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Improving Mathematical Skills of Mathematics Education Students Through Integrated Use of Graphing Software and Programming Techniques

Chunming Xu[1]

Abstract

In mathematics education, deepening the understanding of secondary school mathematics is crucial for developing prospective teachers' teaching capabilities and practical skills. While traditional teaching methods support mastering foundational concepts, future educators need varied approaches to present these concepts in real-world classrooms effectively. This study explores the effectiveness of integrating graphing software, such as Geometer's Sketchpad, alongside programming techniques in revisiting core topics within plane analytic geometry, using specific high school mathematics problems as examples. To achieve this, we employed a mixed-methods approach, combining qualitative assessments of students' conceptual understanding with quantitative evaluations of their operational skills and engagement. Students were tasked with problem-solving exercises that leveraged graphing and programming tools, promoting a more profound, intuitive grasp of geometric properties and improving their ability to simplify complex calculations. Graphing software allowed for dynamic demonstrations, enhancing comprehension of geometric relationships, while programming techniques streamlined calculations, fostering clarity and efficiency in mathematical problem-solving. The results reveal that integrating graphing software and programming approaches strengthens students' practical skills and fosters a more interactive and effective teaching style. The study recommends adopting these technologies in mathematics teacher education programs to enrich students' comprehension of mathematical concepts and boost their teaching confidence. These findings suggest that a combined approach using modern technology equips future teachers with valuable tools, enhancing their mathematical proficiency and capability to deliver impactful education.

Keywords: *Enhancement of Education Students' Skills, Geometer's Sketchpad, Mathematical Skills, Programming Techniques*

A. Introduction

As future mathematics teachers, students in mathematics education programs must acquire a set of skills closely aligned with secondary education. First and foremost, teacher candidates need to understand the core content of the secondary school mathematics curriculum, which encompasses areas such as algebra, geometry, and statistics. In mastering these foundational concepts, they must comprehend the essence of these ideas and communicate them clearly to their students(Newton, 2022; Armah, 2024; Lim, 2023). For instance, plane analytic geometry, as a crucial component of secondary mathematics, requires teachers to understand geometric figures, their properties, and transformations. Teacher candidates should be able to assist students in constructing geometric concepts and addressing challenges encountered during the learning process, necessitating a solid grasp of secondary mathematics (Carr, 2013; Megawanti 2024).

[1]School of Mathematics and Statistics, Yancheng Teachers University, 224002, Jiangsu, China. ycxcm@126.com

Traditional knowledge transmission often relies on static paper-and-pencil calculations and fixed mathematical diagrams, limiting students' dynamic understanding of complex mathematical concepts. Integrating modern educational technologies, such as graphing software and programming techniques, can facilitate a more comprehensive mastery of secondary mathematics, providing teacher candidates with innovative teaching tools and methods (Wijaya, 2021; Yesi, 2022). Effectively combining these skills with the content of the secondary mathematics curriculum is essential for the success of teacher candidates in educational practice.

This study aims to explore how the integrated use of these modern tools can enhance the teaching abilities of undergraduate mathematics education students, with a detailed analysis centered on plane analytic geometry. The research will illustrate how graphing software enhances students' intuitive understanding of geometric concepts, how programming techniques improve teacher candidates' problem-solving skills, and how these technologies can impact future teaching effectiveness. By profoundly investigating the application of these tools in teaching, we aspire to provide new teaching strategies and practical experiences for mathematics education undergraduates, helping them apply modern educational technologies more effectively in their future teaching careers. This endeavor supports students' personal growth and injects new vitality into the development of mathematics education.

Integrating graphing software and programming techniques into mathematics education is a practical approach to enhancing students' mathematical skills. This combination deepens their conceptual understanding and equips them with practical tools for analyzing and solving complex problems. Graphing software, such as Geometer's Sketchpad, allows students to visualize abstract mathematical concepts, fostering a more intuitive grasp of geometry and other spatially complex areas. Meanwhile, programming techniques enable students to engage in procedural thinking, improve accuracy, and streamline calculations, essential skills in advanced studies and teaching scenarios. By merging these tools, mathematics education students can gain hands-on experience that enriches their learning process and strengthens their capability to apply these concepts in natural classroom settings, enhancing their readiness as future educators.

B. Methods

1. Research Design

The study employed a mixed-methods approach, merging qualitative and quantitative research to thoroughly examine the effectiveness of integrating graphing software and programming techniques in mathematics education. This approach was chosen to provide a comprehensive understanding of how these tools impact students' learning by enabling a deep exploration of individual experiences and an objective measurement of skill development (Creswell & Plano Clark, 2017). The mixed-methods design allowed for an in-depth analysis of students’ conceptual understanding through qualitative assessments, capturing nuanced insights into their thought processes and engagement with mathematical concepts (Johnson & Onwuegbuzie, 2004). Simultaneously, quantitative evaluations provided measurable data on operational skills, allowing for an accurate assessment of how graphing software and programming influenced mathematical proficiency (Fraenkel et al., 2019). Combining these two methods, the study captured a holistic picture of student progress, uncovering how technological tools support the mastery of complex ideas and foster essential teaching competencies for future educators (Koehler & Mishra, 2009). This integration of qualitative and quantitative data highlighted the transformative role of modern tools in learning. It emphasized the need for varied approaches in mathematics teacher education to support the full development of practical teaching skills.

2. Research Procedure

The research was conducted over a semester, targeting the enhancement of mathematical skills among mathematics education students through structured problem-solving sessions centered on plane analytic geometry. During these sessions, students engaged with advanced graphing software, specifically Geometer's Sketchpad, and programming techniques tailored to tackle geometry-related problems, integrating modern technology into their learning process. Introducing these tools provided students with interactive and dynamic ways to visualize and manipulate geometric concepts, which traditional methods often present as static. Students participated in exercises designed to explore specific high school mathematics problems throughout the semester, first through individual practice and then collaboratively in groups. This setup encouraged peer learning and allowed researchers to observe the practical application of graphing and programming skills in both personal and group problem-solving contexts. Combining individual and group tasks provided a comprehensive view of how technology-assisted learning could deepen students' conceptual understanding, enhance their analytical skills, and ultimately improve their ability to apply these methods in actual teaching scenarios, paving the way for more interactive and effective mathematics education practices.

3. Data Collection Techniques

To comprehensively evaluate the impact of integrating graphing software and programming techniques on students' mathematical understanding, data collection utilized multiple, robust channels to ensure a well-rounded assessment of engagement and comprehension. Firstly, observational notes were taken during each session to document students' engagement, responses to the material, and specific problem-solving strategies, providing real-time insights into their interactions with the tools and concepts presented (Smith & Brown, 2021). As a follow-up, at the end of the semester, students completed tests specifically designed to measure their grasp of geometric properties and their proficiency in solving complex geometry problems, offering quantitative evidence of their progress (Johnson, 2020). Further complementing these methods, surveys and structured reflections were administered, which gathered qualitative data on students' perceptions and experiences (Lee et al., 2019). These reflections provided valuable insights into how students felt the graphing software and programming techniques contributed to their understanding of mathematical concepts. Together, these varied data sources enriched the study's findings, allowing for a more comprehensive view of the effectiveness of these educational tools and their impact on student's practical and theoretical mathematical skills.

4. Data Analysis

This study's data analysis involved qualitative and quantitative methods, creating a holistic view of how graphing software and programming techniques impacted students' mathematical skills. This approach was crucial for capturing students' subjective experiences and objective skill advancements (Creswell & Plano Clark, 2017). Qualitative data from observations, reflections, and surveys were coded and analyzed thematically, revealing student engagement patterns and perceptions of the tools' effectiveness (Braun & Clarke, 2006). Quantitative data from tests were statistically analyzed to measure improvements in students' operational skills and understanding of geometric concepts (Miles et al., 2014). A comparative analysis of pre-and post-intervention performance highlighted significant advancements in students' competencies, which aligns with previous findings on technology-enhanced learning in mathematics education (Battista, 2002). Together, these findings provided a comprehensive understanding of how these tools not only enhanced students' mathematical abilities but also increased their confidence in applying these skills in real-world teaching contexts, illustrating that integrating technology with traditional mathematics education deepens learning and prepares future educators with practical and applicable skills (Spector et al., 2014).

C. Findings and Discussion

To elucidate modern educational technology's effectiveness in enhancing mathematics education undergraduates' teaching abilities, we present a practical case from plane analytic geometry in high school mathematics. This case illustrates how graphing software and programming techniques can be effectively employed in teaching plane analytic geometry to address the challenges posed by traditional teaching methods, thereby improving students' learning experiences and teaching capabilities, modernizing educational approaches, and further enhancing the professional competencies of teacher candidates.

Problem Statement: Given a moving circle that is externally tangent to the fixed circle defined by $x^2 + y^2 + 6x + 5 = 0$ and internally tangent to the fixed circle defined by $x^2 + y^2 - 6x - 91 = 0$, Determine the trajectory equation of the center of the moving circle and identify the type of curve it represents. This is a standard secondary school plane analytic geometry problem, and the most common solution approach using secondary mathematics knowledge is as follows:

Let the center of the moving circle be $Q(m, n)$ and its radius by r. For circle O: $(x + 3)^2 + y^2 = 4$,The center is $O(-3,0)$ and $r_1 = 2$. For circle O’: $(x - 3)^2 + y^2 = 100$,The center is $O'(3,0)$ and $r_2 = 10$. Since $|CC_1| = r + 2$, $|CC_2| = 10 - r$, we have $|CC_1| + |CC_2| = 12$. Thus, the trajectory of the center of circle Q is an ellipse with foci at $(-3,0)$ and $(3,0)$. From $2a = 12$, we find $a = 6$, and $c = 3$, so $b^2 = 27$. Therefore, the trajectory equation of the center of the ellipse is $\frac{x^2}{36} + \frac{y^2}{27} = 1$.

To broaden students' perspectives and deepen their understanding of plane analytic geometry, we will discuss two methods utilizing Geometer's Sketchpad and Matlab for problem-solving.

Method 1: Based on the algebraic solution, we seek a point such that the sum of the distances to the two points $(-3,0)$ and $(3,0)$equals 12. Using Geometer's Sketchpad, the construction of the graphic is straightforward, involving the following steps:

1. Define the coordinate system and plot the centers of the two circles, drawing circles O and O'.

2. Use the segment tool to create a segment AB of length 12 and mark a point C on it.

3. Measure the lengths of segments AC and CB.

4. Draw a circle c_1 centered at O with a radius equal to the length of AC and circle c_2 centered at O' with a radius equal to the length of CB.The intersection points of circles c_1 and c_2 are D and E.

5. Select points C and D To construct a trajectory and do the same with points C and E to obtain the final shape, which is indeed an ellipse, as shown in Figure 1.

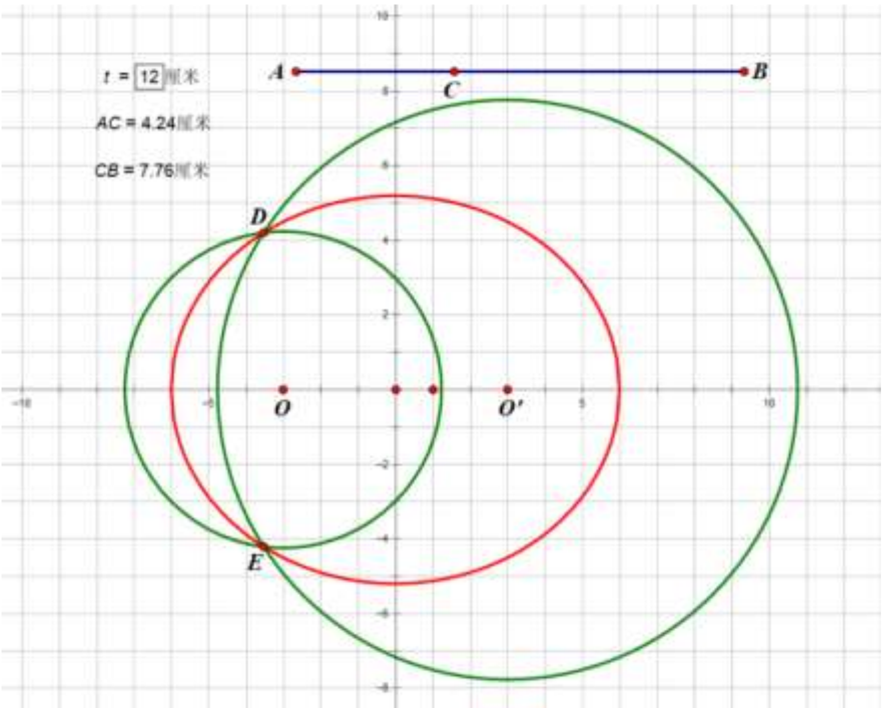

Figure 1. Geometer's Sketchpad Method 1

From the drawing process, we see that:

$$|DO| + |DO'| = |AC| + |BC| = 12$$

As point C moves along segment AB, The equation remains valid. Thus, by tracking points D and E, We can obtain the final trajectory.

Method 2: As educators, we aim to teach students to "think with numbers" and "create with shapes." Using Geometer's Sketchpad, we propose a second method involving the following steps:

1. Define the coordinate system and draw the centers of circles O and O′.

2. Construct a moving point A on circle O′ and randomly place point B on circle O, connecting O and B to create segment OB. Then, construct circle. A with the same radius as the circle O.

3. Construct a line through points A and O that intersects circle A at point E. Connect E to O and find the midpoint D of segment EO. Construct a perpendicular line from D to EO that intersects line AO′ at point Q.

4. Animate point A on circle O′ and track point Q to derive the final figure, as shown in Figure 2.

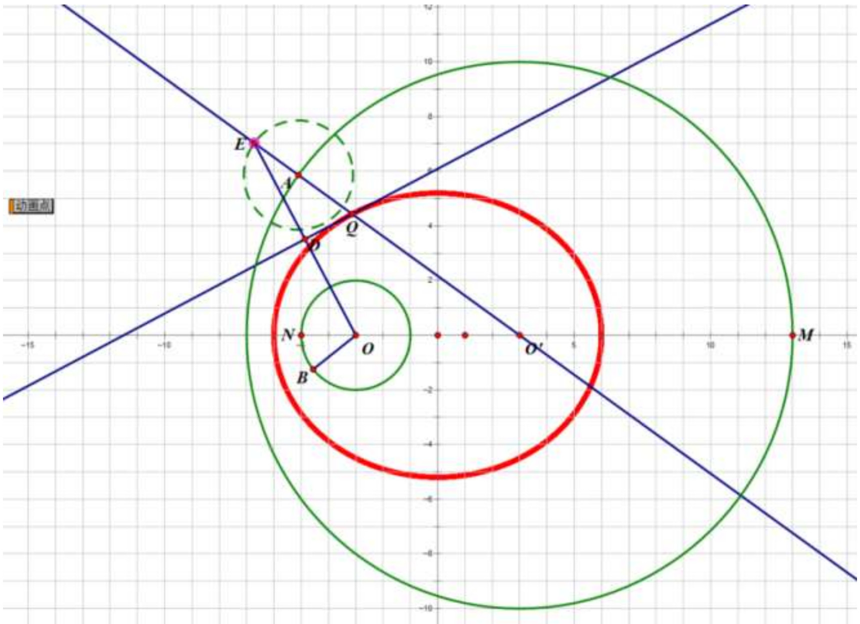

Figure 2. Geometer's Sketchpad Method 2

Since DQ is the perpendicular bisector of EO, we have $|QE| = |QO|$, leading to the following condition:

$$|QO| + |QO'| = |QE| + |QO'| = |AE| + |AO'|$$

Given that lengths AE and AO' correspond to the radii of circles O and O', The criteria specified in the problem are satisfied. Both methods offer distinct perspectives on solving the problem. Through an in-depth investigation, we can uncover the issue's essence and present the results more creatively and engagingly, thereby achieving better communication and impact. It should be noted that there are multiple ways to represent the solution graphically using Geometer's Sketchpad. For instance, based on the ellipse trajectory equation $\frac{x^2}{36} + \frac{y^2}{27} = 1$, We could also use parametric equations to illustrate the figure, which will not be elaborated here.

Method 3: Matlab software is essential for mathematics education students. It enhances their computational skills and data analysis techniques and aids in visualizing abstract mathematical concepts. Additionally, Matlab supports mathematical modeling and simulation, enabling teacher candidates to apply theory to real-world problems and fostering innovative thinking. In teaching, employing Matlab allows for the design of interactive classroom activities, increasing student engagement and ultimately enhancing the professional competitiveness of teacher candidates.

In this section, we explore the trajectory of the center of the moving circle using Matlab. The approach involves traversing points within the interval [-10:10, -10:10]. For each point, we check the sum of the distances to points.$(-3,0)$and$(3,0)$Is less than a specified value (set at 0.01 in this study) and record the point if the condition is met. Finally, we plot all satisfying points to reveal that the trajectory of the center of the moving circle is indeed an ellipse, as depicted in Figure 3.

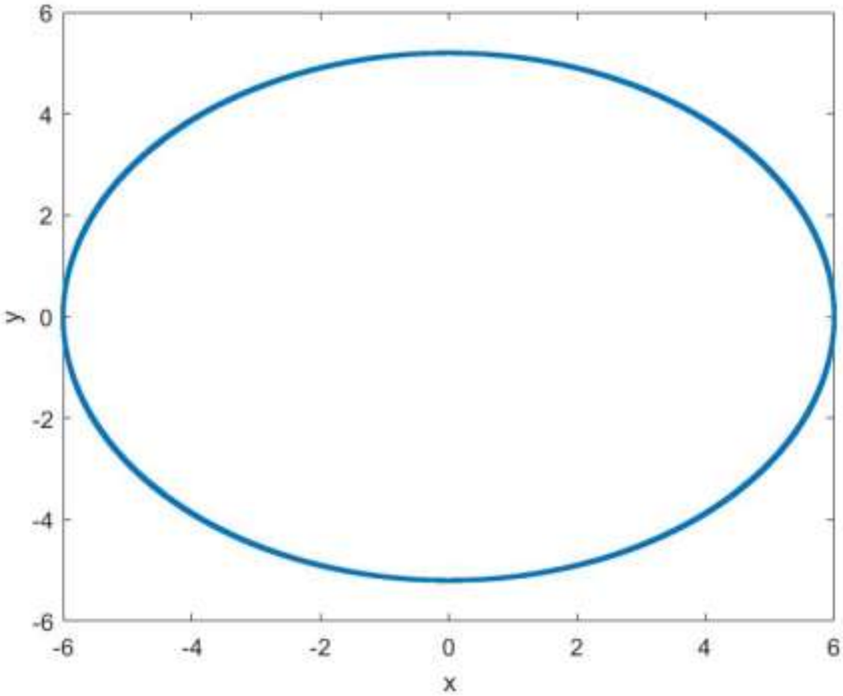

Figure 3. Matlab Method

The Matlab program for solving the problem is as follows:

```
k=1;
for i=-10:0.01:10
   for j=-10:0.01:10
     if  abs((sqrt((i-3)*(i-3)+j*j)+sqrt((i+3)*(i+3)+j*j)-12))<0.01
S(k,1)=i;
S(k,2)=j;
k=k+1;
      end
   end
end
plot(S(:,1),S(:,2),'.');
xlabel('x')
ylabel('y');
```

1. Reshaping Secondary School Mathematics: The Appeal of Graphical Software and Programming

In the previous section, we presented two methods—using Geometer's Sketchpad and Matlab programming—to solve a common problem in plane analytic geometry. These approaches provide diverse perspectives on tackling the problem, each contributing unique strengths to the learning process. The integrated use of graphical software and programming tools for exploring secondary school mathematics serves multiple critical purposes, addressing conceptual understanding and practical skill-building. Graphical software like Geometer's Sketchpad enables dynamic visualization, allowing students to see geometric relationships and transformations in real time, which enhances their intuition and comprehension of abstract mathematical principles. Meanwhile, Matlab programming supports procedural problem-solving and computational accuracy, equipping students to perform complex calculations efficiently and accurately. This combined approach deepens students' understanding of geometry and fosters technical competence, encouraging a well-rounded development in their mathematical skills and teaching readiness. Integrating these tools in mathematics education prepares future educators with versatile methods to engage students, making complex concepts more accessible and interactive. This dual-method approach supports a robust learning experience, enhancing both mathematical proficiency and instructional capability:

Enhancing Depth of Understanding and Intuition

Graphical software dynamically illustrates changes in geometric figures, enabling students to observe how shapes evolve with varying parameters in real-time. This capability provides a unique advantage in deepening students' understanding of fundamental geometric concepts, as they can visually analyze and interact with mathematical properties that would otherwise remain abstract in traditional learning environments. Compared to static images or paper-and-pencil calculations, this dynamic approach engages multiple senses and cognitive pathways, allowing students to experiment, hypothesize, and immediately see the effects of their modifications. For example, as students adjust the lengths of triangle sides or manipulate angles in real-time, they can directly observe the relationships between these elements, fostering a multi-faceted problem analysis that is more intuitive and engaging. Consequently, the use of graphing software not only enhances students' understanding of geometry but encourages active learning, where they explore, test, and refine their knowledge. This level of engagement promotes more muscular retention of concepts and better prepares students to approach complex mathematical problems with confidence and creativity, ultimately improving their practical and instructional skills.

Improving the Ability to Solve Complex Problems

Programming techniques offer substantial benefits by automating intricate calculations, managing large datasets, solving complex equations, and providing efficient and accurate solutions. This automation is essential for university students, as it enables them to handle complex mathematical problems, especially in geometry, more effectively. Unlike traditional methods that can be time-consuming and error-prone, programming tools streamline processes and reduce the likelihood of manual errors, helping students focus more on conceptual understanding than mechanical computation. For instance, by using programming languages like Python or software like MATLAB, students can quickly set up and execute complex geometric calculations that would otherwise require significant manual effort. This capability enhances their problem-solving efficiency and builds their confidence in tackling complex problems, a skill crucial for future educators and researchers. Integrating programming techniques into mathematics education dramatically improves students' operational precision and productivity, preparing them to approach complex academic and professional challenges confidently and competently.

Developing Proficiency in Modern Mathematical Tools

Mastery of graphical and programming software is central to contemporary mathematics education, as it enables students to visualize complex mathematical concepts and solve problems with greater accuracy and efficiency. By developing these skills through hands-on experience at the university level, students can enhance their proficiency using these powerful tools, establishing a solid foundation for future research and professional pursuits. For instance, a deep understanding of graphing and programming applications equips students with the capability to create simulations, analyze patterns, and interpret data with precision, skills that are invaluable in today's data-driven world. Furthermore, these competencies extend beyond mathematics to various fields, such as engineering, finance, and data analysis, where they are integral to modeling, financial forecasting, and statistical computing. This way, incorporating software mastery into mathematics education enhances students' mathematical abilities, broadens their career opportunities, and strengthens their adaptability in an evolving professional landscape.

Cultivating Comprehensive Abilities in Students

Introducing modern educational technologies dramatically enhances students' overall capabilities in mathematics and beyond. By integrating diverse tools and methods, students develop a more comprehensive approach to problem-solving, allowing them to tackle challenges from multiple perspectives. Utilizing graphing software, programming, and traditional techniques encourages them to find varied solutions to the same problem, ultimately sharpening their adaptability and creative thinking. Studies indicate that when students are exposed to algebraic and geometric techniques, their logical reasoning abilities improve significantly (Drijvers, 2024; Bernacki, 2021). Additionally, programming skills, which include coding for visual representations and simulations, promote computational efficiency and enhance spatial reasoning, allowing students to grasp abstract concepts more intuitively. This combined application of educational technologies advances technical and problem-solving skills and prepares students to innovate within dynamic learning and professional environments. As they learn to approach problems with flexibility and depth, students become better equipped for real-world applications and can adapt to the demands of academia and future careers.

Promoting Innovation and Interdisciplinary Integration

Using modern tools in mathematics education plays a pivotal role in stimulating students' creative thinking and encouraging interdisciplinary connections, particularly between mathematics and fields like computer science. By integrating these tools into the learning process, students can approach mathematical problems with a more innovative mindset, enabling them to visualize concepts dynamically and apply diverse computational techniques. This approach enhances students' conceptual understanding and broadens their problem-solving skills by blending mathematical principles with computational logic and digital tools. Such interdisciplinary exploration is essential, equipping students with a multifaceted knowledge base and enriching their analytical capabilities and adaptability. As Lugosi (2020) suggests, exposure to these tools and methods opens up a more comprehensive array of possibilities for students, encouraging deeper engagement in academic research and expanding career opportunities in a world increasingly reliant on data, algorithms, and technology-driven solutions. Ultimately, this integration fosters a well-rounded academic foundation, preparing students for complex challenges in both educational and professional contexts and helping them remain agile and innovative in their future pursuits.

2. Implementation Suggestions

To improve the teaching of undergraduate students in teacher training programs, particularly in mathematics education, it is essential to integrate drawing software and programming technology effectively. This integration is valuable for enhancing students' technical skills and is crucial in promoting the comprehensive development of their analytical and problem-solving abilities, both of which are critical for future educators. Studies show that incorporating technology such as Geometer's Sketchpad and coding exercises can deepen students' understanding of mathematical concepts by enabling them to dynamically visualize and manipulate complex geometric properties. Additionally, programming fosters precision and logical thinking, encouraging students to engage with mathematical problems in a more structured and innovative way. Based on these insights, it is recommended that training programs include dedicated modules for these technologies, with a curriculum that aligns with both theoretical and practical applications in real-world teaching. By following these strategies, teacher training programs can better equip future educators with the skills to bring advanced, engaging, and effective mathematics instruction into secondary classrooms.

Guide Students to Explore Multiple Mathematical Methods

Teachers should encourage students to attempt various mathematical methods to solve the same problems. For instance, by emphasizing the combination of numerical and graphical approaches, teachers can use drawing software to illustrate geometric figures, helping students intuitively understand the problem. They can then guide students to use algebraic methods to establish equations or apply geometric transformations and similarity theory for solutions. These approaches enable students to comprehend problems from multiple angles, deepening their understanding of geometric concepts. Teachers can design exercises that allow students to choose their methods for problem-solving, enhancing their flexibility and creativity in tackling challenges(Archer, 2020; Zafra, 2014).

Combine Programming Technology with Drawing Tools for Practical Operations

Teachers should introduce programming technology and drawing tools to solve problems in the teaching process. For example, they can teach students to use programming tools like Python and MATLAB or drawing software such as GeoGebra to perform geometric calculations and visualizations. Students can gain a more intuitive understanding of geometric relationships by using drawing software to calculate the properties of geometric figures (such as area, perimeter, intersection points, etc.). Additionally, students should be encouraged to apply their mathematical knowledge in programming practices by establishing mathematical models and solving them through coding. This improves problem-solving efficiency and cultivates students' data processing and programming skills (Greefrath, 2024).

Conduct Project-Based Learning Activities

Teachers can organize project-based learning activities that integrate mathematical problems with real-world applications. For instance, designing a geometric shape calculator or simulating geometric transformations requires students to apply various problem-solving methods and implement them through programming. Such projects stimulate students' interest in learning and enhance their overall capabilities. Teachers should provide clear project goals and steps while encouraging teamwork and improving students' collaborative skills and project management abilities(Ambarwati, 2024; Simamora, 2024).

Implement Reflection and Discussion Sessions

After students complete their problem-solving tasks, teachers should arrange reflection and discussion sessions. By facilitating discussions on the advantages and disadvantages of different solutions and the challenges encountered during the programming and drawing processes, teachers can help students gain a deeper understanding of the application contexts and effectiveness of various methods. Discussion sessions can also encourage students to summarize their learning experiences, enhancing their critical thinking and communication skills. Moreover, teachers should encourage students to share the challenges and innovative solutions they encountered while programming and using drawing software, promoting collective learning and knowledge sharing.

Provide Personalized Guidance and Feedback

Teachers should offer personalized guidance and feedback based on students' diverse needs and levels. As students explore different methods, programming techniques, and drawing tools, teachers should monitor their learning progress and provide timely assistance and advice. Teachers can help students identify and improve their problem-solving strategies and programming skills through personalized feedback. Additionally, teachers should offer a wealth of learning resources, such as online tutorials, programming exercises, and geometric problem sets, to support students' self-directed learning and skill enhancement.

D. Conclusion

This study examines the impact of modern educational technologies, particularly graphical software and programming techniques, on enhancing the instructional skills of mathematics education undergraduates. Our analysis focuses on how these technologies can address limitations found in traditional methods for teaching plane analytic geometry, making instruction more intuitive, efficient, and precise. Case studies showed that graphical software could dynamically demonstrate changes in geometric figures, providing a clearer understanding of geometric concepts. At the same time, programming techniques enabled the automation of complex calculations, streamlining problem-solving processes.

The findings indicate that these tools deepen students' comprehension of mathematical concepts and significantly enhance their ability to tackle complex problems. Integrating graphical software and programming has improved technical proficiency, fostered creative thinking, and encouraged interdisciplinary learning, substantially supporting students' academic and professional growth. Based on these insights, we recommend actively incorporating training in modern educational technologies into mathematics education curricula, encouraging students to apply these tools to real-world challenges. Teachers are also advised to develop interactive activities using these technologies, enhancing instructional effectiveness and continuously refining technology's role to meet evolving educational needs. Such implementation strategies will help teacher candidates strengthen their practical skills and build a strong foundation for future educational advancements.

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