M.I. value between error term e6 and error term e7 is 165.620, which is much larger than the model modification threshold, indicating a significant residual correlation between the two. The parameter change value Par Change is 0.190, indicating practical modification value. According to the structural equation modeling modification criteria, optimizing the model by releasing the residual covariance path between e6 and e7 can effectively reduce the model estimation bias and improve the overall model fitting effect and explanatory power.



Chi Square/ DF=2.874  
 RMSEA= 0.057  
 CFI= 0.988

**Figure 4.**  
 Revised confirmatory factor model.

**Table 7.**  
Modified structural model fit.

Model fitting index	Optimal standard value	Statistic	Fit
CMIN	—	54.613	—
DF	—	19	—
CMIN/DF	<3	2.874	Good
RMR	<0.08	0.021	Good
GFI	>0.9	0.978	Good
AGFI	>0.9	0.957	Good
NFI	>0.9	0.982	Good
IFI	>0.9	0.988	Good
TLI	>0.9	0.982	Good
CFI	>0.9	0.988	Good
RMSEA	<0.08	0.057	Good

Table 7 shows that the CMIN/DF ratio is 2.874, below the 3 threshold. All fit indices (GFI, AGFI, NFI, TLI, IFI, CFI) exceed 0.9, with RMR (0.021) and RMSEA (0.057) both below the 0.08 cutoff. These results confirm that the model meets standard research criteria, demonstrating good fit.

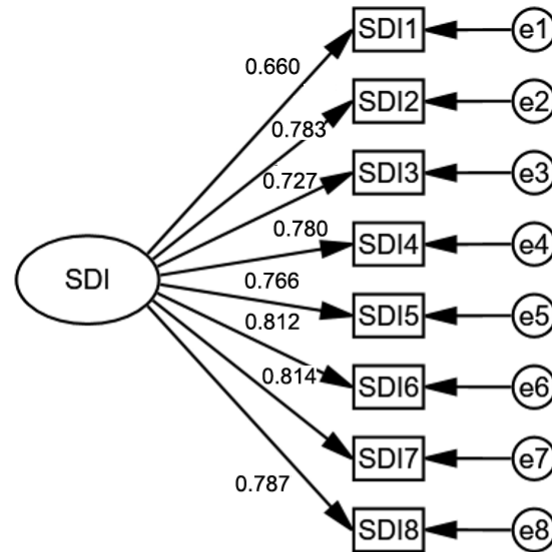
**Table 8.**  
Validating factor analysis results.

Variable	Measurement indicators	Factor loading	CR	AVE
IRS	IRS1	0.72	0.915	0.577
	IRS2	0.649		
	IRS3	0.796		
	IRS4	0.683		
	IRS5	0.883		
	IRS6	0.776		
	IRS7	0.763		
	IRS8	0.781		

As shown in Table 8, all measurement indicators of the variables have standardized factor loadings above 0.6, construct reliability (CR) exceeding 0.7, and average variance extracted (AVE) greater than 0.5, indicating strong convergent validity for each variable.

#### 4.3.3. SDI

The study comprised one dimension with eight measurement items. After conducting confirmatory factor analysis using AMOS 25.0, the results are presented in the figure and table below.



Chi Square/ DF=2.465  
 RMSEA= 0.050  
 CFI= 0.989

**Figure 5.**  
 Revised confirmatory factor model.

**Table 9.**  
 Fit of the confirmatory factor model.

Model fitting index	Optimal standard value	Statistic	Fit
CMIN	—	49.293	—
DF	—	20	—
CMIN/DF	<3	2.465	Good
RMR	<0.08	0.028	Good
GFI	>0.9	0.979	Good
AGFI	>0.9	0.962	Good
NFI	>0.9	0.982	Good
IFI	>0.9	0.989	Good
TLI	>0.9	0.985	Good
CFI	>0.9	0.989	Good
RMSEA	<0.08	0.050	Good

Table 9 shows that the CMIN/DF ratio is 2.465, below the 3 threshold. All fit indices (GFI, AGFI, NFI, TLI, IFI, CFI) exceed 0.9, with RMR (0.028) and RMSEA (0.050) both below 0.08. These results meet standard research criteria, confirming the model's good fit.

**Table 10.**  
Validating factor analysis results.

Variable	Measurement indicators	Factor loading	CR	AVE
SDI	SDI1	0.66	0.92	0.589
	SDI2	0.783		
	SDI3	0.727		
	SDI4	0.78		
	SDI5	0.766		
	SDI6	0.812		
	SDI7	0.814		
	SDI8	0.787		

As shown in Table 10, all measurement indicators of the variables have standardized factor loadings above 0.6, construct reliability (CR) exceeding 0.7, and average variance extracted (AVE) greater than 0.5, indicating strong convergent validity for each variable.

## 5. Discussion

### 5.1. Theoretical Explanation

The empirical findings of this study provide strong support for the proposed mediation framework linking university digital infrastructure (UDI), institutional research support (IRS), and student-driven innovation (SDI). The results indicate that digital infrastructure not only directly enhances student-driven innovation but also exerts an indirect effect through institutional research support. These findings offer several important theoretical insights.

First, the positive relationship between UDI and SDI supports the argument that digital infrastructure functions as a strategic organizational resource in higher education institutions. Consistent with the resource-based view, digital infrastructure enhances the availability, accessibility, and recombination of knowledge resources, thereby expanding students' opportunity recognition and innovation capacity. Unlike traditional physical resources, digital infrastructure enables generativity, allowing students to independently initiate and experiment with innovative ideas. This finding extends digital transformation theory beyond firm-level performance outcomes and demonstrates that digital assets can shape micro-level innovative behaviors within institutional environments.

Second, the significant effect of UDI on IRS highlights the organizational embedding of digital resources. Digital infrastructure alone does not automatically generate innovation outcomes; rather, it reshapes institutional processes and governance mechanisms. By improving coordination efficiency, transparency, and resource allocation systems, digital infrastructure strengthens research support structures within universities. This finding aligns with recent digital ecosystem research, suggesting that technological architecture must be integrated with organizational mechanisms to realize its full value. In this sense, digital infrastructure enhances not only technological capability but also institutional capacity.

Third, the mediating role of institutional research support provides a process-oriented explanation of how digital resources are translated into student innovation outcomes. Rather than assuming a technologically deterministic relationship, the results demonstrate that institutional mechanisms serve as a bridge between structural digital investments and individual-level innovation behaviors. Institutional research support reduces uncertainty, enhances perceived feasibility, and signals organizational endorsement of innovation activities, thereby motivating students to engage in innovative projects. This mediation finding responds to calls in digital transformation research for more nuanced explanations of how digital capabilities generate innovation outcomes through internal organizational processes.

Furthermore, the study contributes to bridging the micro–macro divide in innovation management. By linking macro-level digital infrastructure with micro-level student-driven innovation through a meso-level institutional mechanism, the findings provide a multi-level explanation of innovation

generation within universities. This layered perspective enriches existing management research, which often isolates technological, organizational, or behavioral factors rather than integrating them into a unified framework.

Overall, the results suggest that digital infrastructure should be understood not merely as a technological investment but as a strategic institutional resource whose innovation impact depends on complementary organizational support systems. This integrated theoretical perspective advances our understanding of digital transformation in higher education and contributes to a broader management discourse on resource orchestration and innovation mechanisms.

### 5.2. Comparison with Prior Studies

The findings of this study both align with and extend existing research on digital transformation and innovation.

First, the positive effect of university digital infrastructure on innovation outcomes is consistent with prior research conducted in corporate contexts. Numerous studies have demonstrated that digital capabilities and platform infrastructures enhance firm innovation performance, organizational agility, and knowledge integration [1, 17]. However, most of these studies focus on firm-level outcomes such as product innovation or financial performance. By contrast, the present study shifts the analytical focus to individual-level innovation behaviors within higher education institutions. The findings suggest that the innovation-enhancing role of digital infrastructure extends beyond firms to non-market institutional environments, thereby broadening the contextual applicability of digital transformation theory.

Second, this study's results support prior entrepreneurship education research indicating that institutional support mechanisms significantly influence students' innovation and entrepreneurial engagement [11, 12]. Previous studies primarily emphasize pedagogical interventions, curriculum design, and entrepreneurial intention formation. In contrast, our findings highlight the structural and infrastructural foundations that underpin innovation ecosystems within universities. Specifically, we demonstrate that digital infrastructure shapes institutional research support systems, which in turn foster student-driven innovation. This structural perspective complements existing research that focuses predominantly on educational content and psychological factors.

Third, while earlier digital transformation research often assumes a direct link between digital capability and innovation performance, the present study provides empirical evidence for an indirect, mechanism-based relationship. The identification of institutional research support as a mediating variable responds to recent calls for unpacking the internal processes through which digital investments generate value [1]. By empirically validating the UDI → IRS → SDI pathway, this study extends prior models that rely heavily on direct-effect assumptions.

Moreover, compared with research that treats digital infrastructure as a purely technological determinant, our findings emphasize the importance of organizational alignment. This perspective resonates with emerging digital ecosystem studies suggesting that technology and institutional coordination must co-evolve to produce sustainable innovation outcomes [17]. In the higher education context, digital tools without structured research support mechanisms may not sufficiently stimulate student innovation. Therefore, our results underscore the complementary relationship between technological and institutional resources.

Finally, in the context of emerging economies, relatively few empirical studies have examined digital infrastructure and innovation linkages within Chinese universities. By providing evidence from Shandong Province, this study enriches the geographical and institutional diversity of digital transformation research. It contributes empirical insights from a rapidly digitalizing educational system, thereby complementing existing literature that is predominantly based on Western corporate settings.

Overall, compared with prior studies, this research advances the literature by integrating digital infrastructure, institutional support mechanisms, and individual innovation behaviors into a unified explanatory framework.

## 6. Theoretical Contributions

This study contributes to management and digital transformation literature in several important ways.

### 6.1. Extending Digital Infrastructure Theory to the Educational Context

First, this study extends digital infrastructure theory from corporate settings to higher education institutions. Existing digital transformation research predominantly conceptualizes digital infrastructure as a strategic asset that enhances firm performance, competitive advantage, or market innovation [1, 17]. While these studies provide valuable insights, they largely overlook non-market institutional environments such as universities.

By examining university digital infrastructure (UDI) as a strategic organizational resource influencing innovation within higher education institutions, this study broadens the contextual boundaries of digital infrastructure theory. It demonstrates that digital infrastructure not only drives commercial innovation but also shapes academic and student-level innovation behaviors. In doing so, the study advances a more context-sensitive understanding of digital transformation, suggesting that digital infrastructure operates as a generative institutional resource beyond profit-oriented organizational domains.

### 6.2. Explaining the Internal Mechanism of Innovation in Universities

Second, this research advances innovation management theory by uncovering the internal organizational mechanism through which digital infrastructure influences student-driven innovation. Prior research often assumes a direct relationship between digital capability and innovation outcomes, emphasizing technological determinism. However, such direct-effect models provide limited insight into how structural digital investments are translated into behavioral innovation outcomes.

By introducing institutional research support (IRS) as a mediating construct, this study offers a process-based explanation linking macro-level digital resources to micro-level innovation behaviors. It conceptualizes IRS as a meso-level organizational mechanism that mobilizes digital resources, coordinates research activities, and reduces uncertainty for student innovators. This mechanism-based perspective contributes to bridging the micro–macro divide in innovation research and aligns with emerging calls for resource orchestration and capability alignment frameworks in digital transformation studies.

Thus, the study refines digital innovation theory by demonstrating that the innovation impact of digital infrastructure is contingent upon complementary institutional support systems rather than being purely technology-driven.

### 6.3. Providing Empirical Evidence from the Chinese Context

Third, this study enriches digital transformation and innovation literature by providing empirical evidence from the Chinese higher education context. Much of the existing digital infrastructure research is based on Western corporate environments, limiting its generalizability across institutional and cultural settings.

By examining universities in Shandong Province, a region actively promoting digital education transformation, this study contributes context-specific evidence from an emerging economy undergoing rapid digitalization. The findings highlight how digital infrastructure investments interact with institutional governance systems within Chinese universities to shape innovation outcomes. This contextual contribution enhances the geographical diversity of digital transformation research and supports broader theorization about digital infrastructure in institutionally distinct environments.

Furthermore, the Chinese higher education system represents a hybrid governance model combining state guidance and institutional autonomy. Demonstrating the effectiveness of the UDI → IRS → SDI mechanism within this context suggests that digital infrastructure theory holds explanatory power beyond market-driven settings, thereby strengthening its external validity.

## 7. Practical Implications

The findings of this study offer several important managerial and policy implications for higher education administrators and regional decision-makers engaged in digital transformation initiatives.

### 7.1. Implications for University Administrators

First, the results indicate that digital infrastructure investment directly enhances student-driven innovation. Therefore, university administrators should treat digital infrastructure not merely as an operational necessity but as a strategic asset for fostering innovation ecosystems. Investments in high-speed networks, digital research platforms, cloud-based laboratories, and interdisciplinary collaboration systems should be prioritized as long-term innovation infrastructure rather than short-term technological upgrades.

However, the mediation findings suggest that infrastructure alone is insufficient. Universities must integrate digital infrastructure development with institutional research support systems. Administrators should design structured mechanisms that align digital platforms with accessible research funding schemes, mentorship programs, innovation competitions, and incubation support. Without such institutional embedding, digital tools may remain underutilized.

Second, universities should strengthen the coordination between IT departments and academic governance units. Digital platform development should be guided by research and innovation objectives, ensuring that digital resources are aligned with academic needs. Establishing cross-functional committees that oversee digital strategy and research support integration may enhance organizational alignment.

### 7.2. Implications for Institutional Research Governance

The significant mediating role of institutional research support suggests that universities should enhance internal research governance structures. Specifically, research funding application systems can be digitized to improve transparency and efficiency. Mentorship matching systems may leverage digital platforms to connect students with faculty advisors based on research interests and innovation goals.

Furthermore, universities should cultivate an innovation-supportive culture that signals institutional endorsement of student initiatives. Recognition systems, digital showcases of student innovation achievements, and structured feedback mechanisms can reinforce students' confidence in pursuing innovative projects.

By strengthening institutional research support, universities can transform digital infrastructure from a passive technological resource into an active innovation-enabling mechanism.

### 7.3. Implications for Regional Policymakers in Shandong Province

At the policy level, the findings provide evidence supporting coordinated digital education governance. Regional authorities should ensure that investments in digital campus construction are complemented by programs that enhance institutional innovation capacity. Policy frameworks may encourage universities to integrate digital infrastructure funding with research support performance indicators.

Additionally, inter-university digital collaboration platforms at the provincial level could facilitate resource sharing, joint research initiatives, and student innovation competitions. Such ecosystem-level coordination may amplify the innovation impact of digital infrastructure investments.

Overall, the study underscores that effective digital transformation in higher education requires a dual strategy: technological advancement combined with institutional capability enhancement. Policymakers and university leaders who adopt this integrated approach are more likely to cultivate sustainable innovation ecosystems.

## 8. Limitations and Future Research

Despite its theoretical and practical contributions, this study has several limitations that offer opportunities for future research.

First, this study employs a cross-sectional research design, which limits the ability to establish causal relationships among university digital infrastructure, institutional research support, and student-driven innovation. Although structural equation modeling provides statistical support for the hypothesized relationships, longitudinal data would allow for stronger causal inference and examination of dynamic effects. Future research could adopt longitudinal or panel data designs to explore how digital infrastructure investments influence innovation outcomes over time.

Second, the data were collected from universities in Shandong Province, China. While this regional focus provides meaningful contextual insights, it may limit the generalizability of the findings to other provinces or countries with different institutional environments. Higher education governance structures, digital maturity levels, and innovation ecosystems vary across regions. Future studies could conduct cross-regional or cross-national comparative analyses to test the robustness of the proposed UDI → IRS → SDI framework in diverse institutional contexts.

Third, this study relies on self-reported survey data, which may be subject to common method bias and perceptual limitations. Although procedural remedies and statistical tests were applied to mitigate potential bias, future research could incorporate multi-source data, such as administrative records, objective digital infrastructure metrics, or innovation performance indicators (e.g., patents, competition awards). Such approaches would strengthen measurement validity and reduce potential response bias.

Fourth, while institutional research support was conceptualized as a mediating mechanism, other potential mediators and moderators were not examined. For example, individual-level factors such as digital literacy, entrepreneurial self-efficacy, or innovation motivation may influence how digital infrastructure translates into innovation behavior. Additionally, institutional characteristics such as university type, research intensity, or governance autonomy may moderate the strength of the proposed relationships. Future research could develop more complex moderated mediation models to deepen the understanding of boundary conditions.

Finally, this study focuses on student-driven innovation within universities. Future research could extend the framework to examine faculty innovation, industry collaboration outcomes, or technology commercialization processes. Expanding the outcome variables would help further clarify the broader impact of digital infrastructure within higher education ecosystems.

In summary, while the present study provides a mechanism-based explanation of how digital infrastructure fosters student-driven innovation through institutional research support, future investigations adopting longitudinal designs, multi-source data, and cross-context comparisons would enhance the robustness and generalizability of these findings.

### Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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