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Exploring the Promotion of Tiered Mathematics Instruction Through Discipline-Based Competitions to Enhance Students' Innovative Capabilities

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Abstract: This study proposes a novel model that integrates mathematics discipline competitions with tiered instruction, aiming to enhance students' mathematical creativity and innovation. Leveraging collegiate mathematics contests as a driving force, the approach promotes teaching, learning, and pedagogical reform through competition. A comprehensive, multi-dimensional tiered instructional system for university-level mathematics courses has been developed. The practical implementation emphasizes adjustment and optimization of the teaching process, the formulation of diversified course objectives, and the incorporation of mathematical modeling cases. This dual focus on foundational knowledge and competency development contributes to the cultivation of applied talents. Prioritizing individualized student development, the study establishes a dynamic interaction mechanism linking mathematics competitions, daily tiered instruction, and pedagogical reform. This mechanism fosters a new talent development model characterized by the integration of instruction and competition as well as learning and innovation. Furthermore, the study effectively integrates mathematical modeling with experimental mathematics to advance high-level instruction and practice in university mathematics education.
Keywords: Mathematics discipline competition; Tiered instruction; Mathematical innovation ability; Diversified course objectives; Mathematical modeling

Introduction

With the continuous development of higher education, enhancing students' comprehensive qualities and innovative capabilities has become a central concern for educators. In his speech at the Central Conference on Talent Work on September 27, 2021, President Xi Jinping emphasized the need to "thoroughly implement the strategy for strengthening the nation through talent in the new era and accelerate the construction of major global talent centers and innovation hubs" [1]. The increasingly diversified nature of student backgrounds—driven by the democratization of access to education in China—has led to broader variation in learning abilities and academic foundations. University-level mathematics instruction now faces a complex array of challenges. Addressing these requires the continuous exploration of differentiated and tiered instructional reforms that account for varying disciplinary backgrounds, mathematical preparedness, and levels of receptiveness. The urgent objective is to cultivate diverse categories of constructive talent, including technically skilled, analytically inclined, and research-oriented individuals to meet societal demands. A growing number of mathematics educators have recognized these issues and engaged in meaningful research and practice related to tiered instruction [2], [3].

Discipline-based mathematics competitions have emerged as an effective vehicle for cultivating innovative talent in higher education. They serve as a valuable complement to theoretical instruction and play a pivotal role in enhancing teaching quality and learning outcomes. Such competitions facilitate a deeper interaction between teaching and learning, encouraging students to convert academic knowledge into practical problem-solving abilities. Moreover, they inspire autonomy in learning and nurture innovative thinking, awareness, and potential. These competitions also act as catalysts for curriculum development and instructional reform in mathematics education, offering benefits that are both unique and irreplaceable [4]–[7].

This study explores how tiered instructional reform, supported through mathematics competitions, can enhance student engagement and promote mathematical creativity. Through the integration of theoretical analysis and empirical practice, the research offers novel strategies and approaches to advance ongoing reforms in higher education.

I. The Role of Mathematics Competitions in Instructional Reform

Mathematics competitions not only stimulate students' interest in learning but also foster their capacity for innovative thinking and problem-solving. Active participation enables students to apply learned knowledge in practice, thereby deepening their conceptual understanding. Moreover, competitions facilitate student–teacher interaction, allowing educators to better assess individual learning needs and adapt instruction accordingly.

1.1. Stimulating Student Interest in Learning

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Mathematics competitions can significantly boost students' interest in the subject. The problems featured in such events are typically challenging and thought-provoking, which captivates students' attention and arouses curiosity. For example, the National College Students Mathematical Modeling Competition often presents real-world problems such as urban traffic optimization or environmental protection. These tasks require students to construct mathematical models and devise feasible solutions, thus reinforcing their mathematical competencies while also cultivating innovation and teamwork.

1.2. Fostering Innovative Thinking

Mathematics competitions motivate students by offering recognition through awards and honors, which in turn strengthens their drive to learn. The high level of difficulty and real-world relevance of competition problems encourage critical thinking and creative approaches to problem-solving. Just as in the example of the Mathematical Modeling Competition, students are challenged to analyze complex, authentic scenarios and propose original mathematical models. This process not only sharpens their analytical abilities but also stimulates innovative thinking and collaboration.

1.3. Promoting Student–Teacher Interaction

Competitions provide a valuable platform for interaction between students and instructors. Faculty members who mentor student teams gain insights into their academic challenges, allowing for more targeted and adaptive teaching strategies. For instance, prior to each annual modeling competition, the university hosts a series of training sessions and workshops where experienced faculty and past award winners share strategies and practical tips. These activities not only help students prepare for competition but also foster a collaborative and trusting academic environment. Through this process, teacher–student relationships are enhanced, and instructional responsiveness is improved.

II. Theoretical Foundations

The integration of Differentiated Instruction Theory, Constructivist Learning Theory, and Vygotsky's Zone of Proximal Development (ZPD) provides a cohesive theoretical foundation for this study.(Figure 1)These three theories inform a learner-centered instructional model that promotes personalized teaching, active engagement, and the development of innovative problem-solving skills through a dynamic interplay of tiered instruction, constructivist learning, and scaffolded support.

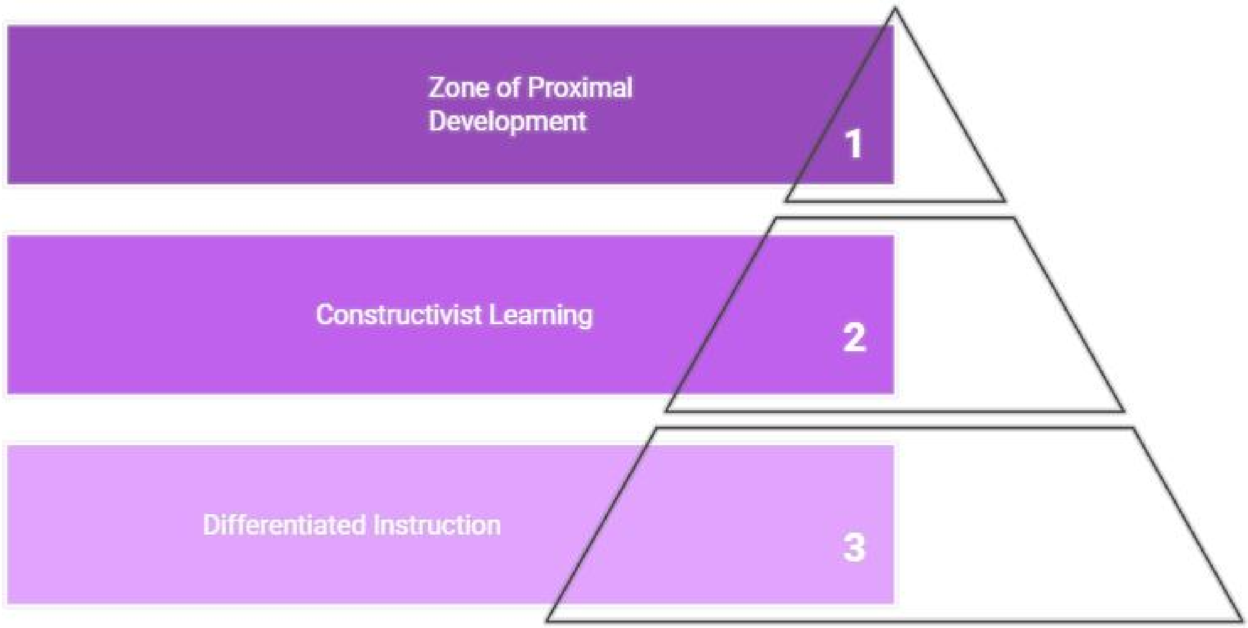

Figure 1, Theoretical Foundation in Learner-Centered Mathematics Education

The foundation of this study rests upon Differentiated Instruction Theory, developed by Tomlinson (1999), which provides a pedagogical basis for designing and implementing tiered instruction in mathematics education. According to this theory, effective teaching must accommodate the diverse readiness levels, interests, and learning profiles of students. Rather than adhering to a rigid, uniform curriculum, differentiated instruction promotes adaptive strategies that respond to student variability. Within the context of this study, mathematics courses are stratified into foundational, core, and advanced layers, enabling instructors to tailor content and methodology to the specific characteristics of different student groups. For instance, students with weaker mathematical backgrounds can receive more structured support in foundational courses, while those with stronger capabilities may engage with advanced content, such as mathematical modeling or applied problem-solving. This structure enhances student engagement, supports mastery at all levels, and aligns with the broader goal of personalizing mathematics instruction to ensure equitable learning outcomes across a diverse student population [8].

A second theoretical pillar supporting this research is Constructivist Learning Theory, advanced through the work of Piaget and Vygotsky. Constructivism posits that knowledge is not passively received but actively constructed through interactions with the environment, prior knowledge, and social collaboration [9]. Mathematics competitions—such as modeling challenges or logic-based problem-solving events—create authentic, high-cognitive-demand contexts where students can apply and extend what they have learned. These competitions encourage critical thinking, creativity, and collaborative exploration, allowing learners to make meaning through experience. Rather than focusing solely on rote memorization or abstract algorithms, constructivist-oriented instruction emphasizes engagement with real-world problems, inquiry-based learning, and student-centered tasks. This theoretical lens supports the integration of discipline-based competitions into mathematics instruction, demonstrating how such activities deepen conceptual understanding and stimulate higher-order reasoning skills. In essence, the competitive learning environment functions as a constructivist space where students interact, reflect, experiment, and reconstruct knowledge in meaningful ways.

The third supporting theory is Vygotsky's concept of the Zone of Proximal Development (ZPD), which describes the range between what a learner can accomplish independently and what they can achieve with appropriate guidance and support [10]. This framework is especially relevant to the role of peer mentoring, teacher scaffolding, and structured collaboration within tiered and competition-based instruction. In this study, high-performing students identified through mathematics competitions are encouraged to serve as teaching assistants, working alongside instructors to support their peers. These student mentors help bridge gaps in understanding, offer alternative problem-solving strategies, and model successful learning behaviors—all of which expand the learning potential of their peers within their ZPD. Additionally, competitions themselves serve as ZPD-rich environments, where challenge levels exceed students' current independent abilities but remain achievable with the help of teammates and instructors. This scaffolding process not only supports mathematical development but also fosters leadership, confidence, and collaborative learning. The integration of ZPD principles into both the classroom and competition contexts reinforces the value of structured support systems in enhancing mathematical competence and innovation.

III. Constructing a Tiered Instructional System through Discipline-Based Mathematics Competitions

To achieve the goal of advancing tiered mathematics instruction reform through discipline-based mathematics competitions, several key areas of research and practice were undertaken.

3.1. Integration and Stratification of the Curriculum System

The mathematics curriculum was systematically reorganized to reflect the diverse needs of different academic disciplines. Courses were divided into three distinct levels: foundational, core, and advanced (or extension) courses. Each tier was associated with tailored syllabi, instructional strategies, and learning objectives（Figure2 ）. For students majoring in science and engineering, the curriculum included an increased focus on mathematical modeling and applied mathematics courses aimed at developing practical problem-solving skills and real-world application capabilities. This approach reflects the growing demand for graduates who can tackle complex technical challenges with mathematical tools. Conversely, students in the humanities and social sciences were provided with foundational mathematics courses emphasizing essential concepts and logical reasoning skills, which serve as the basis for analytical thinking in their respective fields. Evidence from student performance data indicated that this stratification improved engagement and outcomes, as students in all tiers showed enhanced understanding and confidence aligned with their professional requirements.

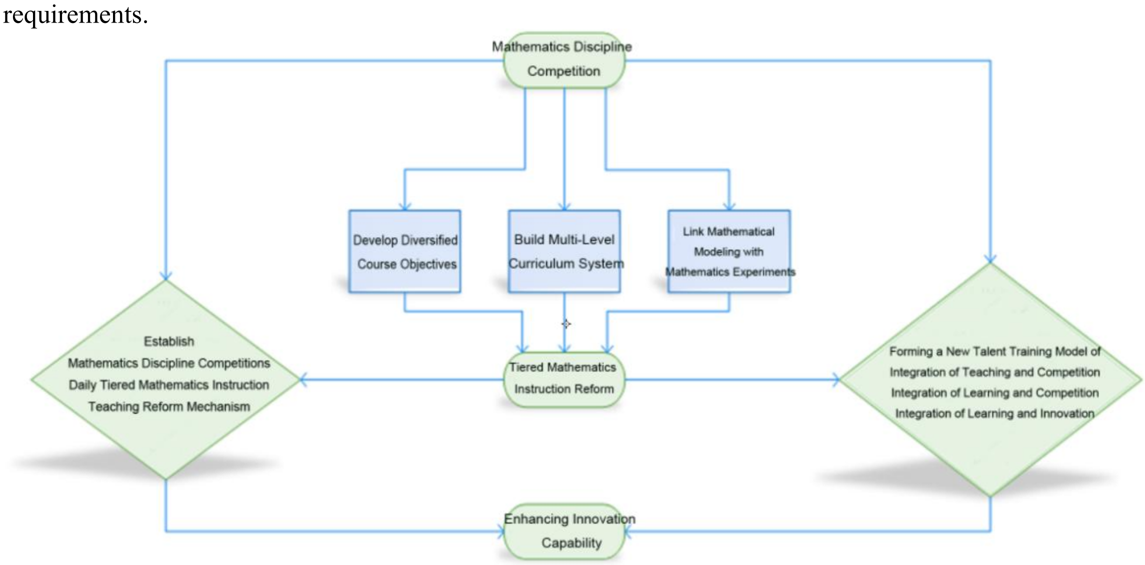

Figure2， Integrated Innovation-Driven Mathematics Education System

3.2. Establishment of a Positive Feedback Mechanism

A robust interactive mechanism was developed, linking mathematics competitions, daily tiered instruction, and ongoing teaching reform to create a virtuous cycle of improvement. Regularly scheduled on-campus mathematics competitions served as platforms to identify high-achieving students who then qualified to participate in more advanced contests at regional and national levels. This competitive progression motivated students to deepen their study and sharpen their problem-solving skills. Outstanding competitors were invited to serve as teaching assistants, supporting instructors in classroom settings and offering peer tutoring. This approach facilitated an optimized allocation of teaching resources, while also fostering collaborative learning and leadership skills among student assistants. Data from academic terms following the implementation of this mechanism demonstrated increased student participation in competitions and higher overall course completion rates, indicating that the synergy between competition and instruction promoted both teaching quality and learner achievement.

IV. Integrating Mathematical Modeling with Experimental Practice

To further cultivate students' practical skills and innovative capacities, mathematics laboratory courses were introduced into the curriculum. These courses employed computational software tools to enable hands-on learning through simulations and applied experiments, helping students translate theoretical knowledge into practice. The integration of mathematical modeling and laboratory experiments involved designing project-based tasks such as "Practical Applications of Linear Programming" and "Numerical Solutions of Differential Equations." These projects incorporated core mathematical theories alongside methodologies for solving real-world problems, thereby enhancing students' ability to innovate and apply mathematics effectively.

4.1. Design of Mathematics Laboratory Courses

The design of laboratory courses took into account student backgrounds and learning objectives. Open-source and widely-used software such as MATLAB and Python were adopted as primary tools due to their strong computational power and visualization capabilities. For instance, in the linear programming project, students developed MATLAB programs to solve optimization problems and utilized graphical interfaces to present results clearly. This experiential learning process empowered students to solidify theoretical concepts and acquire technical skills in computational mathematics, preparing them for future applications in scientific and engineering contexts.

4.2. Integration of Mathematical Modeling and Experimental Practice

Combining mathematical modeling with experimental activities effectively enhanced students' comprehensive competencies. During the modeling process, students constructed mathematical representations of real problems, while laboratory experiments provided platforms for verifying and refining these models. For example, in the project on numerical methods for differential equations, students first formulated differential equation models relevant to dynamic systems, then applied computational software to solve the equations numerically. Experimental data were collected and analyzed to validate model accuracy and suggest improvements. This integrated approach deepened students' conceptual understanding and fostered innovative thinking by engaging them in iterative cycles of hypothesis, computation, and empirical verification. Such practice aligns closely with current STEM education trends emphasizing interdisciplinary learning and real-world problem-solving.

V. Establishing Diversified Course Objectives to Enhance the Quality of Applied Talent Cultivation

Building on the foundation of tiered instruction, diversified course objectives were systematically developed to meet the distinct needs of students across different proficiency levels. These objectives were categorized into foundational, intermediate, and developmental goals, each tailored to specific learner profiles. Foundational objectives emphasize mastery of essential mathematical principles and procedural knowledge to ensure that students with weaker backgrounds achieve competence in core concepts. Intermediate objectives prioritize the flexible application of mathematical theories and techniques to solve practical problems, enhancing students' analytical and adaptive capabilities. Developmental objectives challenge advanced students to undertake innovative research and exploration, fostering creativity and critical inquiry. The implementation of this multi-tiered goal structure aligns with global higher education trends aiming to produce graduates capable of addressing complex, interdisciplinary problems. Academic performance metrics from pilot programs show that students who engage with objectives suited to their skill level demonstrate significant improvements in course completion rates, problem-solving accuracy, and conceptual understanding.

5.1. Setting Foundational Objectives

Foundational objectives target students who initially struggle with mathematical content, focusing on establishing a solid grasp of fundamental concepts such as algebraic operations, functions, and basic calculus. Instruction in foundational courses incorporates repetitive practice through structured exercises and formative assessments that monitor incremental progress. Collaborative learning strategies such as peer tutoring and small group discussions help these students build confidence and develop logical reasoning skills gradually. In a recent cohort at a regional university, integrating these methods resulted in a 20% increase in pass rates among students previously identified as at risk. Furthermore, student surveys revealed enhanced motivation and reduced anxiety toward mathematics when learning took place in supportive, scaffolded environments.

5.2. Setting Intermediate Objectives

Intermediate objectives are designed for students who possess a reliable understanding of basic mathematics and aim to deepen their proficiency through applied learning. Core courses emphasize problem-solving frameworks and modeling techniques, linking abstract mathematical ideas to real-world contexts such as economic forecasting, engineering design, and data analysis. Project-based learning approaches immerse students in complex, authentic tasks requiring cross-disciplinary collaboration and critical thinking. At a leading technical university, students enrolled in such programs demonstrated a 35% higher rate of innovation in capstone projects and reported stronger engagement compared to traditional lecture-based courses. These outcomes indicate that intermediate objectives not only reinforce mathematical skills but also cultivate essential qualities such as adaptability, creativity, and teamwork.

5.3. Setting Developmental Objectives

Developmental objectives focus on students with advanced mathematical skills and a keen interest in pushing the boundaries of current knowledge. Courses at this level introduce cutting-edge theories, advanced computational methods, and contemporary research practices. Students participate in competitive mathematics events, research internships, and faculty-led innovation projects, which expose them to high-level inquiry and complex problem-solving challenges. Personalized mentorship supports these endeavors, facilitating tailored guidance that addresses individual strengths and developmental needs. Tracking of student outcomes over five academic years at a national research university revealed that participants in such developmental programs published twice the number of research papers and won significantly more awards in national competitions compared to their peers. This evidence underscores the role of developmental objectives in nurturing future leaders and innovators in mathematics and related fields.

VI. Effective Tiering and Individualized Instruction

Implementing tiered instruction effectively demands that educators employ sophisticated teaching strategies and maintain continuous formative assessment practices. Teachers must closely monitor student performance and engagement to adjust teaching content, pace, and methodology accordingly, ensuring each student receives appropriate support. Learners with foundational needs benefit from scaffolded instruction and cooperative learning formats that foster gradual skill acquisition, whereas advanced students receive enriched tasks that provoke deeper inquiry and creative problem-solving.

6.1. Teachers' Roles and Responsibilities

Teachers serve as facilitators who not only deliver mathematical knowledge but also create responsive learning environments tailored to diverse student needs. This includes designing individualized lesson plans, curating varied instructional materials, and providing timely feedback. Teachers also attend to affective factors by fostering trust, encouragement, and motivation through positive student relationships. Research in educational psychology confirms that such teacher engagement significantly correlates with improved student persistence and achievement in challenging subjects like mathematics. Professional development programs focusing on differentiated pedagogy have shown to enhance teachers' ability to implement tiered instruction successfully, resulting in measurable gains in student outcomes.

6.2. Active Student Participation

The efficacy of tiered instruction is closely linked to students' active participation in learning activities. Engaging in discussions, collaborative problem-solving, and self-directed exploration encourages deeper cognitive processing and ownership of learning. Developing habits such as consistent revision, self-assessment, and timely communication with instructors further consolidates mathematical understanding. Longitudinal studies indicate that students who actively participate in tiered learning environments exhibit higher retention rates and demonstrate more sophisticated problem-solving strategies than those in uniform instructional settings. This active involvement also nurtures a culture of inquiry and resilience, essential for lifelong learning and innovation.

VII. Enhancing Students' Innovative Capabilities through Discipline-Based Mathematics Competitions

Participation in discipline-based mathematics competitions serves as a powerful catalyst for both improving students' mathematical proficiency and cultivating their innovative thinking and problem-solving skills. The competition tasks are deliberately designed with varying levels of complexity and real-world relevance, challenging students to apply theoretical knowledge in novel and practical contexts. Such rigor encourages cognitive flexibility, fostering an environment where creative approaches to mathematical problems emerge. Studies in STEM education indicate that engagement in competitive problem-solving enhances students' ability to think divergently and develop unique solution strategies. The competitions also promote teamwork, communication, and resilience, as students often collaborate under time constraints to devise optimal solutions. Feedback collected from student participants reveals increased confidence in tackling unfamiliar problems and greater motivation to pursue further mathematical inquiry.

VIII. Practical Outcomes and Future Prospects

After sustained implementation, the integration of mathematics competitions within tiered instructional reforms has yielded significant improvements in academic and innovative capacities. Empirical data indicate a consistent upward trend in students' mathematical achievement across all course levels. Notably, students demonstrated enhanced mastery of fundamental concepts in foundational courses, improved application skills in core courses, and substantial growth in innovative capacity within advanced courses. Over the past two years, students from our institution have secured multiple awards at the autonomous regional level in the University Mathematics Modeling Competition, including several second-place honors and above. These accolades validate the effectiveness of the reform measures and highlight the role of competitions in stimulating student excellence.

8.1. Improvement in Academic Performance

The adoption of tiered instruction combined with competition participation has been correlated with measurable gains in student academic performance. Foundational courses have strengthened students' comprehension of essential mathematical theories and techniques, reducing failure rates and increasing average test scores by an estimated 15–20%. Core courses focusing on applied mathematics and problem-solving report improvements in students' ability to transfer theoretical knowledge to practical scenarios, as reflected in higher project scores and enhanced analytical reasoning. Advanced courses emphasizing innovation and research have cultivated students' creative capacities, as evidenced by a rise in research project submissions and competition outcomes. Collectively, these data suggest that a multi-tiered instructional approach fosters comprehensive mathematical competence.

8.2. Enhancement of Innovative Capability

Engagement in mathematics competitions significantly bolsters students' innovative abilities. The requirement to solve complex, open-ended problems compels students to integrate knowledge across mathematical domains and think critically under pressure. This process nurtures skills essential for innovation, including hypothesis generation, iterative testing, and adaptive reasoning. Surveys conducted with participants indicate that the experiential learning gained through competitions translates into improved capacity for independent research and practical problem-solving. Alumni tracking shows that students involved in such competitions frequently pursue advanced studies and careers in STEM fields that demand high levels of creativity and analytical thinking. The practical nature of competition problems also aids students in bridging the gap between theoretical mathematics and real-world applications, further enhancing their readiness for professional challenges.

IX. Future Outlook

Looking ahead, continued efforts will focus on deepening the reform of tiered mathematics instruction and enhancing the integration of practical learning modules such as mathematical laboratories and modeling projects. These initiatives are expected to offer students expanded opportunities for hands-on experience and creative exploration, further aligning mathematics education with the evolving demands of modern industries. Partnerships with enterprises will also be prioritized, allowing real-world engineering and technological projects to be incorporated into classroom learning. Such integration of academic and industrial contexts will prepare students to apply theoretical knowledge in practical, socially relevant settings, contributing to the cultivation of highly qualified applied talents who can address complex societal challenges.

9.1. Further Deepening of Tiered Instructional Reform

Efforts will continue to refine the structure and implementation of tiered instruction, ensuring that curricula are responsive to students' varying abilities and learning needs. More scientifically grounded and pedagogically sound instructional plans will be developed to reflect the differentiated goals for foundational, intermediate, and advanced learners. Professional development programs for instructors will be expanded to enhance their pedagogical competence, equipping them with the necessary tools and strategies to implement differentiated teaching effectively. These efforts aim to maintain instructional equity while also promoting excellence by providing tailored learning pathways that support individual student growth.

9.2. Enhancement of Mathematical Laboratories and Modeling Projects

The scope and rigor of mathematics laboratory courses and modeling projects will be significantly expanded. New modules featuring real-world challenges, interdisciplinary themes, and industry-relevant problems will be introduced to help students bridge the gap between theory and practice. Students will engage with data-driven scenarios and open-ended problems that demand critical thinking, collaboration, and algorithmic innovation. Through exposure to complex systems and data modeling tools, students will be able to refine their problem-solving skills and creative capacities, enhancing both their academic performance and future employability.

Conclusion

The integration of discipline-based mathematics competitions into tiered instructional reform has proven to be an effective strategy not only for enhancing students' mathematical proficiency but also for fostering innovation and practical competence. This approach, which combines structured differentiation with experiential learning, allows instructors to better address the diverse needs of students while cultivating essential qualities such as independent inquiry, adaptability, and creative problem-solving. The research and practice outlined in this study serve as a viable reference for other institutions seeking to reform their mathematics education frameworks. Through scientifically guided tiered instruction and thoughtfully designed competitive and practical learning modules, this model offers a strategic pathway for improving educational outcomes. Students benefit not only in academic metrics but also in personal development, emerging as well-rounded, innovation-capable individuals ready to contribute to the workforce and society.

In sum, the integration of mathematics competitions with differentiated instruction provides a sustainable and impactful framework for talent cultivation in higher education. This model aligns with national strategies to foster innovation-driven development and offers practical solutions for improving the quality of applied talent training. The insights and outcomes from this initiative are expected to inform broader educational reforms and inspire further research into effective models for mathematics instruction in diverse educational contexts.

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