ISSN 2663-8169 Vol. 8, Issue 7: 46-51, DOI: 10.25236/IJNDE.2026.080708

Visualization-Assisted Teaching Reform of the Mathematical Analysis Course for Information and Computing Science Majors in Local Applied Universities

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Abstract: *Mathematical Analysis is a core foundational course for Information and Computing Science majors, but its high level of abstraction, rigorous logical structure, and emphasis on symbolic reasoning often make it difficult for students in local applied universities. Traditional teaching usually focuses on definitions, theorem proofs, and computational exercises, while students' geometric intuition, computational thinking, and awareness of applications are not sufficiently developed. To address these problems, this paper explores a visualization-assisted teaching reform of the Mathematical Analysis course for Information and Computing Science majors in local applied universities. A teaching framework is proposed by integrating symbolic expression, geometric visualization, numerical experiment, and application interpretation. Within this framework, four dimensions are discussed: concept visualization, process visualization, relation visualization, and application visualization. Typical teaching examples, including limits, derivatives, definite integrals, series convergence, and gradients, are used to illustrate how visualization tools can support students' understanding of abstract concepts and help them connect mathematical theory with computational applications. The proposed approach emphasizes that visualization should not replace rigorous mathematical reasoning, but should serve as a bridge between intuition and proof, theory and computation, and mathematics and application. This study provides a practical reference for improving the teaching quality of Mathematical Analysis and cultivating applied, computational, and innovative talents in Information and Computing Science majors.*

Keywords: *Mathematical Analysis; visualization-assisted teaching; Information and Computing Science; local applied universities; computational thinking; mathematical intuition*

1. Introduction

In recent years, the reform of undergraduate mathematics teaching has received increasing attention. Norton[1] compared several traditional and modern teaching methods in undergraduate mathematics education and showed that teaching methodology is closely related to students' achievement and motivation. For abstract mathematics courses, visualization is an effective means of supporting mathematical cognition, and visualization-assisted teaching has emerged as an important direction. Fokuo et al.[2] reviewed the use of visualization utilities in mathematics teaching and pointed out that visualization tools can help students understand mathematical concepts. By a scoping review, Schoenherr and Schukajlow[3] further indicated that visualization has become a broad research topic in mathematics education.

At the level of undergraduate mathematics teaching, existing studies have also explored the use of visualization tools in specific topics. Medina Herrera et al.[4] discussed spatial visualization tools in mathematical education, while Bos and Wigmans[5] studied dynamic visualization in animated mathematics videos. Milenković et al.[6] investigated software visualization in teaching double integrals, showing that visualization can help students understand multivariable calculus concepts. Xu[7] studied the comprehensive use of computer techniques for improving mathematical skills. Kostadinov et al.[8] used R and Python to create dynamic documents for teaching differential equations. These studies suggest that visualization-assisted teaching is especially valuable when mathematical concepts involve dynamic processes, geometric structures, numerical approximation, or computational implementation.

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Nevertheless, most existing studies focus on general mathematics education or specific topics such as multivariable calculus, mathematical modelling, statistics, analytic geometry and differential equations[9-12]. Relatively few studies address visualization-assisted teaching directly in the Mathematical Analysis course. Ye and Wu[13] examined blended teaching based on mobile Internet and programming tools with Mathematical Analysis as an example, while Dimitrienko et al.[14] discussed blended learning of Mathematical Analysis in the Nomotex digital learning system. These works provide useful references for digital teaching reform, but systematic discussion remains limited on how visualization-assisted teaching can be designed for Information and Computing Science majors in local applied universities, especially for connecting mathematical theory, geometric intuition, and numerical computation.

This paper focuses on the visualization-assisted teaching reform of the Mathematical Analysis course for Information and Computing Science majors in local applied universities. The main contribution of this paper is to construct a visualization-assisted teaching framework for the Mathematical Analysis course by integrating symbolic expression, geometric visualization, numerical experiment and application interpretation, with particular emphasis on the disciplinary characteristics and learning needs of Information and Computing Science majors in local applied universities. The proposed approach can help students better understand mathematical concepts, improve computational thinking and connect Mathematical Analysis with later studies.

2. Problems in the Traditional Teaching

2.1 Overemphasis on symbolic deduction

Mathematical Analysis has a rigorous theoretical system. Traditional teaching usually emphasizes definitions, theorems, proofs, and exercises. This is necessary for cultivating students' logical reasoning ability. However, if teaching only focuses on formal deduction, students may regard Mathematical Analysis as a collection of abstract symbols and mechanical proof techniques. They may know how to use formulas, but not understand the geometric meaning behind them. For the first example, when learning the derivative, students often remember the formula for differentiation but do not fully understand the derivative as a local linear approximation. For the second example, when learning the definite integral, they may master the Newton-Leibniz formula but fail to understand the accumulation process behind integrals. For the third example, when learning uniform convergence, they may memorize the definition but cannot distinguish it intuitively from point-wise convergence. These problems show that symbolic teaching alone is not sufficient for conceptual understanding.

2.2 Separation between mathematics and applications

Information and Computing Science majors have strong computational characteristics. Students will later study programming, numerical computation, data analysis, algorithm design, and mathematical modelling. However, in the traditional teaching of Mathematical Analysis, the relationship between mathematical theory and computer application is often not revealed. For example, the concept of limit is closely related to numerical approximation; the derivative is related to optimization algorithms; the integral is related to numerical quadrature and accumulation models; series are related to approximation, signal processing, and numerical algorithms; multivariable functions are related to machine learning, optimization, and scientific visualization. If these connections are not emphasized in teaching, students may regard Mathematical Analysis as a purely theoretical subject disconnected from their major.

2.3 Passive learning and insufficient participation

In many classrooms, Mathematical Analysis is taught mainly through teacher explanation. Students listen, take notes, and complete exercises after class. This mode is efficient for presenting knowledge, but it may not be sufficient for stimulating active learning. Since many concepts in Mathematical Analysis are abstract, students need opportunities to observe, manipulate, compare, conjecture, and verify them by themselves. In contrast, visualization tools can create an interactive learning platform. For instance, students can adjust parameters in simulation programs, and consequently observe the changes in plots, compare numerical experiment results and eventually validate their conjectures. Such activities can transform students from passive receivers of knowledge into active participants in mathematical exploration.

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2.4 Insufficient cultivation of computational thinking

Computational thinking is one of the important abilities for students majoring in Information and Computing Science. Mathematical Analysis contains many ideas closely related to computation, such as approximation, iteration, discretization, error, convergence, and stability. These ideas are difficult to be explored in traditional teaching, while visualization can conveniently demonstrate them. For example, the Riemann integral can be visualized as a discretization summing process; the Taylor expansion can be shown as a series of local approximations; the convergence of a sequence can be observed through numerical iteration; the gradient of a multivariable function can be connected with the direction of fastest increase/decrease. These examples help students understand that Mathematical Analysis is not only a collection of theoretical results, but also a source of computational methods.

3. Theoretical Basis and Teaching Principles

3.1 Multiple representations of mathematical concepts

Generally speaking, a mathematical concept can be represented in different forms, including symbolic representation, graphical representation, numerical representation, verbal description, and computational representation. Understanding a mathematical concept requires students to move flexibly among different representations. Based on this idea, visualization-assisted teaching helps students connect abstract symbols with geometric images and numerical experiments. For instance, the expression below can be connected with the dynamic change of secant lines approaching a tangent line,

$$f'(x_0) = \lim_{h \to 0} \frac{f(x_0 + h) - f(x_0)}{h}. \tag{1}$$

In this way, a formal definition can be connected with a visual process, and students can consequently build a complete image of the introduced concept.

3.2 Combining visualization with proof

Visualization can provide intuition, but intuition is not equal to proof. Thus, implementing visualization in Mathematical Analysis should follow the path from intuition to rigor: firstly, visualization helps students observe mathematical phenomena, then students make conjectures based on observation and teachers guide students to express these conjectures in mathematical language, eventually, rigorous proof is introduced to confirm or correct intuitive understanding. Take the teaching process of the monotone convergence theorem as an example. Teachers can first use graphs and numerical sequences to show that a bounded monotone sequence seems to approach a fixed value, then guide students to describe this phenomenon using mathematical language, and finally give the rigorous proof. In this way, visualization becomes an entry point into proof.

3.3 Integration of mathematics and computation

For Information and Computing Science majors, visualization-assisted teaching should not only show pictures or animations, but also integrate mathematical theory, computer implementation, and application scenarios. Therefore, students are encouraged to use computer tools to explore mathematical models and implement numerical experiments based on related principles of Mathematical Analysis course. This idea can be realized into a four-level teaching pipeline, as shown Figure 1. In this way, geometric visualization helps students build intuition of symbolic mathematical expressions, then numerical experiments deepen students' understanding and develop computational thinking, and applications connects mathematics with practical problems.

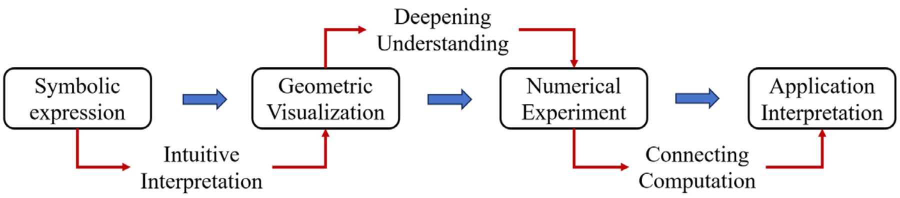

Figure 1: Visualization-assisted teaching pipeline in Mathematical Analysis Course for Information and Computing Science majors

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4. Visualization-Assisted Teaching Framework

To implement visualization-assisted teaching effectively, this paper proposes a teaching framework consisting of four dimensions: concept visualization, process visualization, relation visualization, and application visualization. These four dimensions jointly support students' understanding of the knowledge and methods in Mathematical Analysis course.

4.1 Concept visualization

Many concepts in Mathematical Analysis are difficult to understand due to their non-intuitive processes or abstract relationships. In this situation, visualization tools can help students form images of these concepts before they enter formal reasoning. The concept of limit provides a typical example. The $\varepsilon - \delta$ definition is very abstract for students to understand its meaning. Using GeoGebra, Desmos or Python, teachers can construct a dynamic graph with adjustable values of ε and δ to let students observe: the corresponding range of the function $f(x)$ when changing ε, and whether the graph remains within the required neighborhood of ε by adjusting δ. Then, students will understand that the $\varepsilon - \delta$ definition is a precise description of controllability: if x is sufficiently close to x_0, then $f(x)$ can be controlled to be sufficiently close to $f(x_0)$.

The derivative provides another suitable case. Instead of teaching the derivative only as a calculation rule, teachers can use dynamic plots to show how a secant line approaches the tangent line. For a function $y = f(x)$, two points x_0 and $x_0 + h$ are selected on the graph. As h gradually approaches zero, the secant line changes continuously and approaches the tangent line at x_0. Students can observe that the derivative represents the slope of the tangent line. More importantly, they can understand that near x_0, the function $f(x)$ can be approximated by $f(x_0) + f'(x_0)(x - x_0)$. This case can be further connected with Newton's method in Numerical Analysis course.

4.2 Process visualization

Many mathematical ideas in Mathematical Analysis are not static results, but dynamic processes, such as the definite integral, sequence convergence and Taylor series. In traditional teaching, students learn the definition of definite integral through Riemann sums. However, this method involves partitions, sample points and limiting processes, which may be abstruse for beginners. For this problem, teachers can use software to divide an interval into subintervals and draw rectangles or trapezoids to approximate the area under a curve. As the number of subintervals increases, the approximation becomes more and more accurate. In this way, students can intuitively understand the limiting process from finite summation to definite integral. In fact, teachers can further introduce the idea of numerical integration for students to let them recognize that the definite integral is not only a theoretical concept, but also the basis of numerical algorithms including the rectangle rule, trapezoidal rule and Simpson rule.

Series convergence is another representative example. By plotting the sequence of partial sums of an infinite series, students can visually understand the convergence if the partial sums approach a fixed value, while they can observe non-convergence when the partial sums oscillate or diverge. For function series, teachers can plot several partial sum functions and compare them with the target function. Fourier series is especially useful because students can see how partial sums approximate a periodic function. For Information and Computing Science majors, this topic can be further connected with numerical approximation and signal processing.

4.3 Relation visualization

Mathematical Analysis is not a set of isolated knowledge points. Concepts such as continuity, differentiability, integrability, convergence, and approximation are deeply connected. Relation visualization is used to reveal the connections among concepts, theorems and methods. For example, visual comparison allows students to see why differentiability implies continuity, but continuity does not necessarily imply differentiability.

In multivariable calculus, relation visualization is particularly important. Students need to move from two-dimensional curves to three-dimensional surfaces. Teachers can use MATLAB or Python to draw the surface $z = f(x, y)$ and its contour map. Then, students can observe that the points along a contour line possess the same function value. Besides, by adding gradient vectors to the contour map, students can find out that the gradient direction is perpendicular to the contour line and points in the fastest

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increasing direction. This case is especially useful for Information and Computing Science majors. The gradient is a fundamental concept of gradient descent method and related algorithms, which are very common in optimization, matrix computation and deep learning[11].

4.4 Application visualization

Application visualization connects Mathematical Analysis with practical problems and computational techniques. For example, derivatives connect with optimization algorithms; integrals relate to numerical quadrature and probability distribution, infinite series is in connection with approximation and digital signal processing, multivariable functions play the fundamental role in numerical methods for solving partial differential equations, and convergence appear in various theoretical analyses of numerical algorithms. Therefore, this dimension is particularly important for Information and Computing Science majors. Students need to comprehend not only mathematical models and solution methods, but also the mathematical theory behind them. Through application visualization, students can realize the crucial role of Mathematical Analysis as a foundation course.

5. Teaching Reflection and Implementation Suggestions

Visualization-assisted teaching can improve the teaching of Mathematical Analysis, but its effectiveness depends on appropriate instructional design. Based on classroom teaching practice and the characteristics of the Mathematical Analysis course for Information and Computing Science majors, four reflections and implementation suggestions are summarized as follows.

First, visualization should serve mathematical understanding rather than replace mathematical reasoning. In classroom teaching, dynamic graphs, numerical experiments, and software demonstrations should be used to help students observe mathematical phenomena, form intuitive conjectures, and then return to formal definitions, theorem statements, and rigorous proofs.

Second, visualization activities should be closely related to the characteristics of Information and Computing Science majors. For these students, visualization is not only a way to understand abstract concepts, but also a bridge between mathematics and applications.

Third, the difficulty of visualization tasks should be controlled according to students' mathematical foundation and computer techniques. In the early stage, teachers may mainly use prepared demonstrations to reduce the learning burden. In the later stage, students can be encouraged to modify parameters, complete simple programming, compare results and explain phenomena. This progressive design can help students move from passive observation to active exploration.

Finally, visualization-assisted teaching should be implemented gradually in local applied universities. Teachers can first build a small teaching resource library, including dynamic graphs, Python notebooks, MATLAB scripts, exploration tasks and students' examples. At the same time, simple questionnaires, classroom feedback, and homework analysis can be used to evaluate students' learning experience and conceptual understanding. In this way, visualization-assisted teaching can become a sustainable teaching reform rather than a temporary classroom demonstration.

6. Conclusion

This paper discussed the visualization-assisted teaching reform of the Mathematical Analysis course for Information and Computing Science majors in local applied universities. We proposed a four-level framework consisting of concept visualization, process visualization, relation visualization and application visualization. Using several visualization-assisted teaching examples, we demonstrated that the proposed approach provides a practical way to help students understand formal concepts more intuitively. Since the framework connects symbolic expression, geometric intuition, numerical experiment and application interpretation, students can better understand how Mathematical Analysis supports following courses, such as numerical analysis, mathematical modelling, optimization, machine learning, and scientific computation. Besides, four teaching reflections and implementation suggestions are concluded from real classroom teaching experience.

In future teaching practice, more systematic classroom experiments, questionnaire surveys, and learning data analysis will be conducted to further evaluate the effectiveness of visualization-assisted teaching. This reform provides a practical reference for improving the quality of university mathematics

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teaching and cultivating applied, computational, and innovative talents for Information and Computing Science majors in local applied universities.

Acknowledgements

This work was supported by Experimental Course Teaching Reform Project of Shaanxi University of Technology, entitled "Innovation and Practice of an Integrated Experimental Course Combining Dynamic Mathematics Graphing Software and PBL in the Context of New Teacher Education", Grant Number: SYGX202530; Undergraduate and Continuing Education Teaching Reform Research Project of Shaanxi University of Technology, entitled "Research and Revision of the 2026 Talent Training Program for the Information and Computing Science Major", Grant Number: PYFA202522; Undergraduate and Continuing Education Teaching Reform Research Project of Shaanxi University of Technology, entitled "Research and Practice on the Talent Cultivation System for Information and Computing Science Majors Oriented toward 'Mathematical Engineers' ", Grant Number: XJG2441; Shaanxi Higher Education Teaching Reform Research Project, entitled "Research and Practice on the Teacher Education Talent Cultivation System for Rural Basic Education in the New Era", Grant Number: 23BZ047.

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