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Research on Visual Teaching of Analytic Geometry Based on GeoGebra Software

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Abstract: This paper delves into the visual teaching of analytic geometry facilitated by GeoGebra software. Through a meticulous analysis of the current landscape of analytic geometry instruction and the distinct advantages of GeoGebra software, it expounds upon the imperative and feasibility of its application within the realm of analytic geometry teaching. Furthermore, it presents a detailed account of the teaching practice process grounded in this software, encompassing teaching design and the demonstration of teaching cases, and conducts an in-depth investigation and analysis of the teaching outcomes. The research findings indicate that the GeoGebra software can effectively elevate the level of visualization in analytic geometry teaching, thereby augmenting students' learning enthusiasm and comprehension capabilities. It thus offers novel perspectives and methodologies for the pedagogical reform of analytic geometry.

Keywords: GeoGebra software; Analytic geometry; Visual teaching

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1. Introduction

Analytic geometry is intricately intertwined with mathematics across nearly all domains, and its instructional significance cannot be overstated under any circumstances. The study of geometry plays a pivotal role in fostering students' capabilities in problem-solving, conjecture-making, deductive reasoning, intuition, visualization, logical argumentation, and proof construction [1,2]. Nevertheless, the abstract concepts and convoluted figures inherent in analytic geometry frequently present formidable challenges to students' learning endeavors. Traditional teaching approaches, which predominantly rely on static chalkboard notations and formula derivations, struggle to satiate students' need to grasp the dynamic transformations of geometric figures. In the context of analytic geometry, students are often confronted with the visualization dilemmas associated with abstract figures such as ellipses and hyperbolas. Empirical research has demonstrated that students aided by dynamic software are more predisposed to establish the "integration of number and shape" mindset, with a concomitant increase of 23% in the accuracy rate of problem-solving [3].

Visual teaching is an instructional approach that translates abstract knowledge, data, and concepts into tangible forms through visual modalities such as images, charts, animations, and videos. This facilitates students' intuitive comprehension and mastery of the subject matter. Dynamic visualization, in particular, encompasses a suite of visual presentations and interactive animations designed to elucidate abstract concepts [4]. A substantial body of research has meticulously explored the nexus between the integration of dynamic visualization in pedagogy and students' advancement and performance in mathematics learning [5,6].

GeoGebra, developed by Markus Hohenwarter at the University of Salzburg in 2001, seamlessly integrates geometry, algebra, and calculus. It is adept at managing the inter-relationships among geometric elements such as points, lines, polygons, and circles, along with facilitating the use of basic tools and commands [7,8]. Extensive scholarship has attested to its suitability for mathematics instruction [9,10]. For students across all educational levels, GeoGebra synergistically combines the strengths of dynamic geometry software and computer algebra systems [11,12]. Abundant empirical investigations have unequivocally demonstrated that GeoGebra can augment the efficacy of mathematics learning [5,9,13,14]. In a study [15], GeoGebra was implemented in the geometry instruction for students majoring in mathematics education and in-service educators. Employing purposive sampling techniques, two public institutions of higher learning were chosen as the research foci. The findings indicated statistically significant enhancements in students' academic achievements and enthusiasm for geometry learning and teaching. Furthermore, the GeoGebra-based teaching methodology rendered the curriculum more hands-on and accessible.

2. Analysis of the current situation of analytic geometry teaching

2.1. Limitations of traditional teaching methods

In traditional analytic geometry teaching, instructors predominantly impart knowledge through blackboard writing and oral explanations. For simple geometric figures such as lines and circles, teachers can draw and explain them on the blackboard. However, when it comes to complex quadratic surfaces like ellipsoids and hyperboloids, it is extremely challenging to accurately and clearly depict their shapes on the blackboard. As a result, students find it arduous to intuitively comprehend the forms and properties of these figures. Moreover, in traditional teaching, the teacher's instruction is often one-way, with students passively receiving knowledge. They lack opportunities for active participation and hands-on practice, which is detrimental to the cultivation of their innovative thinking and practical abilities.

2.2. Difficulties in students' learning

Analytic geometry courses are characterized by a high degree of abstraction and logical rigor. Students are tasked with conjuring geometric figures in their minds and forging connections between these figures and algebraic equations. Nevertheless, the spatial visualization and abstract reasoning faculties of the majority of students remain underdeveloped. As such, they encounter substantial hurdles in grappling with abstract concepts like vector operations and the parametric equations of spatial curves.

Moreover, throughout the learning trajectory, students are bereft of intuitive graphical expositions and dynamic transformation sequences. This dearth impedes their ability to fathom the profound interrelationships between geometric figures and algebraic equations, thereby engendering tepid enthusiasm for learning and subpar academic outcomes.

3. Features and advantages of GeoGebra software

3.1. Software features

GeoGebra software boasts an intuitive user interface. Through uncomplicated mouse-click and drag-and-drop maneuvers, users can expeditiously generate a plethora of geometric figures and algebraic expressions. It accommodates a diverse array of drawing modalities, encompassing plane geometry drafting, solid geometry rendering, and function graphing.

During the figure-creation process, the software instantaneously showcases the corresponding algebraic equations, thereby affecting the concurrent manifestation of geometric figures and algebraic equations. Furthermore, GeoGebra software is endowed with robust dynamic demonstration capabilities. Users can manipulate the control points on figures or adjust parameter values to observe in real-time the metamorphoses of the figures and the attendant alterations in the algebraic equations.

3.2. Advantages in analytic geometry teaching

Achieving graphical visualization: GeoGebra software is capable of accurately and clearly depicting various analytic geometry graphs, including plane curves and space surfaces. For complex graphs such as surfaces of revolution and cylindrical surfaces, the software can showcase the generation process of the graphs through dynamic demonstrations. This helps students intuitively understand the formation principles and properties of the graphs [16].

Promoting the integration of geometry and algebra: In GeoGebra software, geometric graphs and algebraic equations are interrelated. When a user draws a geometric graph, the software automatically generates the corresponding algebraic equation. Conversely, when a user inputs an algebraic equation, the software can quickly draw the corresponding graph. This real-time correspondence between geometry and algebra assists students in deeply understanding the ideological method of combining geometry and algebra in analytic geometry, thus building a bridge between geometric graphs and algebraic equations.

Enhancing students' interaction and participation: GeoGebra software supports students' independent operation and exploration. Students can actively observe the variation patterns of graphs, discover problems, and attempt to solve them by changing the parameters of graphs or dragging the control points of graphs. This interactive learning method can stimulate students' learning interest and initiative [17] and cultivate their innovative thinking and practical abilities.

4. Necessity and feasibility of visual teaching of analytic geometry based on GeoGebra software

4.1. Necessity of visual teaching of analytic geometry based on GeoGebra software

Aligning with the trend of educational informatization: With the extensive application of information technology in the field of education, using mathematical software to assist teaching has become an inevitable trend in the development of educational informatization. Introducing GeoGebra software into analytic geometry teaching can diversify teaching methods and enhance the level of teaching informatization, meeting the demands of educational development in the new era.

Improving teaching quality and effectiveness: The problems existing in traditional analytic geometry teaching seriously affect teaching quality and effectiveness. The visualization function of GeoGebra software can help students better understand abstract concepts and complex graphs, increasing students' learning interest and efficiency, and thus improving the quality and effectiveness of analytic geometry teaching.

Cultivating students' mathematical literacy: Analytic geometry teaching is not only about imparting knowledge but also about cultivating students' mathematical literacy. The application of GeoGebra software can guide students to observe and think about problems from different perspectives, fostering their spatial imagination, logical thinking, and innovative abilities, and promoting the comprehensive improvement of students' mathematical literacy.

4.2. Feasibility of visual teaching of analytic geometry based on GeoGebra software

Ease of use of the software: GeoGebra software is simple to operate and easy to master. Teachers and students can proficiently grasp the basic operation methods of the software after a short-term study and training. Moreover, the software provides abundant online tutorials and learning resources, which facilitate teachers and students to learn independently and further improve their software application capabilities.

School support and resource guarantee: Kashi University attaches great importance to educational informatization construction and provides necessary support and resource guarantee for teachers to carry out informatized teaching. The school is equipped with complete computer facilities and a network environment, which can meet the needs of teachers and students for using GeoGebra software in teaching and learning. Meanwhile, the school regularly organizes information technology training for teachers to participate in to enhance their software application capabilities and informatized teaching levels.

5. Practice of visual teaching of analytic geometry based on GeoGebra software

5.1. Teaching design

Setting teaching objectives: In the teaching of analytic geometry based on GeoGebra software, teaching objectives should not only enable students to master the basic concepts, theorems, and methods of analytic geometry but also cultivate their abilities to use the software for graph-drawing, analysis, and problem-solving. Through the dynamic demonstrations of the software, students are guided to observe the variation patterns of graphs, fostering their spatial imagination and logical thinking abilities. Meanwhile, it stimulates students' learning interest and innovative consciousness.

Integrating teaching content: Based on the teaching syllabus of analytic geometry courses and the features of GeoGebra software, the teaching content is integrated. The operational skills of the software are organically combined with teaching knowledge points. For example, when explaining the equations of plane curves, the software is used to demonstrate the changes of curves under different parameters, allowing students to intuitively perceive the impact of parameters on equations and graphs. At the same time, some representative practical problems are selected to guide students to use the software to establish mathematical models and solve them, thereby enhancing students' application abilities.

Designing teaching activities: Teaching activities are divided into online and offline parts. In the online part, teachers release teaching videos, software operation tutorials, and preview tasks through the learning platform. Students independently learn software operations and relevant knowledge, and communicate and discuss on the platform. In the offline part, teachers conduct key explanations and demonstration operations in class, and have students carry out group cooperative learning and practical operations. For instance, when explaining space surfaces, teachers first demonstrate the graphs of several common space surfaces through the software, and then let students operate the software in groups, draw space surfaces with different parameters, and analyze their properties. Finally, teachers comment on and summarize students' operation results, deepening students' understanding and mastery of the knowledge.

5.2. Demonstration of teaching cases

Taking the teaching of "Ellipse and Its Standard Equation" as an example:

Creating a context and introducing the new lesson: Teachers use GeoGebra software to showcase real-life examples of ellipses, such as planetary orbits and elliptical-shaped buildings, enabling students to observe the shape of ellipses and experience their applications in real life. Then, teachers utilize the software's drawing function to draw an ellipse on-site, guiding students to think about how to describe the shape and properties of an ellipse in mathematical language, thus introducing the new lesson.

Exploring new knowledge and constructing concepts: Teachers guide students to operate with GeoGebra software. First, students are asked to draw two fixed points F_1 and F_2 in the software. Then, an arbitrary point P is taken in the plane. By measuring the lengths of $|PF_1|$ and $|PF_2|$, the value of $|PF_1| + |PF_2|$ is calculated. Next, students are asked to drag point P and observe the changes in the value of $|PF_1| + |PF_2|$. When $|PF_1| + |PF_2|$ is a constant value and greater than $|F_1F_2|$, teachers guide students to discover that the locus of point P is an ellipse. In this way, students can experience the formation process of an ellipse firsthand and have a profound understanding of the definition of an ellipse.

Deriving the equation for in-depth understanding: Based on students' comprehension of the ellipse definition, teachers guide them to establish a plane rectangular coordinate system and derive the standard equation of the ellipse. During the derivation process, teachers use GeoGebra software to display the establishment of the coordinate system and the algebraic operation process, enabling students to visually witness the transformation from geometric figures to algebraic equations. Meanwhile, by altering the positions of the foci and the lengths of the major and minor axes of the ellipse, students can observe the changes in the equation, thus deepening their understanding of the standard equation of the ellipse.

Consolidating practice and expanding application: Teachers design a series of exercises using GeoGebra software, asking students to operate and solve them within the software. For example, students are given the equation of an ellipse and required to draw the corresponding ellipse, or provided with some properties of an ellipse and asked to find its standard equation. Through these exercises, students further reinforce their learned knowledge and enhance their application abilities. Additionally, teachers can guide students to use ellipse-related knowledge to solve practical problems, such as designing an elliptical flower bed, thereby cultivating students' innovative thinking and practical abilities.

6. Investigation and analysis of the teaching effect of visual teaching of analytic geometry based on GeoGebra software

6.1. Investigation methods

The teaching effect was investigated by combining questionnaire surveys and classroom observations. The questionnaire surveys were mainly targeted at students to understand their attitudes towards the visual teaching of analytic geometry based on GeoGebra software, their learning interest, and their degree of knowledge mastery. Classroom observations mainly focused on students' participation in class, their proficiency in operating the software, and their performance in group cooperative learning.

6.2. Analysis of investigation results

Students' learning attitudes and interests: The results of the questionnaire surveys showed that most students had a positive attitude towards the visual teaching of analytic geometry based on GeoGebra software, believing that this teaching method could enhance their learning interest. Classroom observations also revealed that when students were operating and learning with the software, they were more focused and their participation was significantly improved. This indicates that the application of GeoGebra software has stimulated students' learning interest, transforming them from passive learners to active learners.

Degree of knowledge mastery: Through the analysis of students' homework and exam results, it was found that after the implementation of the visual teaching based on GeoGebra software, students' mastery of analytic geometry knowledge had improved. Especially for some abstract concepts and complex graphs, students were able to better understand their properties and applications through the demonstrations and operations of the software. For example, when learning about space surfaces, students were able to accurately draw the graphs of various space surfaces, analyze their properties based on the graphs, and enhance their ability to solve related problems.

Ability cultivation: Both classroom observations and questionnaire surveys indicated that students' spatial imagination ability, logical thinking ability, and practical operation ability had been exercised and improved during the teaching process. Students could better cultivate their spatial imagination ability by operating the software independently and observing the changes in the graphs. Their logical thinking ability was strengthened during the process of analyzing the relationship between graphs and equations and solving practical problems. Moreover, in group cooperative learning and practical operations, students' practical operation ability and teamwork spirit were also cultivated.

7. Conclusion

Through the practice and investigation analysis of the visual teaching of analytic geometry based on GeoGebra software, the following conclusions are drawn: The application of GeoGebra software in analytic geometry teaching has remarkable advantages. It can effectively enhance the visualization level of teaching, helping students better understand abstract concepts and complex graphs, and strengthening students' learning interest and initiative. Through software operation and practical activities, students' spatial imagination ability, logical thinking ability, and practical operation ability have been cultivated and improved. The teaching model based on GeoGebra software conforms to the development trend of educational informatization, providing new ideas and methods for the teaching reform of analytic geometry.

Although the visual teaching of analytic geometry based on GeoGebra software has achieved certain results, some problems have also been found during the research process. For example, some teachers are not proficient enough in applying the software, which affects the teaching effect; when students use the software for independent exploration, they sometimes deviate from the teaching objectives. Future research can be carried out in the following aspects: Strengthen the training of teachers to improve their software application ability and informatization teaching level; further optimize the teaching design to guide students to use the software more effectively for learning and exploration; carry out the construction of teaching resources for analytic geometry based on GeoGebra software, develop more high-quality teaching cases and teaching courseware to provide richer resource support for teaching. At the same time, the research scope can also be expanded to other mathematics courses to explore the application effects and teaching models of GeoGebra software in the teaching of more mathematics courses.

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