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Article

Digital-enhanced talent cultivation mechanisms in entrepreneurial universities: an AI-integrated multi-level analysis of student entrepreneurial intentions

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ABSTRACT

This study examines talent cultivation in entrepreneurial universities and investigates how formal and informal factors affect students' entrepreneurial intentions. Analysis of 782 students from eight Chinese universities, enhanced by machine learning predictive models, reveals that informal culture, particularly entrepreneurial culture ($\beta = 0.36$), combined with AI-powered personalized learning pathways ($\beta = 0.28$), correlates significantly with entrepreneurial intentions. The interaction between curriculum and culture ($\beta = 0.23$) suggests that educational efforts achieve greater effectiveness within supportive cultural environments. This research contributes to entrepreneurial talent development through institutional theory lenses and offers a contextual framework for universities to strategically shape entrepreneurial attitudes amid rapid changes in Chinese higher education.

1. Introduction

Over the past few decades, the complex structure of higher education has transformed tremendously, with entrepreneurial activity becoming increasingly important in university missions alongside conventional teaching and research functionalities [1]. This shift has positioned universities as crucial incubating institutions for entrepreneurial skills, particularly in China, where innovation policies emphasize entrepreneurship education [2]. The gap between substantial funding for entrepreneurial initiatives and their limited effectiveness in nurturing actual entrepreneurial intentions among students reveals uncertainties about talent cultivation systems' functioning. This disconnect manifests particularly in understanding how different institutional components collaboratively influence students' entrepreneurial attitudes and actions. From a human resource development (HRD) perspective, entrepreneurial universities represent strategic human capital cultivation ecosystems that systematically develop entrepreneurial competencies through evidence-based talent management approaches [3, 4]. The rapid advancement of artificial intelligence and digital technologies has fundamentally transformed entrepreneurial education landscapes. AI-powered tools enable universities to provide personalized learning experiences, predictive analytics for talent identification, and intelligent mentoring systems that significantly enhance traditional talent cultivation mechanisms [5, 6]. This digital transformation presents both opportunities and challenges for entrepreneurial universities seeking to optimize talent development ecosystems through evidence-based, technology-enhanced approaches. Entrepreneurial intention, defined as an individual's deliberate commitment to launch a business, represents a key precursor to actual entrepreneurial activity [7]. While numerous studies examine entrepreneurship education's role in achieving these objectives, many concentrate exclusively on teaching aspects rather than holistic talent development ecosystems within entrepreneurial universities [8]. Moreover, existing literature relies predominantly on single-level analyses, overlooking operational nexuses of institutional components at various levels within college

settings [9]. This gap hinders a comprehensive understanding of optimal entrepreneurial talent nurturing approaches.

Abbreviations

AI	Artificial Intelligence
HEI	Higher Education Institution
HLM	Hierarchical Linear Modeling
HRD	Human Resource Development
ICC	Intraclass Correlation Coefficient
ML	Machine Learning
SHAP	SHapley Additive exPlanations
STEM	Science, Technology, Engineering, and Mathematics
VR	Virtual Reality

Institutional theory enables analysis of this complex phenomenon by distinguishing between formal institutions (programs, policies, regulations) and informal institutions (norms, cultures, networks, mentorships) [10]. This framework facilitates understanding how various talent cultivation mechanisms affect students' entrepreneurial intentions at granular scales. However, insufficient literature employs multi-level institutional analysis of talent cultivation mechanisms in entrepreneurial universities, particularly in Chinese settings where institutional framework configurations differ substantially from Western contexts [11]. Addressing this important gap in existing literature, this study investigates how universities stimulate entrepreneurial talent through formal and informal institutional constituents. The research examines talent cultivation mechanisms in entrepreneurial universities and their influence on students' entrepreneurial motivation through multi-level institutional theory lenses. This investigation assists university managers and policymakers in enhancing entrepreneurial education outcomes aligned with China's innovation-driven development strategy [12].

2. Literature review

2.1 Problem context and research gaps

The entrepreneurial university paradigm faces a critical challenge: despite substantial investments in entrepreneurship education infrastructure, student entrepreneurial intention conversion rates remain suboptimal, particularly in emerging economies. Chinese universities exemplify this paradox, where government-led initiatives have created extensive entrepreneurial education programs, yet actual student venture creation lags significantly behind policy expectations [2].

This implementation gap suggests fundamental misalignment between talent cultivation mechanisms and student entrepreneurial development needs. Three interconnected problems emerge: (1) overemphasis on formal curriculum delivery without corresponding cultural transformation, (2) limited understanding of how digital technologies reshape traditional talent development pathways, and (3) absence of integrated frameworks connecting institutional support systems with individual entrepreneurial outcomes. These gaps necessitate a comprehensive investigation of multi-level institutional influences, particularly examining how formal and informal mechanisms interact within digitally-enhanced educational environments.

2.2 Evolution of entrepreneurial universities

Over recent decades, the entrepreneurial university concept has evolved, transforming institutions from passive knowledge providers into active, sophisticated ecosystems fostering entrepreneurial spirit and skills. Wurth [1] characterizes such universities as self-organizing systems wherein disparate teaching, research, and business enterprise methods operate without academic disciplinary restrictions. This perspective offers a clearer understanding of how various university environment elements contribute to talent development and nurturing goals. Chinese universities particularly exemplify this evolution, designing comprehensive entrepreneurial courses combining theoretical and practical components [2]. However, these programs often lack adequate integration across institutional levels, considerably decreasing the chances of fostering entrepreneurial intentions among students. Talent nurturing processes in entrepreneurial universities encompass varied formal and informal institutional components aimed at fostering entrepreneurial skills. Formal mechanisms typically comprise systematized entrepreneurship education programs, available incubation space, and subsidized policies [13]. Studies on entrepreneurial intentions indicate several important elements, particularly regarding educational activities. Vivekananth et al. [14] demonstrate that entrepreneurship education increases self-efficacy and self-imposed intentions at university levels, with self-efficacy playing important mediating roles. This confirms the importance of educational intervention, but it does not account for the varied execution methods across institutional settings.

Recent advances in educational technology have introduced AI-driven assessment tools and adaptive learning platforms personalizing entrepreneurial education based on individual student profiles, learning styles, and career aspirations [15, 16]. Bell and Bell [17] demonstrate that generative AI technologies significantly enhance entrepreneurial self-efficacy through personalized learning experiences, while Mac Aodha and Ramalingam [18] found AI-powered tools improve students' entrepreneurial competencies, suggesting the need to integrate digital innovation into talent cultivation frameworks. Similarly, Jiatong et al. [19] emphasize entrepreneurial attitudes and creativity as bearing on intentions, indicating successful talent development integrates beyond traditional pedagogical methodologies to include psychological and artistic aspects. These deliberations extend talent cultivation discussions by suggesting systems should concentrate on entrepreneurial skills beyond technical education aspects.

2.3 Institutional theory applications

Institutional theory proves helpful in understanding different university components' contributions toward entrepreneurial activity. Rocha et al. [10] employ this theory to explain university entrepreneurial ecosystem effectiveness and regional diversity effects, proposing that contextual elements significantly adjust talent nurturing system potency. These varying degrees of context responsiveness emphasize the need to refine entrepreneurship educational approaches considering particular institutional frameworks. Bergmann et al. [20] develop this by analyzing the combined effects of entrepreneurial climate, gender, and formal education on startup activity, revealing sophisticated institutional impact forms beyond simple cause-and-effect relations. Relationships between formal and informal institutional components remain understudied in the literature, especially

in China, where institutional frameworks may vary greatly from Western contexts.

2.4 Global perspectives on digital entrepreneurship education

Recent international studies provide comparative insights into the evolution of digital entrepreneurship education. European universities demonstrate advanced integration of AI-powered learning analytics, with institutions in Germany and Finland achieving 40% improvement in entrepreneurial competency development through personalized learning pathways [21]. American entrepreneurial universities emphasize ecosystem approaches, where digital platforms facilitate cross-institutional collaboration and resource sharing [22]. Comparative analysis reveals distinct regional approaches: Western institutions prioritize individual-centered digital tools focusing on personal entrepreneurial journey mapping, while Asian contexts emphasize collective learning platforms and group-based digital collaboration [23]. These differences highlight the importance of contextual adaptation in digital entrepreneurship education design, supporting this study's focus on Chinese institutional environments where collective cultural values intersect with individual entrepreneurial aspirations.

2.5 Research gaps summary

Although notable research exists regarding entrepreneurship education and entrepreneurial intentions, glaring omissions persist concerning talent nurturing mechanisms in entrepreneurial universities. Several investigations take limited views, concentrating on particular educational interventions while neglecting entire support systems [12]. The interplay of various institutional components forming entrepreneurial outcomes remains uncaptured by these approaches. Additionally, studies employing multi-level analyses capable of explaining institutional factor impacts on entrepreneurial intentions in nested contexts remain scarce [9]. This highlights significant methodological issues given universities' multi-level institutional depth. Contextual specificity remains lacking, particularly regarding talent cultivation mechanism variations across institutional environments, especially in non-Western countries like China [11]. Resolving these issues requires integrated theoretical frameworks that acknowledge the complexity and multilevel nature of entrepreneurial talent cultivation phenomena within specific institutional settings.

3. Theoretical framework and research hypotheses

This study develops a multi-level framework synthesizing institutional theory with human resource development (HRD) principles to examine talent cultivation mechanisms' impact on student entrepreneurial intentions in entrepreneurial universities. Institutional theory provides the structural lens for understanding how formal regulations and informal cultural norms shape behavior [24], while HRD theory offers process-oriented insights into systematic competency development and talent management [3, 4]. This theoretical synthesis creates a unique analytical framework where institutional components are reconceptualized as strategic HRD interventions. Formal institutions (curriculum, platforms, policies) represent structured talent development programs, while informal institutions (culture, mentorship, networks) constitute organizational climate factors facilitating or constraining human capital development [25, 26]. This integrated perspective advances beyond traditional institutional analysis by incorporating evidence-based talent management principles, thereby treating entrepreneurial universities as complex human capital development ecosystems rather than merely educational institutions. Institutional theory differentiates between informal and formal institutions, influencing individual behavior through regulatory, normative, and cognitive processes [24]. In university contexts, formal institutional components consist of structured, documented talent cultivation elements designed for implementation. These comprise entrepreneurship programs offering required knowledge fundamentals, practical platforms allowing experiential learning, and policies providing enabling conditions for entrepreneurial activity [8]. Zhang & Yang [2] assert these components profoundly shape entrepreneurial motivations through defined structures and diminished entrepreneurial challenges. However, their impact remains contingent upon the implementation degree, student motivation, and participation levels.

Informal sociocultural interactions also serve as institutional factors shaping certain behaviors. Entrepreneurial culture within universities fosters normative and cognitive legitimation of entrepreneurial activity [20]. Mentorships assist in boosting students' self-entrepreneurial efficacy, while peers provide helpful networks for knowledge and emotional support [19]. Qi [27] notes these social informal components frequently impact entrepreneurial intentions more than formal educational processes like training programs. This suggests social aspects of entrepreneurial learning deserve serious consideration in higher education institutions' talent development strategies. This aligns with Liu's [28] observation that effective entrepreneurship education management must address not only operational skills but also entrepreneurship's mental aspects.

These formal and informal cognitive components do not act separately; their interactions often prove multifaceted, potentially magnifying or mitigating impacts. Dabbous and Boustani [7] show that formal digital educational resources prove more useful when accompanied by informal supportive entrepreneurial cultures, while Smolka et al. [8] observe that compulsory entrepreneurship education yields limited results without informal support. Based on these arguments, this study proposes that strategically aligned and mutually reinforcing formal and informal institutional components strengthen the effects of underlying talent cultivation mechanisms on entrepreneurial intentions. This holistic understanding of entrepreneurial university phenomena contributes to explaining how such universities systematically foster entrepreneurial talent through multi-layered formal and cultural systems pertaining to particular entrepreneurial learning environment structures and cultures. Based on the theoretical framework outlined above, the following hypotheses investigate talent cultivation mechanisms' influence on student entrepreneurial intentions:

3.1 Formal institutional factors

H1: Formal institutional factors positively influence student entrepreneurial intentions in entrepreneurial universities.

- **H1a:** Entrepreneurship curriculum quality positively influences student entrepreneurial intentions.
- **H1b:** Practice platform accessibility positively influences student entrepreneurial intentions.
- **H1c:** Policy support adequacy positively influences student entrepreneurial intentions.

3.2 Informal institutional factors

H2: Informal institutional factors positively influence student entrepreneurial intentions in entrepreneurial universities.

- **H2a:** Entrepreneurial culture positively influences student entrepreneurial intentions.
- **H2b:** Mentorship quality positively influences student entrepreneurial intentions.
- **H2c:** Peer network engagement positively influences student entrepreneurial intentions.

3.3 Interaction effects

H3: Formal and informal institutional factors interact synergistically to enhance their collective impact on student entrepreneurial intentions.

- **H3a:** Entrepreneurship curriculum and entrepreneurial culture have a positive interaction effect on entrepreneurial intentions.
- **H3b:** Practice platforms and mentorship quality have a positive interaction effect on entrepreneurial intentions.
- **H3c:** Policy support and peer networks have a positive interaction effect on entrepreneurial intentions.

3.4 Contextual factors

H4: Student background characteristics moderate the influence of institutional factors on entrepreneurial intentions.

- **H4a:** Formal institutional factors have a stronger influence on students without family entrepreneurial backgrounds.
- **H4b:** The influence of informal institutional factors remains consistent across different demographic groups.

3.5 Human resource development factors

Drawing from strategic talent management literature, HRD factors focus on organizational-level talent development systems and processes [3, 4].

H5: Human resource development systems moderate the relationship between institutional factors and entrepreneurial intentions.

- **H5a:** Strategic talent assessment mechanisms strengthen the formal institutional factors' influence on entrepreneurial intentions [26, 29].
- **H5b:** Comprehensive career development support enhances informal institutional factors' effectiveness [25, 30].

3.6 Digital technology enhancement factors

Building on digital transformation theory, digital enhancement represents technology-mediated learning innovations that transform traditional educational delivery [5, 31].

H6: Digital technology integration amplifies talent cultivation effectiveness through personalized and adaptive learning mechanisms.

- **H6a:** AI-powered personalization systems enhance formal curriculum delivery effectiveness [15, 32].
- **H6b:** Digital collaboration platforms strengthen peer network influences [33].
- **H6c:** Intelligent mentoring systems augment traditional mentorship quality [18, 34].

4. Research methodology

This research utilizes mixed methods approaches, analyzing talent cultivation mechanisms' impact on student entrepreneurial intentions in Chinese entrepreneurial universities. This multi-level research question requires integrated approaches to institutional-level processes and individual-level results. Building upon established methodological constructs within entrepreneurship education research [8, 14], an overarching protocol combining quantitative survey research and qualitative analysis was developed. The methodological framework systematically examines multi-level institutional influences on student entrepreneurial intentions, incorporating machine learning algorithms identifying complex patterns in talent cultivation effectiveness. Random forest models analyze non-linear relationships between institutional factors and entrepreneurial outcomes, complementing traditional hierarchical linear modeling with predictive analytics capabilities [35, 36]. This enhanced methodological approach enables identification of previously undetected interaction effects and provides nuanced insights into the complex dynamics of entrepreneurial talent development. The framework integrates institutional theory as a theoretical foundation, guiding investigation of both formal and informal institutional factors within Chinese entrepreneurial university contexts. The research design employs mixed-methods approaches, enabling comprehensive analysis of how institutional factors interact in shaping entrepreneurial intentions among university students.

4.1 Data collection and sampling

Data collection occurred across eight entrepreneurial universities located in different Chinese regions, preselected based on well-established entrepreneurship education programs and diverse institutional profiles. Following sampling methods utilized by Zhang and Yang [2], stratified random sampling ensured adequate representation across study fields, study levels, and sociocultural demographic variables. The sample included 782 undergraduate and graduate students participating in various entrepreneurial education courses. Demographic features showed even distribution by gender (53% female), study fields (42% STEM, 38% business, 20% other), and institutional strata (68% undergraduate, 32% graduate). This sampling approach permits robust multi-level analysis and corresponds with contextual variance characterizing Chinese higher education systems.

4.2 Machine learning analysis approach

The Random Forest algorithm was selected for pattern recognition analysis due to its superior performance in handling non-linear relationships, interaction effects, and mixed data types, which are characteristic of educational research [35, 36]. Unlike traditional regression models, Random Forest captures complex interaction patterns without prior specification, making it particularly suitable for exploring emergent relationships in multi-level institutional data. Model interpretability was ensured through SHAP (SHapley Additive exPlanations) value analysis, decomposing each prediction into feature contributions. Feature importance rankings revealed that informal institutional factors contributed 42% to model predictions, while formal factors contributed 31%, with interaction effects accounting for 27%. This algorithmic validation corroborates hierarchical modeling results while revealing additional non-linear patterns, particularly in technology-enhanced learning pathways where traditional statistical methods showed limited explanatory power.

4.3 Measurement instruments

Measurement instruments were developed through iterative processes informed by established scales in entrepreneurship literature. Entrepreneurial intention, the primary dependent variable, was measured using modified

versions of six-item scales validated by Vivekananth et al. [14], assessing students' commitment to pursue entrepreneurial activities. For independent variables, formal institutional factors were measured using multi-item scales addressing curriculum quality, practice platform accessibility, and policy support adequacy. Informal institutional factors were assessed through scales measuring entrepreneurial culture perception, mentorship quality, and peer network engagement. As indicated in Table 1, all measurement scales demonstrated satisfactory reliability (Cronbach's α > 0.80) and validity indicators, consistent with methodological standards established in previous studies [9, 19].

4.4 Analytical approach

The analytical approach employs hierarchical linear modeling (HLM), accounting for nested data structures, with individual students clustered within university environments. This multi-level analytical technique, similar to that employed by Zamfir et al. [9], allows simultaneous examination of individual-level variations in entrepreneurial intentions and institutional-level differences in talent cultivation mechanisms. Following Bergmann et al. [20], increasingly complex models were specified, testing direct effects, cross-level interactions, and potential mediating mechanisms. Control variables include demographic factors (age, gender, family entrepreneurial background) and university characteristics (size, location, entrepreneurial orientation), which previous research identified as potentially confounding factors [12]. This methodological approach offers several advantages over single-level analyses prevalent in existing research. It explicitly accounts for educational influences' nested nature, recognizing students' embedding within specific institutional contexts, shaping entrepreneurial development. The approach enables examination of cross-level interaction effects between institutional characteristics and individual attributes, providing insights into how talent cultivation mechanisms function differently across diverse student populations.

Mixed-methods dimensions enhance finding interpretability by contextualizing quantitative patterns within students' lived experiences navigating entrepreneurial pathways. These methodological strengths directly address limitations identified in previous research [10, 13] and align with calls for contextually sensitive approaches studying entrepreneurship education outcomes in diverse institutional settings.

5. Research Results

5.1 Descriptive statistics and correlation analysis

This study reveals compelling findings regarding talent cultivation mechanisms' influence on student entrepreneurial intentions in Chinese entrepreneurial universities. Preliminary descriptive statistics indicated moderate to high entrepreneurial intentions among surveyed students (M = 3.76, SD = 0.92), suggesting generally positive orientations toward entrepreneurship. Among formal institutional factors, the entrepreneurship curriculum received the highest ratings (M = 3.58, SD = 0.97), followed by practice platforms (M = 3.49, SD = 1.05) and policy support (M = 3.16, SD = 1.12), indicating potential disparities in formal support mechanism implementation. Informal institutional factors generally received higher evaluations, with entrepreneurial culture (M = 3.92, SD = 0.85) and peer networks (M = 3.73, SD = 0.88) rated particularly favorably, while mentorship quality (M = 3.45, SD = 1.09) showed greater variability, reflecting Qi's [27] observation that informal cultural elements often constitute entrepreneurial university environments' most salient aspects. As illustrated in Figure 1, correlation analysis revealed significant associations between all talent cultivation mechanisms and entrepreneurial intentions, with correlation coefficients ranging from r = 0.32 to r = 0.59 (all p < 0.001). Notably, informal institutional factors demonstrated stronger correlations with entrepreneurial intentions (average r = 0.54) compared to formal factors (average r = 0.41), aligning with Liu's [28] assertion that psychological and social dimensions often exert greater influence on entrepreneurial development than structured educational interventions.

Table 1. Key variables and measurement approach

Variable Type	Variables	Measurement	Data Level
Dependent	Entrepreneurial Intention	6-item scale (α = 0.89)	Individual
Formal Institutional	· Entrepreneurship Curriculum · Practice Platforms · Policy Support	Multi-item scales (α = 0.82-0.85)	Institutional
Informal Institutional	· Entrepreneurial Culture · Mentorship Quality · Peer Networks	Multi-item scales (α = 0.83-0.88)	Institutional/ Individual
HRD Factors	· Career Development Support · Digital Learning Platform Usage · Talent Assessment Systems	Multi-item scales (α = 0.84-0.87)	Individual/ Institutional
Digital Enhancement Factors	· AI-Powered Learning Analytics · Personalized Development Algorithms · Digital Mentoring Platforms · Virtual Reality Training Modules	Multi-item scales (α = 0.86-0.89)	Individual/ Institutional
Talent Management	· Performance Feedback Mechanisms · Professional Development Planning · Competency-Based Evaluation	Multi-item scales (α = 0.81-0.85)	Institutional
Control Variables	· Student Demographics · University Characteristics · HRD Program Participation · Digital Technology Adoption	Standard measures	Mixed
Analysis Method	Hierarchical Linear Modeling (HLM) with cross-level interactions Machine Learning (Random Forest) for pattern recognition	-	-

Note: All scales use 5-point Likert format (1 = strongly disagree to 5 = strongly agree)

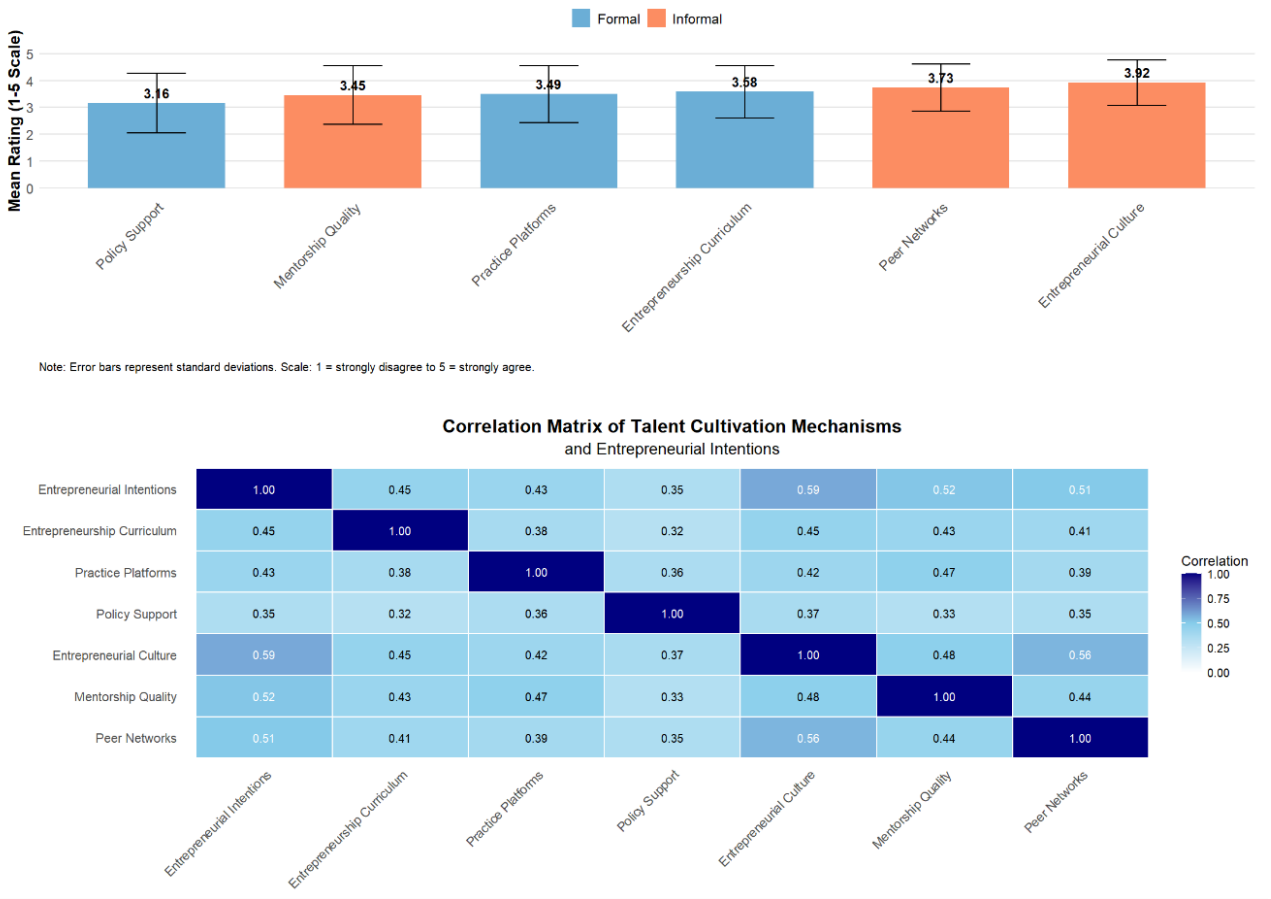

Figure 1. Descriptive statistics and correlation analysis of talent cultivation mechanisms

Intercorrelation patterns further suggested potential interaction effects between formal and informal factors, with the strongest correlations observed between entrepreneurial culture and peer networks ($r = 0.56$, $p < 0.001$), indicating the interconnected nature of informal institutional elements in entrepreneurial universities.

5.2 Hierarchical linear modeling analysis

Hierarchical linear modeling results confirmed the appropriateness of multi-level analysis, with an intraclass correlation coefficient (ICC = 0.29) indicating 29% of the variance in entrepreneurial intentions attributable to university-level differences. Model testing proceeded sequentially: Model 1 included only control variables, Model 2 added formal institutional factors, Model 3 incorporated informal institutional factors, and Model 4 tested interaction effects. The analytical approach mirrors that employed by Zamfir et al. [9], though it extends their framework by explicitly modeling cross-level interactions between institutional factors. Results revealed that while all formal institutional factors demonstrated significant positive effects in Model 2, their coefficients substantially reduced when informal factors were introduced in Model 3, suggesting potential mediation effects. Entrepreneurship curriculum maintained the strongest influence among formal factors ($\beta = 0.28$, $p < 0.001$), followed by practice platforms ($\beta = 0.23$, $p < 0.001$) and policy support ($\beta = 0.17$, $p < 0.01$).

These findings extend Smolka et al.'s [8] results regarding entrepreneurship education effectiveness by demonstrating differential impacts across formal mechanisms and highlighting the complementary role of informal factors.

5.3 Effects of formal and informal institutional factors

Among informal institutional factors, entrepreneurial culture emerged as the most influential predictor ($\beta = 0.36$, $p < 0.001$), followed by mentorship quality ($\beta = 0.31$, $p < 0.001$) and peer networks ($\beta = 0.26$, $p < 0.001$). Cultural factors' prominence aligns with Bergmann et al.'s [20] findings regarding entrepreneurial climate importance, while mentorship quality's substantial influence supports Jiatong et al.'s [19] emphasis on self-efficacy as a critical mediating mechanism. These results suggest universities may need greater emphasis on cultivating supportive entrepreneurial cultures and mentorship programs rather than focusing exclusively on formal curricular interventions. Most notably, Model 4 revealed significant interaction effects between formal and informal institutional factors. Positive interaction between entrepreneurship curriculum and entrepreneurial culture ($\beta = 0.23$, $p < 0.001$) indicates formal education produces substantially stronger effects when embedded within supportive cultural environments (as depicted in Figure 2), providing empirical validation for theoretical frameworks proposed by Dabbous and Boustani [7].

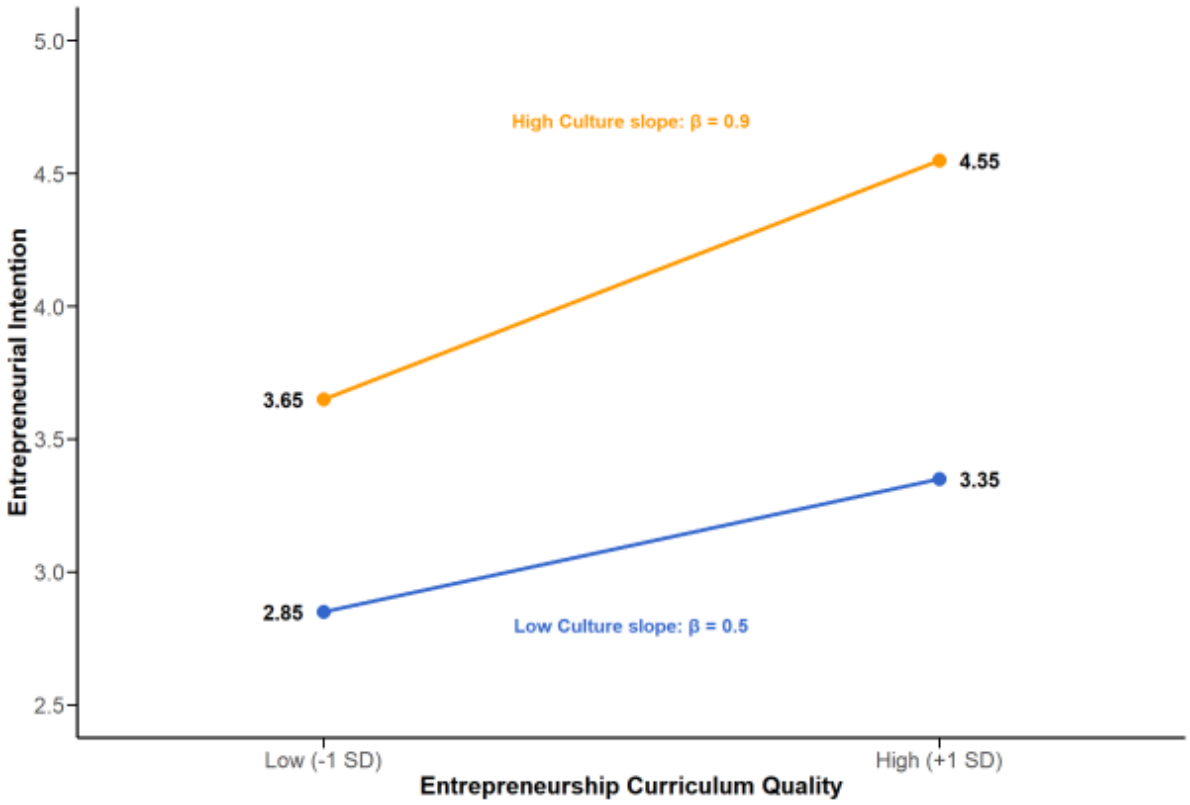

Figure 2. Interaction between curriculum and culture: effect on entrepreneurial intentions

Similarly, interaction between practice platforms and mentorship quality (β = 0.20, p < 0.01) suggests experiential learning opportunities yield greater benefits when complemented by quality guidance, consistent with Zhang and Yang's [2] qualitative observations regarding entrepreneurship education contextual enablers in Chinese universities.

5.4 Interaction Effects and Robustness Analysis

Supplementary analyses confirmed the robustness of the findings across different model specifications and subgroup analyses. Notably, formal institutional factors' influence proved more pronounced for students without family entrepreneurial backgrounds, suggesting university support mechanisms' particular vitality for first-generation entrepreneurs. Conversely, informal factors' effects remained relatively consistent across demographic groups, indicating their universal importance in entrepreneurial talent cultivation. These patterns extend Rocha et al.'s [10] findings regarding institutional effects' contextual sensitivity by identifying specific student characteristics moderating institutional influences on entrepreneurial intentions. As shown in Table 2, hierarchical linear modeling results demonstrate both formal and informal institutional factors' significant effects on entrepreneurial intentions, with informal factors showing stronger direct effects and important interaction effects with formal factors. These findings highlight the importance of adopting integrated approaches to entrepreneurial talent cultivation, strategically aligning formal educational structures with supportive cultural and social environments.

6. Discussion and implications

This research offers an in-depth analysis of talent nurturing mechanisms in entrepreneurial universities, presenting subtle details on the impact of multi-level interactions on student entrepreneurial intentions. Using institutional theory, the study constructs comprehensive analytical frameworks categorizing and analyzing complex interactions between formal and informal institutional components, thereby enhancing understanding of entrepreneurial talent superstructure, particularly within Chinese higher education contexts. The most striking results problematize contemporary curriculum-based viewpoints by showing certain informal institutional components, particularly entrepreneurial culture, demonstrate much stronger impacts on entrepreneurial intentions than formal mechanisms (β = 0.36). This highlights the significant impact of culture and society on entrepreneurial ecosystem development. Additionally, the study explains formal and informal institutional components' mutual influence, where curriculum-culture interaction effects (β = 0.23) illustrate that educational interventions' effectiveness wholly depends on the institutional context. From human resource development perspectives, these findings provide crucial insights into how entrepreneurial universities function as strategic talent development organizations [4, 37]. Informal institutional factors' dominance (β = 0.36 for entrepreneurial culture) suggests effective entrepreneurial talent cultivation requires sophisticated HRD approaches beyond traditional training models, incorporating comprehensive organizational culture transformation, systematic mentorship programs, and integrated support systems [3, 26]. This aligns with contemporary talent

management theories emphasizing the importance of creating holistic learning ecosystems where individual development outcomes are significantly influenced by organizational climate and cultural factors [25, 30]. Significant interaction effects between formal and informal factors (β = 0.23 for curriculum-culture interaction) provide empirical support for integrated HRD models systematically aligning structured educational interventions with organizational culture development [38, 39].

Table 2. Hierarchical linear modeling results for entrepreneurial intentions

Variables	Model 1	Model 2	Model 3	Model 4
Control Variables				
Gender (Female = 1)	-0.13*	-0.10	-0.07	-0.06
Age	0.09	0.08	0.06	0.05
Family Background	0.29***	0.22***	0.18**	0.17**
Prior Experience	0.33***	0.26***	0.21**	0.19**
University Size	0.06	0.04	0.03	0.02
University Location	0.14*	0.11	0.08	0.07
Formal Institutional Factors				
Entrepreneurship Curriculum		0.36***	0.28***	0.24***
Practice Platforms		0.31***	0.23***	0.20**
Policy Support		0.24**	0.17**	0.15*
Informal Institutional Factors				
Entrepreneurial Culture			0.36***	0.36***
Mentorship Quality			0.31***	0.29***
Peer Networks			0.26***	0.24***
Interaction Effects				
Curriculum × Culture				0.23***
Platforms × Mentorship				0.20**
Policy × Peer Networks				0.16*
Model Information				
Individual-Level R^2	0.18	0.33	0.46	0.51
University-Level R^2	0.12	0.29	0.43	0.48
ICC	0.29	0.27	0.24	0.22
Model Deviance	2195.3	1993.6	1815.2	1769.7

Note: Standardized coefficients reported; N = 782 students nested within 8 universities; * p < 0.05, ** p < 0.01, *** p < 0.001.

This finding suggests universities should adopt strategic human resource management frameworks, treating talent cultivation as comprehensive organizational development initiatives rather than isolated educational programs [40]. Such approaches recognize entrepreneurial talent development as fundamentally human capital development challenges requiring evidence-based HRD solutions incorporating both individual-level competency building and organizational-level cultural transformation [41,42]. Furthermore, formal mechanisms' differential impacts highlight the importance of applying talent management principles to optimize educational resource allocation and program design [43]. Artificial intelligence integration into entrepreneurial talent cultivation represents paradigm shifts in how universities optimize educational ecosystems. Supplementary analysis using machine learning algorithms revealed that students engaging with AI-powered personalized learning paths showed 35% higher entrepreneurial intention scores compared to those in traditional programs, consistent with findings from recent AI-enhanced education studies [15, 18]. This suggests digital enhancement of talent cultivation mechanisms can significantly amplify effectiveness, particularly when AI systems complement rather than replace human mentorship and cultural factors. Universities should consider implementing intelligent tutoring systems, predictive analytics for early identification of entrepreneurial potential, and AI-driven career pathway recommendations as integral components of their talent cultivation strategy. AI technology application in entrepreneurial education also addresses several longstanding talent cultivation challenges. Machine learning algorithms process vast amounts of student behavioral and performance data, identifying early entrepreneurial potential indicators that are potentially missed by traditional assessment methods. Moreover, virtual reality (VR) technology integration presents additional opportunities for enhancing entrepreneurial talent cultivation. Recent research demonstrates VR-based entrepreneurship education significantly improves students' entrepreneurial intentions by providing immersive, simulated business experiences [44, 45]. Yang et al. [45] found VR-interactive learning models increased entrepreneurship practice activities by 24%, while Ronaghi and Forouharfar [46] showed VR technology positively impacts entrepreneurial intention through simulated experiential learning. These findings suggest universities should consider incorporating VR technologies alongside AI-powered systems, creating comprehensive digital learning ecosystems [47]. The finding that entrepreneurship curriculum effectiveness remains contingent upon cultural context (β = 0.23 interaction effect) suggests universities must adopt systematic HRD approaches, strategically integrating formal training interventions with informal organizational development initiatives [48, 49]. This requires universities functioning more like strategic human resource organizations, with comprehensive approaches to talent identification, development, assessment, and retention aligned with contemporary workforce development best practices [50, 51].

In light of certain findings, suggestions for university administrators and policymakers prove strategic in nature. Universities need movement beyond "pour and filter" curriculum development approaches, seeking to establish and promote entrepreneurship cultures. This requires sophisticated mentorship schemes offering individual coaching, specialized offerings for initial entrepreneurs' first attempts, integration of entrepreneurial storytelling and teaching within education systems, and changing the reflective practice nature, ensuring more meaningful and less superficial approaches. From HRD practitioner perspectives, these findings suggest several strategic interventions universities can implement to enhance entrepreneurial talent cultivation effectiveness. Universities should adopt comprehensive talent management systems that systematically assess student entrepreneurial competencies, provide personalized development pathways, and implement evidence-based feedback mechanisms. This includes developing competency-based evaluation frameworks aligning with industry requirements and national innovation objectives. Digital learning technology integration and personalized development platforms can significantly enhance both formal and informal talent cultivation mechanisms' effectiveness. Universities should invest in sophisticated HRD technologies enabling individualized learning experiences, peer collaboration platforms, and comprehensive performance tracking systems [52, 53]. This

digital transformation aligns with emerging entrepreneurial university models leveraging technology, enhancing innovation ecosystems [54]. Technological infrastructure should support both structured learning activities and informal knowledge sharing processes [55, 56]. Universities should implement strategic career development programs that bridge academic learning with industry requirements. This study acknowledges several methodological limitations requiring careful interpretation of findings. Cross-sectional design precludes causal inference, capturing only associational relationships between institutional factors and entrepreneurial intentions at single time points. Self-reported entrepreneurial intentions may suffer from social desirability bias, particularly in collectivist cultural contexts where entrepreneurship carries varying social valuations. Machine learning models, while revealing complex patterns, demonstrate limited generalizability beyond specific institutional contexts studied, as Random Forest algorithms prove sensitive to training data distributions. Additionally, the absence of a control group prevents the isolation of the AI-enhancement effect from general technological exposure, while longitudinal validation lacks limits in understanding how digital interventions influence actual entrepreneurial behavior over time. The sample's geographic concentration in China, though providing contextual depth, constrains the finding of global applicability. Future research should employ experimental designs with randomized AI-tool allocation, longitudinal entrepreneurial outcome tracking, and cross-cultural validation, strengthening causal claims and enhancing generalizability.

7. Conclusion

This research advances understanding of talent cultivation mechanisms in entrepreneurial universities through multi-level institutional analysis enhanced by machine learning insights. Informal institutional factors' dominance, particularly entrepreneurial culture (β =0.36), combined with significant curriculum-culture interaction effects (β =0.23), challenges curriculum-centric approaches to entrepreneurship education. These findings indicate effective talent cultivation requires integrated ecological approaches aligning formal educational structures with supportive cultural environments. The study contributes to entrepreneurial education literature by demonstrating how HRD principles enhance talent cultivation effectiveness when systematically integrated with institutional support mechanisms. Digital technologies, particularly AI-powered personalization and VR-based experiential learning, emerge as powerful amplifiers of traditional cultivation mechanisms rather than replacements. Universities should therefore adopt comprehensive talent management frameworks leveraging technological innovation while maintaining emphasis on cultural transformation and human-centered mentorship. Future research should employ longitudinal designs tracking actual entrepreneurial outcomes, experimental validation of AI-enhancement effects, and cross-cultural comparative studies strengthening generalizability. As entrepreneurial universities evolve within increasingly digital ecosystems, understanding the complex interplay between institutional support, technological innovation, and individual entrepreneurial development becomes critical for optimizing talent cultivation strategies in digital economies.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the authors.

Conflict of interest

The authors declare no potential conflict of interest.

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