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Study on Improving the Teaching Effect of Mathematical Methods for Physics Using Manim Animation Technology

Yong Niu*, Linhao Wang, Ying Wang, Pan Wang

School of Physics and Information Science, Shaanxi University of Science & Technology, Xi'an 710021, Shaanxi, China

***Corresponding author:** Yong Niu, niuyong1905@sust.edu.cn

Abstract: With the development of educational digitalization, how to effectively apply digital animation technology to traditional classroom teaching has become an urgent problem to be solved. This study explores the application of Manim in the course of Mathematical Methods for Physics. Taking the visualization of Fourier series, complex numbers, and other content as examples, it improves students' understanding of complex and abstract mathematical physics concepts through dynamic and visual teaching methods. The teaching effect shows that Manim helps to enhance students' learning experience, improve teaching efficiency and effectiveness, and has a positive impact on students' active learning ability. The research in this paper can provide references and inspiration for the educational digitalization of higher education.

Keywords: Manim; Mathematical methods for physics; Educational digitalization; Animation visualization

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1. Introduction

In the field of higher education, with the rapid development of information technology and the increasing popularity of the Internet, digital teaching is gradually penetrating all levels and types of education, becoming an important means to promote teaching reform and improve teaching quality [1,2]. Especially in the teaching process of courses such as Mathematical Methods for Physics, teachers often have to face a large number of teaching difficulties, including formula derivation, theorem proof, and complex concept analysis [3]. The content of these courses is highly abstract and theoretical. Due to their theoretical depth and abstractness, many mathematical and physical theorems are often difficult for students to intuitively understand their logical and internal connections through simple verbal explanations or traditional blackboard writing. Traditional teaching methods usually rely on static graphics and text descriptions, which are inadequate in demonstrating the dynamic changes of mathematical concepts, derivation processes, and interactions between various mathematical objects. As a result, they often struggle to stimulate students' interest in learning and initiative in exploration [4]. As pointed out by Pinter *et al.* [5], the application of multimedia technology can greatly improve students' ability to perceive abstract knowledge and make the teaching process more vivid and intuitive.

In recent years, with the continuous advancement of digital animation technology, more and more educators have begun to try to apply animation technology in classroom teaching, aiming to make up for the shortcomings of traditional teaching methods through dynamic demonstrations. Digital visual animation can present abstract concepts such as mathematical formulas, geometric figures, and physical phenomena in a vivid and intuitive way [6], enabling students to intuitively perceive the dynamic relationships and evolution processes between various mathematical objects when watching animations, thereby achieving a twice-the-result-with-half-the-effort teaching effect [7]. However, traditional animation production tools, such as animations made based on Adobe After Effects or GeoGebra, although capable of realizing dynamic display to a certain extent, have obvious shortcomings in terms of object control accuracy, production process simplicity, and post-modification.

In contrast, Manim, as a powerful Python-based animation library [8], has quickly gained wide application in mathematics and physics teaching due to its advantages such as open-source availability, flexible operation, and high customizability. Manim not only supports the dynamic display of complex mathematical objects but also can realize the precise customization of formulas and the detailed control of animation effects through the seamless integration of LaTeX and Python code. Using Manim, teachers can accurately demonstrate the dynamic characteristics of mathematical concepts, such as derivation processes, change trajectories, and geometric transformations, making abstract mathematical theories intuitive and vivid, while also stimulating students' interest in learning and desire to explore [9].

Therefore, this study aims to explore how to use visual animations produced by Manim in the Mathematical Methods for Physics course to break through the limitations of traditional teaching models and improve classroom teaching quality and students' understanding of complex mathematical and physical concepts. The introduction of advanced digital animation technology can not only effectively solve the problem that abstract knowledge is difficult to present intuitively in higher education but also promote the development of students' active learning and critical thinking, providing new theoretical and practical support for the construction of a modern education system. The continuous advancement of educational digitalization will surely inject new vitality into China's education reform, and the digital animation technology based on Manim provides an innovative and practical teaching tool for this process [10,11].

2. Introduction to Manim

Manim, whose full name is Mathematical Animation Engine, is a powerful mathematical animation library developed by Grant Sanderson. Compared with other animation production tools, Manim's advantage lies in its high customizability and expandability. In addition, Manim can generate mathematical formulas that comply with LaTeX standards, ensuring that the formulas are displayed with extremely high precision in animations, which meets the high requirements of academic research and teaching.

Another notable feature of Manim is its powerful visualization function. It can handle various complex mathematical processes and visualize these processes through graphics and animations. Through dynamic demonstrations, students can not only intuitively see the derivation process of mathematical formulas but also personally experience how various mathematical concepts transform and evolve in practical applications. This visualization process not only improves students' comprehension ability but also stimulates their learning interest, making abstract mathematical knowledge more vivid and accessible.

3. Application of Manim in the teaching of mathematical methods for physics

In the course of Mathematical Methods for Physics, many key mathematical tools and methods are suitable for visual demonstration through animations, thereby helping students more intuitively understand complex theoretical derivations and calculation processes. For example, the geometric interpretation of complex functions, the relationship between Fourier transform in the frequency domain and the time domain, and the evolution process of special functions are often difficult to fully present through static images or traditional explanations. However, animations can dynamically show the changes, transformations, and interactions of these mathematical concepts, enabling students to not only see the logical derivation behind the theories but also personally experience how these tools work in practical applications. This method can not only improve the teaching efficiency in the classroom, but also stimulate students' learning interest and help them connect abstract mathematical theories with actual physical phenomena. **Figure 1** dynamically demonstrates the process of synthesizing SUST using the complex form of Fourier series, with four frames captured from the animation.

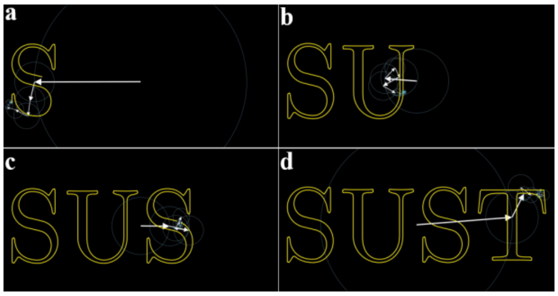

Figure 1. Synthesizing SUST using the complex form of Fourier series, with four frames captured from the animation

3.1. Fourier epicycloid superposition for SUST

The geometric meaning of the complex form of Fourier series is to regard a signal or graph as the superposition of epicycloids. An epicycloid means that the center of the next circle moves circumferentially on the circumference of the previous one. Each circle operates independently, starting from a different initial phase and rotating at different speeds; the trajectory of the center of the last circle can form any head-to-tail connected graph on a two-dimensional complex plane. When explaining the complex form of Fourier series, students often struggle to understand that its geometric meaning lies in using the superposition of rotating circles to synthesize the target function. To deepen their understanding of this concept and convince them of the superposition capability of rotating circles, we created an animation that dynamically demonstrates the superposition of rotating circles to form "SUST"—the English abbreviation of Shaanxi University of Science & Technology—as shown in **Figure 1**.

3.2. Visualization of roots of $x^2 + 1 = 0$

When introducing complex numbers, students have never seen where $x^2 + 1 = 0$ intersects with anything, yet they are told that this equation has two roots $x = \pm i$. For students, it is impossible to truly accept the existence of complex numbers from the depths of their hearts. By using animation to show the process of pulling the independent variable x from one dimension to two dimensions and dynamically demonstrating the formation process of the function image of $x^2 + 1$, which is a saddle surface (as shown in **Figure 2**), through the intuitive display of the animation, students can deeply understand the reason why this equation has solutions, and accept the real existence of complex numbers, and recognize that complex numbers are two- dimensional numbers.

3.3. Synthesis of square waves via Fourier series

Animations of Fourier series expansion can show how various frequency components superimpose to form a complex waveform, as illustrated in **Figure 3**. This dynamic demonstration not only helps students understand the basic concepts of Fourier analysis but also stimulates their interest in the mathematical models behind physical phenomena. Additionally, this model can dynamically demonstrate the Gibbs phenomenon that occurs during the synthesis of square waves using sine waves.

3.4. Geometric meaning of the imaginary unit i

The representation method of the real axis and the imaginary axis in the complex plane is very similar to the Cartesian coordinate system. Many students mistakenly think that the representation of complex numbers in the complex plane is a simple repetition of the Cartesian rectangular coordinate system. By using animation to reveal the position of imaginary numbers i, as shown in **Figure 4**, students can understand why the real axis is perpendicular to the imaginary axis and the geometric meaning of i: an imaginary number i is located on the imaginary axis at a distance of one unit from the origin; multiplying a number by i represents a rotation of 90°. While deepening students' understanding of knowledge, this learning method also prompts them to think about the historical origin of knowledge and cultivate the spirit of exploration.

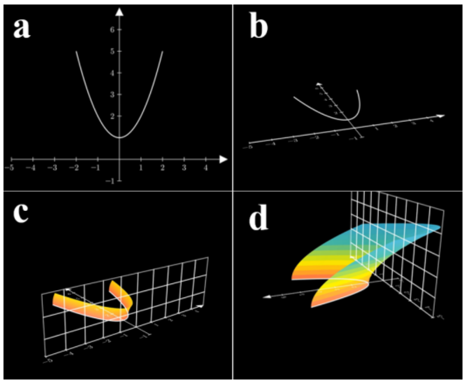

Figure 2. The positions of the equation's solutions, with four frames captured from the animation

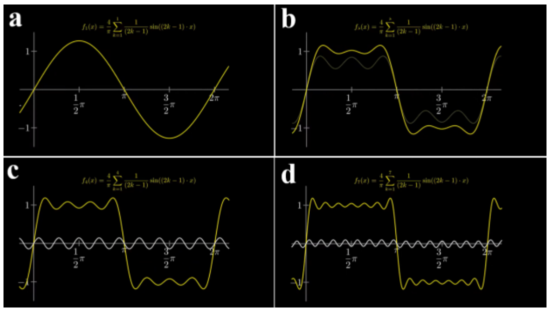

Figure 3. The process of synthesizing a square wave by superimposing sine waves and the Gibbs phenomenon, with four frames captured from the animation

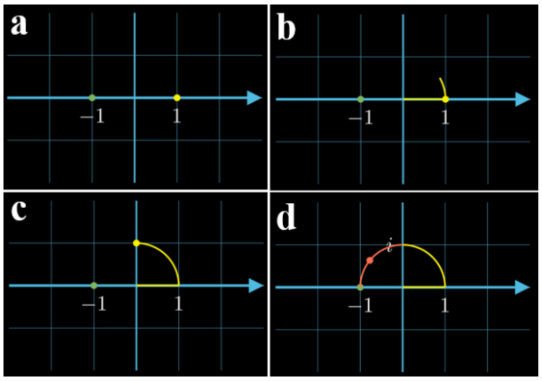

Figure 4. The geometric meaning of the imaginary unit *i*, with four frames captured from the animation

4. Experiments and results

4.1. Teaching experiment design

To evaluate the application effect of Manim animation in the Mathematical Methods for Physics course, this study conducted a teaching experiment among 2023 and 2022 grade students at Shaanxi University of Science & Technology. The subjects were students taking the Mathematical Methods for Physics course from the two grades: the 2023 grade students were taught using Manim-made animations, while the 2022 grade students received traditional teaching. Through this experimental design, we compared differences between the two groups in terms of academic performance, learning interest, and classroom participation, thereby assessing the practical application of Manim animation in teaching.

The experimental design included the following key steps:

Selection of experimental class and control class: Two classes from the 2023 and 2022 grades were selected. The 2023 grade class served as the experimental group, with teaching assisted by Manim animation; the 2022 grade class acted as the control group, using traditional blackboard writing and multimedia teaching methods.

Course content and teaching arrangement: Both groups were taught the same content, covering core concepts in Mathematical Methods for Physics such as Fourier series, the geometric meaning of complex numbers, and special functions. Teaching mainly consisted of explanations and example demonstrations. The experimental group additionally used Manim animations to demonstrate mathematical formula derivations, changes in function graphs, and dynamic processes of physical phenomena.

Evaluation indicators: To comprehensively assess teaching effectiveness, multiple evaluation indicators were set, including students' academic performance (i.e., exam scores), classroom participation, learning interest, depth of knowledge understanding, and mastery of abstract mathematical concepts. Specific evaluation methods included classroom feedback surveys, comparative analysis of midterm and final exam scores, and after-class questionnaires.

Data collection: Collect data on students' exam scores and classroom performance for comparative analysis by statistics, and combine with students' feedback on the course content. The after-class questionnaire also covered students' opinions on the animations, changes in interest in the learning process, and their satisfaction with the application of Manim animation in teaching.

4.2. Data analysis and results

Based on the feedback data and statistical results of the teaching experiment, we can clearly observe the significant role of Manim animation in improving students' learning effectiveness.

Improvement in students' academic performance: The experimental class using Manim animation significantly outperformed the control class with traditional teaching methods in the final exam. Specifically, the average score of students in the experimental group increased from 62 to 76, a 14-point improvement, demonstrating the positive role of Manim animation in enhancing students' comprehension and knowledge mastery. Statistical analysis shows that students using Manim also achieved significant improvements in problem-solving abilities and the depth of conceptual understanding. The experimental results indicate that Manim animation not only helps students understand complex mathematical and physical phenomena but also deepens their grasp of abstract concepts, especially in the learning of geometric figures, complex numbers, Fourier transforms, and other content.

Figure 5 shows the comparison of average scores between students who did not use Manim and those who received Manim animation-based teaching. It can be seen that the academic performance of the experimental group is significantly better than that of the control group, further confirming the role of Manim in improving learning effectiveness.

Student engagement and classroom satisfaction: In terms of classroom engagement, the experimental class using Manim animation also far surpassed the control class. Through classroom observations and teacher feedback, students in the experimental class showed significantly higher engagement: they were more proactive in asking questions and displayed greater enthusiasm in discussions and interactions. With animations, students could not only watch the derivation process of mathematical and physical concepts but also see in real time how abstract mathematical formulas are transformed into concrete graphics, which increased their interest in and engagement with the course.

In addition, classroom surveys and student feedback revealed a significant improvement in student satisfaction. Eighty-five percent of students stated that Manim animation helped them maintain high interest during classes, making the content more vivid, interesting, and easy to understand. Only 15% of students reported no impact from the animation-based teaching method, further verifying the effectiveness of Manim animation in stimulating students' learning interest.

Figure 6 illustrates the changes in students' learning interest after using Manim for teaching, with 85% of students indicating a significant increase in interest through animation-based instruction. Data analysis shows that visual teaching tools have significantly improved students' learning experience, enabling them to be more focused and proactive in class.

Students' feedback on Manim animation: According to the questionnaire results, most students hold a positive attitude towards the application of Manim animation in teaching. They generally believe that Manim can effectively visualize abstract mathematical and physical concepts—especially in the process of complex formula derivation and geometric figure demonstration, animations help them understand the dynamic evolution of knowledge. Furthermore, students stated that watching animations made classroom content more interesting and comprehensible, enhancing their learning motivation and effectiveness.

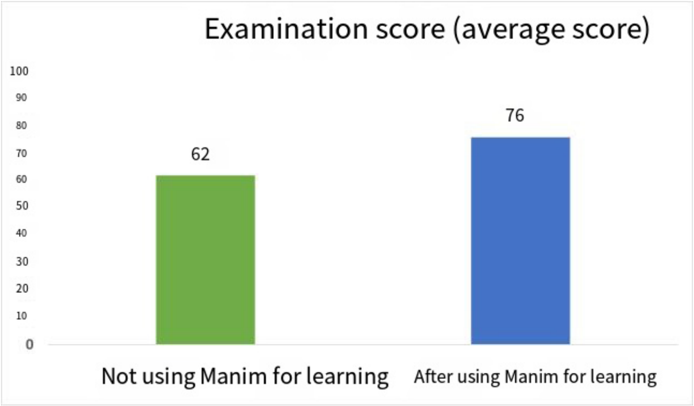

Figure 5. Comparison of students' average scores before and after using Manim animation for teaching

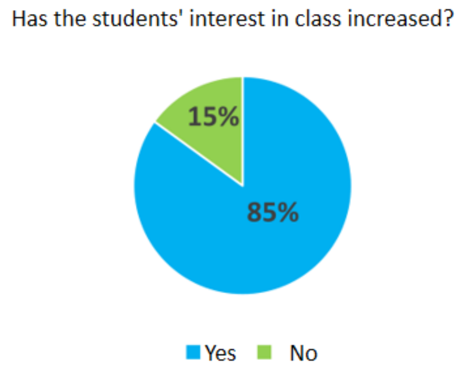

Figure 6. Changes in students' learning interest after teaching with Manim

To sum up, Manim animation has demonstrated significant teaching advantages in the Mathematical Methods for Physics course, especially in enhancing students' comprehension, learning interest, and classroom participation, with remarkably effective results. Based on the analysis of experimental data, we can conclude that digital animation technology can not only effectively strengthen students' intuitive understanding of abstract concepts but also greatly improve classroom interactivity and learning enthusiasm.

5. Conclusion

Through this study, we found that Manim, as a digital animation teaching tool, can effectively improve the teaching effect of the Mathematical Methods in Physics course, especially in enhancing students' mathematical comprehension ability and mastery of physical concepts. The research shows that after using Manim animations for teaching, students' average scores have significantly improved, and classroom participation and student satisfaction have also increased noticeably. Animations not only enable students to intuitively understand abstract mathematical and physical theories but also stimulate their learning interest and promote their proactive learning attitude and in-depth thinking. This result indicates that digital animation, especially efficient and accurate visualization tools like Manim, has broad application prospects in modern teaching.

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Disclosure statement

The authors declare no conflict of interest.

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