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A Five-Chain Collaborative Framework for Integrated Innovation Talent Development: A Document-Based Case Study of Mianyang, China

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Abstract
Cultivating innovative talents calls for joint efforts across education, scientific research, industrial sectors, human resource development and public governance. This coordination agenda carries special practical weight in Mianyang, a city well-known for its dense concentration of research institutes, tech-focused industries and local innovation assets. Even so, merely having abundant regional science and industrial resources cannot guarantee that such assets will be smoothly embedded into educational practices across successive learning stages. This paper explores how a five-chain coordination framework may underpin continuous innovative talent cultivation covering preschool, primary, secondary and tertiary education. Adopting a documentary regional case study design, this research sorts out national and provincial policy texts, public materials documenting Mianyang's science and education progress, plus existing scholarship on regional innovation systems, collaborative innovation and STEM teaching. Four interlinked bottlenecks emerge from the analysis: potential gaps between industrial labour demands and educational outputs, obstacles hindering the transformation of scientific resources into teachable content, a lack of coherent progression across schooling phases, and insufficient mechanisms to identify and nurture students' innovative potentials. To tackle these constraints, this work puts forward an integrated framework built on five mutually connected dimensions: the industrial chain, innovation chain, education chain, talent chain and policy chain. Three actionable implementation routes are further elaborated: vertical coherence linking different educational stages, horizontal partnerships between schools and external stakeholders, and dynamic assessment that tracks individual students' growth trajectories. This context-specific conceptual model bridges local innovation resources with long-term talent cultivation. That said, its practical value and reliability still require further verification through field surveys and pilot programmes.

Keywords
Five-chain collaboration; innovative talent cultivation; continuous education; regional innovation system; Mianyang Science and Technology City; STEM education

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1. Introduction

Innovation-led growth has raised social demand for learners capable of framing research questions, synthesising multidisciplinary knowledge, conducting inquiry work and generating creative solutions for complex real-world challenges. Such competencies do not only take shape during university study. They develop gradually via sustained learning experiences: early exploratory play, nurtured scientific curiosity, hands-on investigations, interdisciplinary training and progressively advanced problem-solving. Therefore, cultivating innovators should be viewed as a long-run growth process, rather than a training burden confined to one particular school phase.

Chinese policy circles have grown increasingly aware of the interwoven ties connecting education, science and technology, and talent development. The Education Power Building Plan (2024–2035) calls for well-refined mechanisms to discover and foster top innovative talents, boost the scientific literacy of K-12 learners, and push forward coordinated development across education, science and technology sectors [1]. This policy also stresses that talent training should match socioeconomic demands and strengthen partnerships among schools, families and local communities. Such policy signals suggest that the cultivation of innovative talents cannot rely merely on internal reforms within individual schools; it also demands stronger connections across diverse organisations and social sectors.

Even so, matching fragmented school stages with external innovation resources remains a complicated organisational challenge.

Educational institutions follow distinct curriculum schedules, developmental expectations, assessment schemes and administrative routines. By contrast, research institutes and enterprises organise their operations around research priorities, technological iteration, production targets and professional industry standards. Although these organisations own resources relevant to innovation education, those resources are rarely originally designed for direct classroom use. Meaningful collaboration thus demands supporting mechanisms that translate external knowledge and technological assets into age-appropriate learning activities.

Mianyang offers a valuable regional setting to investigate this issue. As China's Science and Technology City, it hosts a unique science and industrial ecosystem supported by research bodies, defence technology resources, advanced manufacturing clusters, electronic information industries and regional innovation platforms. Sichuan's policies for collaborative innovation position China (Mianyang) Science and Technology City as a core node within the province's regional innovation layout [2]. Open data also shows that the city gathers a large number of research institutions and innovation infrastructure [3]. These local advantages create favourable conditions to connect scientific and industrial resources with educational development.

Still, the aggregation of regional resources cannot be equated with successful educational integration. A research laboratory, high-tech firm or university research platform does not automatically become accessible learning material for children and teenagers. This conversion process needs deliberate curriculum design, age-adapted activities, teacher capacity building, inter-institutional negotiation, safety protocols and matched evaluation tools. Without such supporting arrangements, scientific resources will stay confined inside professional research and industrial circles.

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This issue becomes more prominent when we consider the full educational pipeline stretching from preschool to higher education. Preschool education centres on fostering curiosity, observation, exploratory behaviours and the willingness to raise questions. Even so, matching fragmented school stages with external innovation resources remains a complicated organisational challenge. Primary education helps learners steadily build skills in systematic observation, basic experimental awareness and collaborative problem-solving. Secondary schooling introduces organised scientific exploration, cross-disciplinary projects and real-world application scenarios. Tertiary study opens doors for specialised research, technological innovation and engagement with authentic industrial challenges. These stages ought to connect with one another, yet each should retain its unique developmental positioning instead of adopting identical learning arrangements.

Existing STEM scholarship offers insights into this layered developmental logic. A systematic review of STEM integration in early childhood and primary education confirms the value of authentic interdisciplinary learning, alongside pedagogical approaches such as problem-based and project-based learning [4]. Studies focused on preschool scientific inquiry also highlight children's natural curiosity and the supportive role of teachers in facilitating meaningful inquiry activities [5]. Taken together, these findings indicate that integrated training for innovative talents must strike a balance between consistent developmental progression and stage-specific differentiation.

Against this backdrop, this paper addresses four research questions: (1) What regional and institutional features make Mianyang an appropriate case site for exploring integrated innovative talent cultivation? (2) What coordination hurdles emerge when scientific and industrial resources are linked to multi-stage education? (3) How can the industrial, innovation, education, talent and policy chains be integrated into a collaborative governance framework? (4) What practical implementation pathways can support the rollout of this framework?

This study develops a five-chain collaborative framework to illustrate how local innovation resources can be embedded into preschool, primary, secondary and tertiary education. Instead of assessing an already implemented programme, it adopts documentary analysis and puts forward a conceptual mechanism to inform future empirical research.

2. Materials and Methods

2.1. Theoretical Framework

This study draws on theories of regional innovation systems and collaborative innovation. From the regional innovation system perspective, innovation performance depends not merely on the capacity of individual firms or research institutes, but on interactive relationships among enterprises, universities, research organisations, government agencies and supporting service bodies [6]. Knowledge exchange and institutional conditions jointly shape local innovation outcomes.

The Triple Helix model likewise describes interactions among universities, industries and governments in knowledge creation and innovation [7]. Although this model lays a solid foundation for analysing cross-sector cooperation, the present study extends its analytical scope to accommodate the unique needs of integrated education and talent development. In particular, educational continuity, early identification of promising

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learners and cross-tier policy coordination are explicitly incorporated into this extended framework.

Accordingly, the study proposes a five-chain analytical framework:

（1）ndustrial chain: identifies regional industrial development priorities and the associated demand for knowledge, skills, and innovative capabilities.

(2) Innovation chain: It covers research institutes, universities, laboratories, technical platforms and various innovation assets that can be leveraged to deliver learning opportunities.

(3) Education chain: It links curriculum design, instructional implementation, learner activities and smooth progression across preschool, primary, secondary and tertiary education stages.

(4) Talent chain: It centres on the continuous discovery, nurturing, support and assessment of students' innovative potential throughout their learning journey.

(5) Policy chain: It supplies institutional rules, cross-party coordination mechanisms, resource allocation schemes and guarantee measures to maintain stable collaborative operations.

These five dimensions can be separated for analytical discussion, yet they rely on one another in practical operation. The industrial chain sets the overall orientation; the innovation chain supplies knowledge and material resources; the education chain converts these inputs into structured learning experiences; the talent chain enables ongoing identification and continuous growth of learners; the policy chain builds a supportive environment to keep collaboration running. These assets can open doors for schools to engage with scientific theories, technical applications, expert guidance and real-world problem scenarios.

2.2. Data Sources and Research Methods

The study adopts a qualitative, document-based regional case study approach. It draws on three categories of materials.

First, national and provincial policy documents were examined to identify policy priorities concerning innovative talent development, scientific education, regional innovation, and institutional collaboration. The principal materials include the Education Power Building Plan (2024–2035) and Sichuan's Action Plan for Enhancing Collaborative Innovation Development [1,2].

Second, publicly available regional materials concerning Mianyang were reviewed to understand the city's scientific and educational context. These include public information on the development of China (Mianyang) Science and Technology City and the publicly released 2024 departmental budget of the Science City Office, which refers to cooperation between scientific research institutions and local education, school development, and initiatives related to innovative talent cultivation [3,8].

Third, academic literature on regional innovation systems, university-industry-government collaboration, and STEM education was used to establish the theoretical basis for interpreting the relationship between regional resources and educational development [4–7].

The materials were analysed through qualitative content analysis and thematic synthesis. The analysis pro-

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ceeded in three steps. First, relevant policy objectives and institutional responsibilities were identified. Second, the materials were examined in relation to the five analytical dimensions. Third, potential coordination challenges and corresponding implementation mechanisms were synthesized.

This approach has several limitations. The study does not claim to have completed a comprehensive census of Mianyang's scientific resources or educational institutions. It does not include newly collected questionnaires, interviews, classroom observations, or student performance data. Nor does it evaluate the effectiveness of an implemented pilot programme. Its findings should therefore be interpreted as document-based analytical conclusions and conceptual propositions rather than statistically verified empirical results.

3. Results and Discussion

3.1. Regional Characteristics and Challenges in Integrated Innovation Talent Development

3.1.1. Regional innovation resources create opportunities for educational collaboration

Mianyang's scientific and technological characteristics provide a distinctive foundation for exploring integrated innovation talent development. The city's development as China (Mianyang) Science and Technology City has been supported by regional innovation policies and the presence of research institutions, technology-oriented enterprises, and innovation platforms [2,3]. Such resources potentially provide schools with access to scientific knowledge, technological applications, professional expertise, and authentic problem contexts.

The 2024 public departmental budget released by the Science City Office also records plans for educational partnerships with research institutions, school development within the Science City zone and innovative talent training initiatives [8]. This evidence shows that links between local scientific assets and schooling have already been embedded within regional policies and institutional layouts.

Even so, whether these resources can generate educational value hinges on their organisation and application. Research sites usually impose strict access controls; enterprises give priority to production and commercial goals; meanwhile, many schools lack curriculum development capacity or professional guidance to transform sophisticated technologies into teachable activities. Hence the core concern is not the mere existence of resources, but whether supporting mechanisms can be built to make these resources usable for teaching.

3.1.2. Potential mismatch between industrial demand and educational provision

The first bottleneck lies in the fit between industrial growth and educational output. Local industries demand a range of knowledge and competencies, such as scientific awareness, technical literacy, engineering mindsets, digital skills and problem-solving capacity. In contrast, school curricula are framed around pedagogical goals and disciplinary frameworks, instead of catering to the immediate needs of particular industries.

It would be improper to make school education fully match short-term industrial demands, particularly for early childhood and compulsory education. A more reasonable approach is to draw on industrial development

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to select authentic learning scenarios and define long-term training priorities. For instance, electronic information and smart manufacturing can offer context for age-appropriate tasks around observation, material exploration, structural design, simple mechanical systems and computational thinking.

This distinction matters greatly. Bringing industrial scenarios into education does not aim to train young learners as junior practitioners. Its goal is to help them gradually grasp how scientific knowledge solves practical issues and how different subjects jointly drive technological advancement.

3.1.3. Barriers to translating scientific resources into educational resources

The second difficulty relates to resource conversion. Research organisations and enterprises hold knowledge and technologies with educational potential, yet specialised research content needs thorough adaptation before it can be adopted in classrooms. This adaptation includes four core steps: screening content suitable for teaching, simplifying intricate concepts while preserving their core logic, designing learning tasks tailored to different age brackets, and equipping teachers to guide such learning.

For instance, research outputs from an institute focusing on materials science or information technology cannot be imported directly into preschool classrooms. For young children at this stage, suitable learning arrangements might centre on exploring the traits of common materials, spotting regular patterns, or exploring straightforward cause-effect links. By secondary school, learners are ready to take part in more rigorously designed experiments and cross-curriculum projects. In this sense, the same local innovation resource can serve varied learning goals, adjusted to match learners' developmental levels.

In the absence of a structured transformation system, collaborative activities often stay superficial: one-off site tours, guest talks or popular science sessions. These events can spark students' initial interest in science, yet they seldom build up a coherent, progressive learning trajectory.

3.1.4. Discontinuity across educational stages

The third obstacle lies in the lack of continuity within the talent cultivation pipeline. Preschool, primary, secondary and tertiary institutions follow separate curriculum focuses, teaching schedules and evaluation rules. Learners may join science-related activities at multiple schooling phases, but these tasks are rarely anchored to a shared set of developmental targets.

To illustrate: science activities in preschool aim to inspire observation and questioning. Primary science gradually guides children toward organised inquiry. Secondary schooling further builds students' skills in experimental design, evidence-driven reasoning and interdisciplinary problem solving. Higher education then links these foundational competencies to specialised research and technological innovation.

If these learning episodes remain isolated, learners may keep repeating introductory tasks without advancing to deeper inquiry. On the other hand, bringing highly technical research tasks in too early runs the risk of mismatching children's developmental readiness.

Studies into early-years STEM education stress that educators should prioritise age-appropriate tasks, scaffolding from teachers and purposeful integration, instead of mechanically stacking subject knowledge [4,5].

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Accordingly, continuity across education stages should be built around gradually advancing competencies, rather than delivering identical content at every level.

3.1.5. Limitations of outcome-oriented talent identification

The fourth challenge relates to how we spot and assess innovative potential. Contest awards, exam marks and project deliverables offer valuable reference information, yet they fail to fully capture traits such as curiosity, creative thinking, resilience, teamwork and openness to revising ideas.

Innovation potential often reveals itself through ongoing learning processes. A student may show curiosity by raising continuous questions, discovering uncommon research angles, keeping trying after failed attempts, or merging knowledge from different disciplines. Such qualities are hard to record via single, snapshot assessments.

A holistic talent development system thus needs to balance final outputs with process-based evidence. It should also refrain from attaching fixed labels to learners too early, especially for young children, whose interests and abilities are still evolving.

3.2. The Five-Chain Collaborative Mechanism

Based on the document analysis and theoretical synthesis, this study proposes a five-chain collaborative mechanism for integrated innovation talent development.

Table 1. Five-chain collaborative framework for integrated innovation talent development

Chain	Core function	Main participants or resources	Educational contribution
Industrial chain	Identifying development priorities	Technology-oriented enterprises, industrial sectors, professional associations	Provides authentic problem contexts and long-term capability directions
Innovation chain	Supplying scientific and technological resources	Research institutions, universities, laboratories, innovation platforms	Provides scientific knowledge, expertise, facilities, and inquiry resources
Education chain	Transforming resources into learning experiences	Kindergartens, primary and secondary schools, universities	Organizes curricula, teaching activities, and cross-stage learning
Talent chain	Supporting identification and development	Teachers, students, mentors, educational institutions	Tracks developmental progress and supports individual potential
Policy chain	Coordinating institutions and resources	Government departments, education authorities, research and industry partners	Establishes rules, incentives, resource allocation, and safeguards

Note: The framework is a conceptual synthesis proposed by this study. It does not represent a measured evaluation of existing institutional performance.

3.2.1. Industrial chain: connecting educational priorities with regional development

The industrial chain provides a contextual basis for identifying the types of knowledge and capabilities that may become increasingly important in regional development. In Mianyang, tech-focused industries and ongoing research activities can supply authentic scenarios for innovation-oriented education. The core logic here

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is not to transplant routine industrial production tasks directly into classrooms. Instead, firms and industrial associations may join in selecting suitable educational themes, designing simplified real-world challenges, backing project-based learning, and creating chances for older students to grasp how technologies are applied in practice.

For young learners, industrial contexts need to be transformed into easy-to-access experiences. For instance, activities inspired by information electronics can revolve around light, sound, regular patterns or basic circuits, rather than drilling into the intricate technical parameters of industrial products. As students grow older, they can gradually tackle more sophisticated engineering and technological puzzles.

3.2.2. Innovation chain: transforming research resources into educational resources

The innovation chain bridges research resources and educational organisations. Universities, research institutes, laboratories, science museums and tech enterprises can take part by delivering science outreach, organising field visits, offering expert tutoring, developing curriculum materials and launching joint projects.

Even so, resource sharing cannot work well without a structured conversion workflow. A regional resource platform may catalogue available educational assets, mark out their target age groups, note access rules, safety requirements and viable forms of school cooperation. Schools can then pick matching resources according to their curriculum plans.

This setup helps move beyond sporadic, one-off resource use toward steady, organised cooperation. It also protects research institutes and enterprises from taking on extra duties outside their professional scope.

3.2.3. Education chain: establishing progressive learning across stages

The education chain takes charge of turning external resources into coherent learning journeys. Its core mission is to maintain developmental continuity while respecting the unique positioning of each schooling phase.

Preschool work prioritises curiosity cultivation, observation, free exploration, question-raising and hands-on engagement. At the primary stage, learners can gradually build skills in systematic observation, simple trials, classification and group problem-solving. Secondary schooling opens up interdisciplinary projects, evidence-led reasoning, engineering design and deeper inquiry. At the tertiary level, students get involved in specialised research, innovation initiatives and industry-linked practice.

In this five-chain system, the education chain lays the pedagogical foundation. Without thoughtful curriculum design and teacher support, outside resources will remain disconnected from students' real learning processes.

3.2.4. Talent chain: supporting dynamic identification and development

The talent chain centres on tracking students' growth trajectories instead of one-off selection screening. It calls for a broader understanding of innovative potential and long-running educational support.

Useful observation indicators include curiosity, willingness to question, observation skills, problem-finding,

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creative thinking, teamwork, perseverance and evidence use. These indicators should be interpreted differently across stages. Preschool assessment, for example, focuses on observable learning behaviours and participation, instead of formal tests or rankings. When students enter secondary and higher education, structured project outputs and research competencies become relevant reference points.

Growth portfolios can help teachers capture shifts in students' interests and learning demands. These records, however, serve to adjust supporting strategies rather than label students rigidly or limit their future development space.

3.2.5. Policy chain: providing institutional coordination and safeguards

The policy chain binds the other four chains together via governance, resource allocation, incentive schemes and institutional safeguards. Relevant government departments can conduct overall coordination, clarify the responsibilities of all participating bodies and back the development of shared educational resources.

The policy dimension carries special weight when research resources involve specialised facilities, confidential data or strict safety protocols. Cooperation must follow clear access procedures, age-adapted activity design, responsibility division and risk management frameworks.

Well-designed incentive policies can also motivate enterprises and research institutes to engage in science education. Such arrangements ought to recognise their educational contributions, while avoiding excessive administrative burdens or unrealistic expectations.

3.3. Implementation Pathways for Integrated Innovation Talent Development

The five-chain framework needs practical operating mechanisms to link different institutions, resources and teaching activities. Three actionable pathways are proposed below.

3.3.1. Vertical articulation: building a continuous developmental pathway

Vertical articulation means aligning learning goals and practical experiences sequentially from preschool all the way through higher education.

Its guiding principle is developmental progression rather than identical curricula. Each stage builds a foundation for subsequent learning while keeping its own educational priorities.

Take the theme of materials and structures as an example, which can be designed in differentiated ways for different groups. Preschool children explore the texture, bending characteristics, floating properties and load-bearing capacity of various materials. Primary learners compare material features and run simple experiments. Secondary students examine material performance within engineering contexts. University learners carry out targeted research on materials science or manufacturing technologies.

This progressive design allows regional innovation resources to support long-term talent cultivation, without imposing overly advanced technical requirements on younger children.

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3.3.2. Horizontal collaboration: establishing a regional resource-sharing network

Horizontal collaboration refers to partnerships among schools and external organisations, across the same or different educational stages.

A regional science education resource platform can act as the coordination hub. It may collect information on research bodies, enterprises, universities, science education venues, available specialists and educational programmes. Each resource entry should specify its suitable education level, preconditions and participation rules.

Schools select resources based on their own needs; enterprises and research institutes provide professional expertise or learning opportunities within agreed boundaries. Universities can contribute through teacher training, curriculum co-development and student mentorship.

This platform is more than a simple information directory. Its core value lies in facilitating communication, matching resources with teaching demands and nurturing stable long-term partnerships.

3.3.3. Dynamic evaluation: shifting from isolated outcomes to developmental evidence

Dynamic evaluation delivers ongoing feedback throughout the whole talent cultivation process. It balances final learning results with records of inquiry processes and evolving competencies.

The evaluation system covers four dimensions:

（1）Scientific curiosity and exploration: the readiness to observe, raise questions, conduct investigations and seek explanations.

（2）Creative and problem-solving capacity: the ability to identify challenges, put forward solutions and refine ideas iteratively.

（3）Collaboration and communication: competence in exchanging viewpoints, joining group inquiry and presenting findings.

(4) Learning progression and reflection: proof of persistence, reflective thinking and increasingly rigorous application of knowledge.

These dimensions require stage-based adjustment. At the preschool level, teachers can rely on observation notes, children's verbal explanations, learning portfolios and documented exploratory activities. Primary and secondary stages add project files, experiment reports, presentations and collaborative outputs as evidence. For university students, research projects, practical innovation achievements and academic works become valid references.

Evaluation is not intended to single out a fixed cohort of gifted learners at an early age. Instead, it helps spot emerging strengths, deliver tailored learning opportunities and leave room for students' potential to unfold gradually.

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4. Conclusions

This paper explores how the five-chain collaborative framework can support integrated innovative talent cultivation in Mianyang Science and Technology City. Based on document analysis and theoretical integration, the study argues that regional scientific and industrial resources can empower education only when proper connecting mechanisms are in place to link resource suppliers, educational institutions, learners and policy stakeholders.

The proposed framework consists of five mutually dependent components: the industrial chain, innovation chain, education chain, talent chain and policy chain. Together, they illustrate how regional development priorities can be converted into research resources, learning experiences, growth support and institutional guarantees. Three implementation routes are also put forward: vertical alignment across educational stages, horizontal cooperation among regional stakeholders, and dynamic assessment that tracks students' growth.

The framework also clarifies that integrated education does not mean uniform teaching content for all phases. Preschool education should protect children's natural curiosity and exploratory learning; primary schooling consolidates basic scientific inquiry skills; secondary education supports interdisciplinary investigation and problem-solving; higher education creates access to specialised research and innovation practice. Developmental continuity is therefore realised through layered learning objectives and coordinated educational support.

This research has certain limitations. Its conclusions are drawn from public documents and existing academic literature, rather than newly collected empirical data. The framework has not yet been verified through systematic interviews, classroom observation or pilot interventions. Follow-up research may survey the actual distribution and accessibility of local innovation resources, investigate the real experiences of schools and cooperative partners, and test the operability of this framework via pilot programmes. Such empirical work will provide more solid evidence to judge its effectiveness and its transferability to other regions with concentrated science and technology resources.

Conflicts of Interest

The author(s) declare that there is no conflict of interest regarding the publication of this article.

Author Contributions

Conceptualization: Manqin Zhou; Methodology: Manqin Zhou; Formal analysis: Huizhen Fan; Writing—original draft:Xiangjun Zhou; Writing—review & editing: Xinyu Liu,; Funding acquisition:Manqin Zhou

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