

Manim: A Review of Programmatic Mathematical Animation for Visualization and Education

Mayanka Gupta¹, Riya Shah, Rohit Raj, Sagar Kumar, Shazia Aslam

NIET Business School, Greater Noida¹

Abstract : *Mathematical visualization has become an essential component of modern mathematics education due to its ability to improve conceptual understanding, cognitive engagement, and dynamic representation of abstract mathematical concepts. Recent advances in educational technology have accelerated the development of interactive and computational visualization systems, leading to the emergence of programmatic animation frameworks such as Manim. This study presents a bibliometric and systematic review of mathematical visualization research using data collected from the OpenAlex scholarly database. The study combines bibliometric analysis, topic modeling using BERTopic, and thematic synthesis to examine the evolution of mathematical visualization systems and identify emerging trends in computational and programmatic educational visualization. The analysis reveals that research themes have evolved from geometry-based visualization and spatial learning toward animation-supported learning, computational thinking, and programmable educational systems. The findings also indicate increasing integration of programming and computational pedagogy within mathematics education. Furthermore, the study proposes a taxonomy of mathematical visualization systems categorized into static, interactive, computational, programmatic, and AI-assisted visualization paradigms. The review positions Manim as an emerging representative of programmatic mathematical animation systems emphasizing reproducibility, automation, scalability, and mathematical precision. The paper concludes by identifying major research gaps and future directions including AI-assisted animation generation, immersive mathematical visualization, and automated educational content creation.*

Keywords - Mathematical Visualization, Mathematics Education, Educational Animation, Computational Thinking, Manim, Bibliometric Analysis, BERTopic, Educational Technology

1. Introduction

Visualization has long played a central role in mathematics education due to its ability to transform abstract symbolic expressions into meaningful conceptual representations. Mathematical concepts such as derivatives, vector transformations, geometric constructions, and multivariable systems often involve motion, spatial relationships, and dynamic changes that are difficult to communicate through static textual explanations alone. Consequently, educational researchers increasingly emphasize the importance of dynamic visualization techniques capable of enhancing cognitive understanding and reducing conceptual abstraction.

The rapid growth of digital educational technologies has significantly expanded the range of visualization tools available to educators and researchers. Early visualization methods relied primarily on textbooks, static diagrams, and chalkboard demonstrations. However, advancements in computational systems enabled the emergence of interactive geometry software, graphing systems, simulation environments, and mathematical animation engines. These technologies have transformed mathematics education by allowing students to interact with visual representations and explore mathematical relationships dynamically.

In recent years, a new paradigm has emerged in the form of programmatic mathematical visualization systems. Unlike traditional graphical interfaces, programmatic systems allow animations and mathematical demonstrations to be generated directly through code. Such approaches provide enhanced reproducibility, automation, scalability, and precision. Among these systems, Manim has gained substantial attention due to its ability to create high-quality mathematical animations through Python-based scripting.

Despite growing interest in educational visualization technologies, existing review studies primarily focus on interactive learning systems and multimedia environments while providing limited discussion of computational and programmatic animation frameworks. Furthermore, there remains insufficient understanding regarding the evolution of visualization paradigms within mathematics education and the relationship between computational thinking and educational visualization.

This study addresses these limitations by conducting a bibliometric and systematic review of mathematical visualization research. Using data collected from the OpenAlex database, the study applies bibliometric analysis and BERTopic-based thematic modeling to examine research trends, dominant themes, and emerging computational paradigms. Additionally, the paper proposes a taxonomy of mathematical visualization systems to conceptualize the transition from static and interactive systems toward programmatic educational animation ecosystems.

The major contributions of this study include:

1. A bibliometric analysis of mathematical visualization research.
2. BERTopic-based thematic identification of dominant educational visualization themes.
3. A comparative discussion of major visualization systems.
4. A proposed taxonomy of mathematical visualization paradigms.
5. Identification of research gaps and future directions related to programmatic educational animation.

2. Literature

2.1 Importance of Visualization in Mathematics

Educational research consistently demonstrates that visualization significantly improves mathematical understanding and conceptual retention. Dynamic visual representations support cognitive engagement by transforming symbolic mathematical structures into intuitive graphical interpretations. Such visual approaches reduce abstraction and assist learners in understanding relationships involving motion, continuity, and transformation.

Visualization is particularly valuable in domains such as geometry, calculus, linear algebra, and vector analysis where spatial reasoning and dynamic change play central roles. Static diagrams often fail to communicate temporal transitions or multidimensional transformations effectively. Consequently, animation-based approaches increasingly serve as important pedagogical tools for improving mathematical intuition.

Visualization also supports exploratory learning and constructivist educational practices. Interactive systems allow students to manipulate mathematical objects, observe transformations, and develop conceptual understanding through experimentation. This active learning process improves engagement and enhances problem-solving abilities.

2.2 Evolution of Mathematical Visualization Systems

Mathematical visualization systems have evolved substantially over time. Early educational visualization primarily relied on static textbooks and classroom demonstrations. The introduction of graphing calculators and computer algebra systems enabled more dynamic forms of mathematical representation. Subsequently,

interactive geometry software such as GeoGebra and graphing environments such as Desmos expanded access to interactive learning experiences.

More recently, computational visualization frameworks have emerged through environments including MATLAB and Mathematica. These systems introduced programmable mathematical computation and advanced rendering capabilities. The latest stage of this evolution involves programmatic animation systems such as Manim, which integrate scripting, automation, and reproducible animation workflows into mathematics education.

This progression reflects a broader shift from passive representation toward computationally driven educational ecosystems emphasizing automation, scalability, and dynamic visualization.

2.3 Educational Theories Supporting Visualization

Several educational theories support the use of visualization and animation in mathematics learning. Multimedia Learning Theory suggests that learners process visual and textual information through separate cognitive channels, improving understanding when both are integrated effectively. Similarly, Dual Coding Theory proposes that combining verbal and visual representations enhances retention and comprehension.

Cognitive Load Theory further emphasizes that properly designed animations can reduce unnecessary cognitive burden and improve conceptual clarity. Dynamic visualization systems allow complex mathematical processes to be segmented into manageable visual transitions, facilitating deeper understanding.

Constructivist educational theory also supports visualization-based learning because interactive systems encourage active experimentation and knowledge construction rather than passive memorization.

3. Research Methodology

3.1 Research Design

This study adopts a combined bibliometric and systematic review methodology to examine the development of mathematical visualization research. Bibliometric analysis was used to identify publication trends, dominant themes, and conceptual relationships, while BERTopic-based topic modeling was employed to uncover thematic structures within the literature.

3.2 Data Source

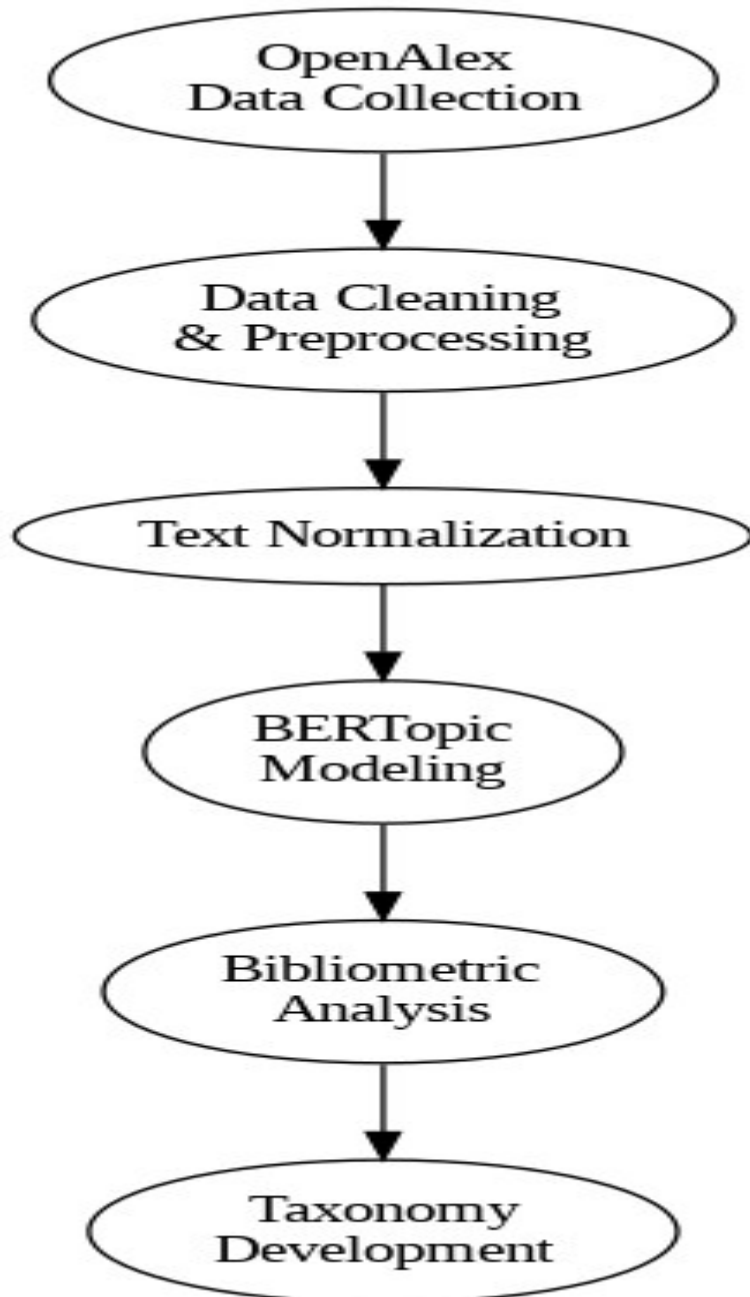
The dataset was collected using the OpenAlex scholarly database. OpenAlex was selected because of its extensive scholarly coverage, open accessibility, and compatibility with reproducible computational workflows. The database provides metadata including titles, abstracts, concepts, authors, citations, and publication years.

3.3 Search Strategy

The literature search included keywords associated with mathematical visualization and educational animation. Representative search terms included:

- mathematical visualization
- mathematics education visualization
- mathematical animation
- dynamic mathematics learning
- visual learning mathematics
- computational mathematics education

The search focused on publications between 2000 and 2026.



3.4 Inclusion and Exclusion Criteria

The inclusion criteria required papers to:

- focus on mathematics education or educational visualization
- include visualization, animation, or computational educational methods
- be published in English
- contain accessible metadata and abstracts

The exclusion criteria removed:

- unrelated scientific visualization studies
- biology and physics visualization papers

- duplicate records
- non-educational visualization studies

3.5 Data Processing

The collected data underwent preprocessing involving text normalization, stopword removal, duplicate elimination, and filtering of incomplete records. Abstracts and titles were combined into a unified text representation for topic modeling. BERTopic was then applied to identify thematic clusters within the dataset.

3.6 Analytical Techniques

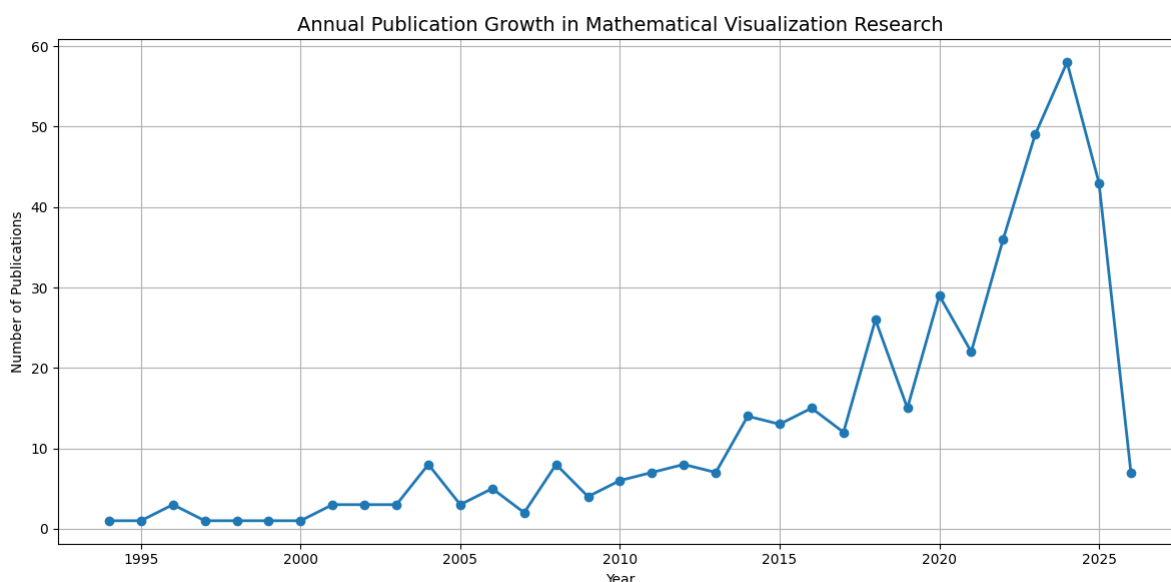
The analysis included:

- publication trend analysis
- citation analysis
- topic modeling
- thematic synthesis
- concept co-occurrence analysis
- comparative framework development

4. Figures and Tables

4.1 Publication Trends

The bibliometric analysis indicates significant growth in mathematical visualization research over the past two decades. Publication volume increased substantially after 2015, reflecting growing interest in digital educational technologies and visualization-supported learning. The acceleration became particularly visible after 2020, likely influenced by the expansion of online education and remote learning environments.



The findings suggest that visualization-based mathematics education has transitioned from a specialized research area into a broader interdisciplinary educational technology domain.

4.2 Dominant Research Themes

BERTopic analysis identified several dominant thematic clusters within the literature. One of the strongest themes focused on geometry, spatial reasoning, and interactive learning environments. This theme highlights the longstanding importance of dynamic geometry systems within mathematics education.

Topic ID	Theme Label	Representative Keywords	Interpretation
1	Geometry and Spatial Learning	geometry, geogebra, spatial	Interactive geometry education
2	Animation-Supported Learning	animation, cognitive, learning	Dynamic educational explanation
3	Computational Thinking	programming, computational	Code-integrated pedagogy
4	Augmented Reality	augmented, reality	Immersive educational systems

Table 2. Dominant thematic clusters identified using BERTopic analysis.

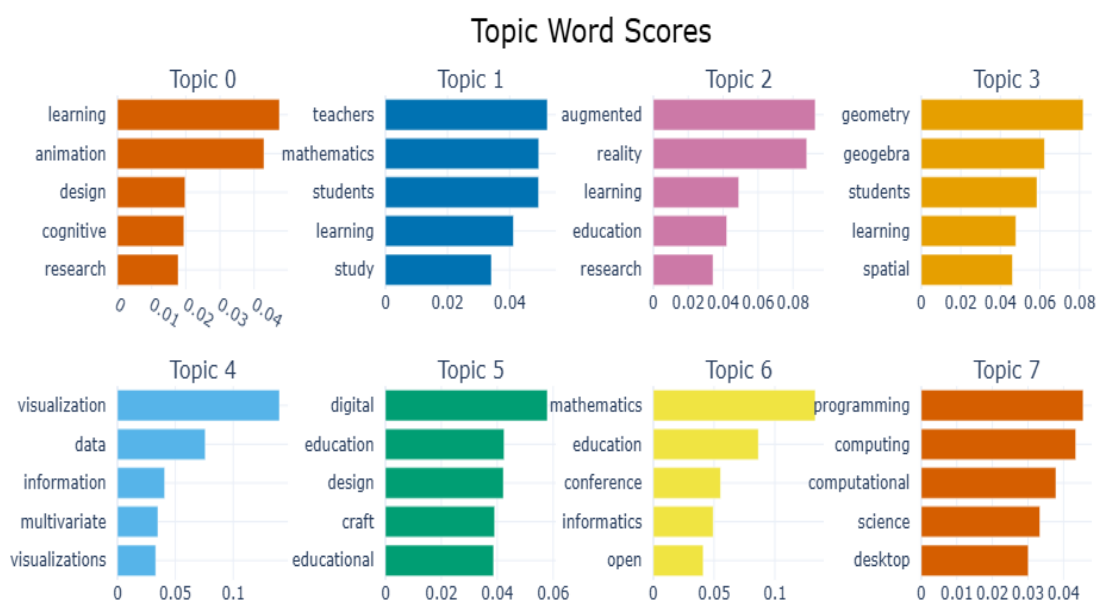


Figure 3. Distribution of dominant research themes identified through BERTopic modeling.

A second major theme involved animation-supported learning and cognitive educational design. The literature within this cluster emphasized multimedia learning, conceptual transitions, and visual explanation of mathematical processes. These findings support the increasing pedagogical importance of animation-based instruction.

Another important theme centered on programming, computational thinking, and computational pedagogy. This theme suggests a growing integration of programming-oriented educational approaches within mathematics education. The emergence of computational thinking within visualization research reflects the transition toward programmable educational ecosystems.

Category	Characteristics	Example
Static	Fixed diagrams	Textbooks
Interactive	GUI interaction	GeoGebra
Computational	Numerical simulation	MATLAB
Programmatic	Code-driven animation	Manim
AI-Assisted	Generative visualization	Emerging AI systems

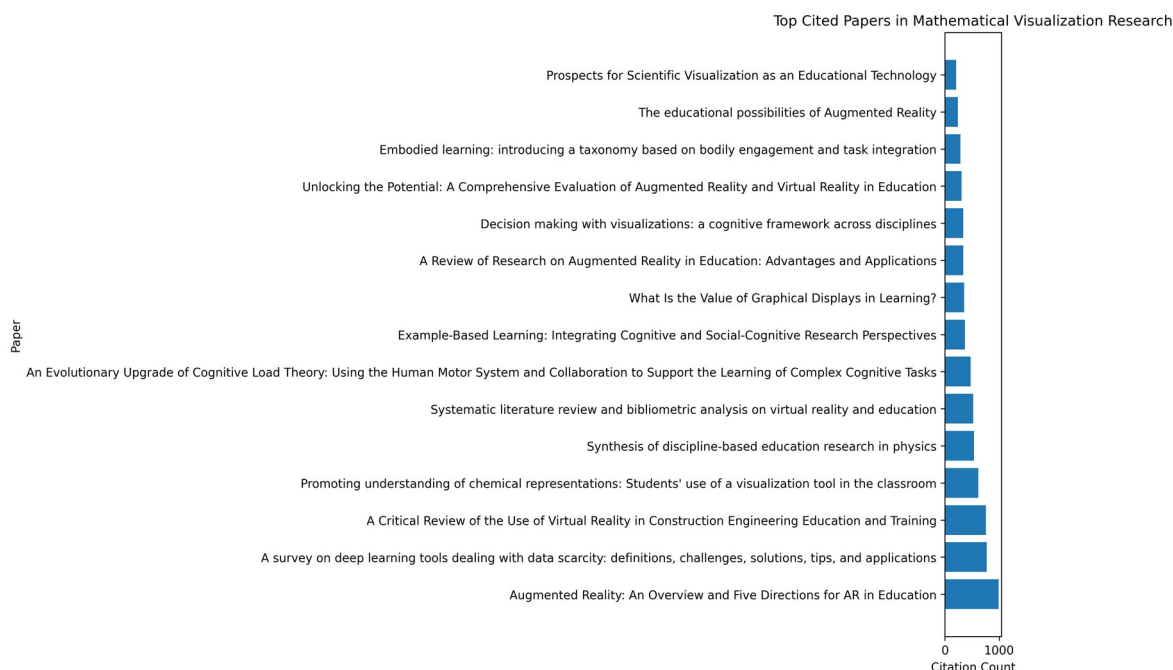
Figure 3. Distribution of dominant research themes identified through BERTopic modeling.

Additional themes included augmented reality, multimedia educational systems, and digital learning technologies, indicating diversification of visualization methodologies within educational research.



4.3 Citation Analysis

Citation analysis revealed that foundational research in mathematical visualization primarily focused on geometry learning, interactive educational systems, and cognitive educational theory. Highly cited works frequently discussed visualization-based pedagogy, spatial reasoning, and multimedia educational design.



The analysis also demonstrated increasing citation activity associated with computational educational methods and digital learning technologies. This trend suggests expanding academic interest in programmable and automated educational systems.

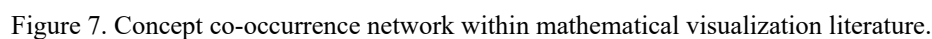
4.4 Topic Evolution

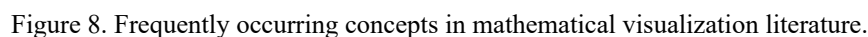
The thematic evolution analysis indicates a gradual transition in mathematical visualization research paradigms. Early studies primarily emphasized geometry visualization and interactive educational systems. Later research increasingly incorporated multimedia learning environments and digital educational technologies.

More recent studies demonstrate growing emphasis on computational thinking, programming integration, and animation-supported educational methodologies. This progression suggests that mathematical visualization research is evolving toward computational and programmatic paradigms emphasizing reproducibility and automation.

4.5 Conceptual Relationships

Concept co-occurrence analysis revealed strong relationships between visualization, learning, cognition, geometry, and computational thinking. The increasing co-occurrence of programming and educational visualization concepts indicates integration between computational pedagogy and mathematical education.





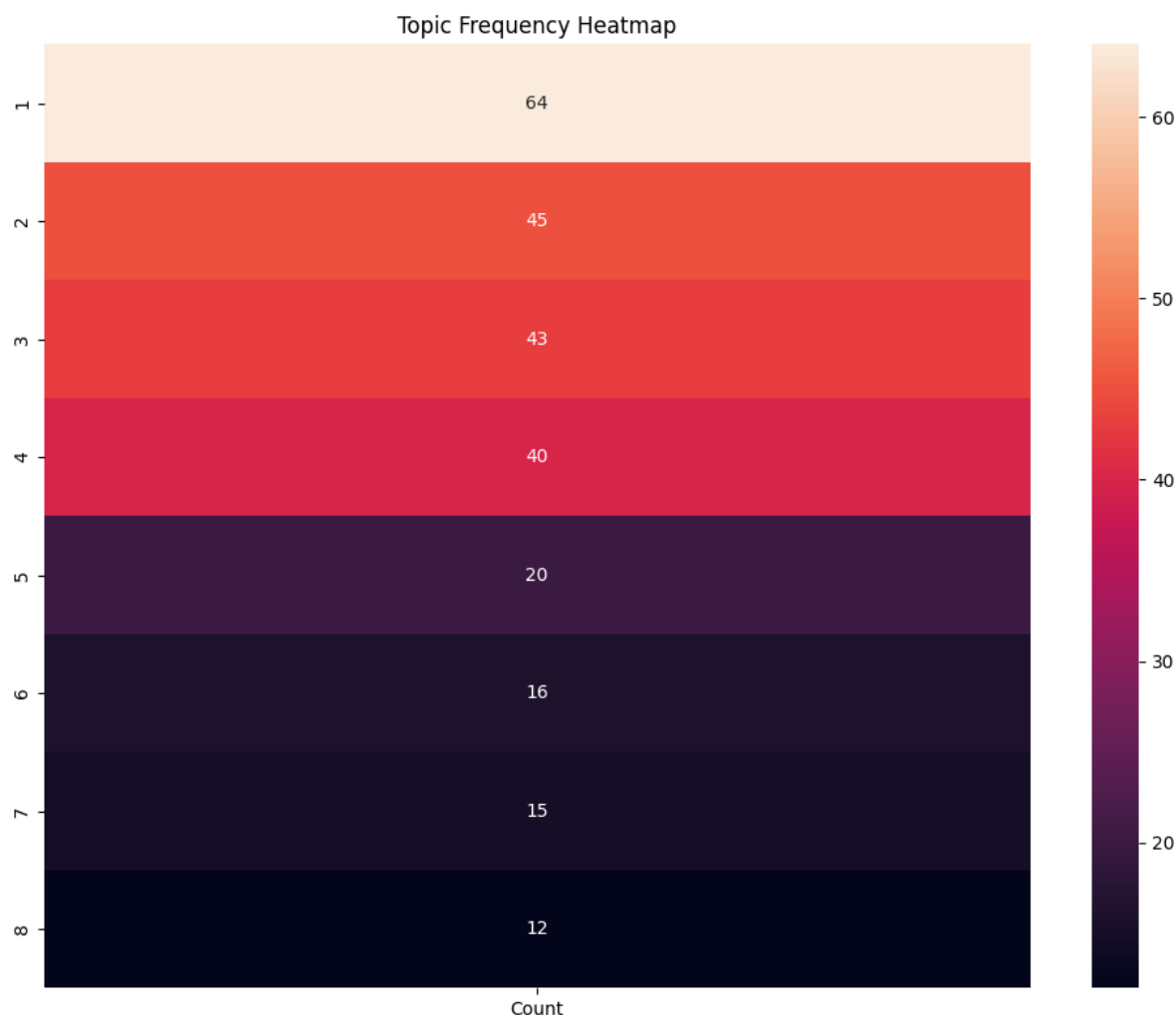


Figure 9. Frequency distribution of BERTopic thematic clusters.

These findings support the emergence of programmatic visualization systems capable of combining computational precision with educational animation.

5. Comparative Analysis and Taxonomy

5.1 Comparative Analysis of Visualization Systems

Mathematical visualization tools differ significantly in terms of interactivity, reproducibility, scalability, and computational flexibility. Interactive systems such as GeoGebra provide accessible graphical interfaces and strong support for geometry-based learning. Desmos offers intuitive graphing functionality suitable for rapid conceptual exploration.

Tool	Interactivity	Reproducibility	Automation	Animation Quality
GeoGebra	High	Low	Low	Medium
Desmos	Medium	Low	Low	Low

Tool	Interactivity	Reproducibility	Automation	Animation Quality
MATLAB	Medium	Medium	Medium	Medium
Mathematica	Medium	Medium	Medium	Medium
Manim	High	High	High	High

Computational environments such as MATLAB and Mathematica provide advanced numerical and symbolic computation capabilities. However, these systems are often designed primarily for scientific computing rather than educational storytelling.

Programmatic animation frameworks such as Manim introduce a distinct paradigm based on code-driven educational visualization. Unlike conventional graphical systems, Manim enables precise scripting of animations and mathematical transformations. This approach supports reproducibility, automation, and modular educational content generation.

5.2 Proposed Taxonomy of Mathematical Visualization Systems

Based on the thematic and comparative analysis, this study proposes a taxonomy of mathematical visualization systems consisting of five categories:

1. **Static Visualization Systems**
These systems rely on fixed graphical representations including textbooks and static diagrams.
2. **Interactive Visualization Systems**
These platforms support user interaction and manipulation of mathematical objects through graphical interfaces.
3. **Computational Visualization Systems**
These systems integrate numerical computation and mathematical simulation.
4. **Programmatic Animation Systems**
These frameworks generate mathematical animations through scripting and programmable rendering.
5. **AI-Assisted Visualization Systems**
Emerging systems employing artificial intelligence and automated educational content generation.

5.3 Positioning of Manim

Manim represents an emerging example of programmatic mathematical animation systems. Its Python-based architecture allows animations to be generated through reusable and reproducible code. This capability distinguishes programmatic animation from traditional interactive visualization systems.

Furthermore, Manim aligns closely with computational pedagogy and modern software engineering practices including automation, modularity, and version control. Such characteristics make programmatic visualization particularly relevant for future educational technology development.

6. Discussion and Future Directions

The findings demonstrate that mathematical visualization research is undergoing substantial conceptual transformation. Earlier visualization paradigms focused primarily on graphical interaction and geometry exploration. In contrast, recent trends emphasize computational thinking, programmable educational systems, and animation-supported conceptual learning.

The increasing integration of programming within mathematics education suggests that future educational visualization systems may prioritize reproducibility, automation, and computational scalability. Programmatic frameworks such as Manim exemplify this transition by combining mathematical precision with animation-based pedagogy.

Despite these developments, several research gaps remain. Existing literature provides limited investigation of reproducible educational visualization workflows and automated mathematical animation generation. Additionally, relatively few studies examine the long-term pedagogical effectiveness of programmatic educational animation systems.

Future research may explore:

- AI-assisted mathematical animation generation
- integration of visualization systems with Jupyter notebooks
- VR and AR educational visualization environments
- automated proof visualization
- real-time mathematical rendering systems
- LLM-assisted educational content generation

if desired.

7. Conclusion

This study presented a bibliometric and systematic review of mathematical visualization research with particular emphasis on emerging programmatic animation paradigms. The findings indicate that mathematical visualization has evolved from static graphical representation toward dynamic, computational, and programmable educational ecosystems.

The bibliometric analysis revealed increasing integration between visualization, computational thinking, animation, and educational technology. Topic modeling further demonstrated the growing importance of programming-oriented educational methodologies within mathematics education research.

The proposed taxonomy conceptualizes the evolution of mathematical visualization systems across static, interactive, computational, programmatic, and AI-assisted paradigms. Within this framework, Manim represents an important example of programmatic educational animation emphasizing reproducibility, automation, scalability, and mathematical precision.

As educational technologies continue to evolve, programmatic mathematical visualization systems are likely to play an increasingly important role in future mathematics education and computational pedagogy research.

References

- [1] Mayer, R. E., "Multimedia Learning," Cambridge University Press, 2009.
- [2] Sweller, J., "Cognitive Load During Problem Solving: Effects on Learning," *Cognitive Science*, vol. 12, no. 2, pp. 257–285, 1988.
- [3] Paivio, A., "Dual Coding Theory and Education," *Educational Psychology Review*, vol. 3, no. 3, pp. 149–210, 1991.
- [4] Hohenwarter, M., and Jones, K., "Ways of Linking Geometry and Algebra: The Case of GeoGebra," *Proceedings of the British Society for Research into Learning Mathematics*, vol. 27, no. 3, pp. 126–131, 2007.
- [5] Borba, M. C., and Villarreal, M. E., "Humans-with-Media and the Reorganization of Mathematical Thinking," Springer, 2005.
- [6] Arcavi, A., "The Role of Visual Representations in the Learning of Mathematics," *Educational Studies in Mathematics*, vol. 52, no. 3, pp. 215–241, 2003.
- [7] Moreno, R., and Mayer, R., "Interactive Multimodal Learning Environments," *Educational Psychology Review*, vol. 19, no. 3, pp. 309–326, 2007.
- [8] Sedig, K., and Sumner, M., "Characterizing Interaction with Visual Mathematical Representations," *International Journal of Computers for Mathematical Learning*, vol. 11, no. 1, pp. 1–55, 2006.
- [9] Kaput, J., "Technology and Mathematics Education," *Journal of Mathematical Behavior*, vol. 11, no. 1, pp. 515–556, 1992.
- [10] Papert, S., "Mindstorms: Children, Computers, and Powerful Ideas," Basic Books, 1980.
- [11] Wilensky, U., and Reisman, K., "Thinking Like a Wolf, a Sheep, or a Firefly," *Cognition and Instruction*, vol. 24, no. 2, pp. 171–209, 2006.
- [12] Freitas, R., and Silva, N., "Visualization Technologies in Mathematics Education: A Systematic Review," *Computers & Education*, vol. 162, 2021.
- [13] González, G., and Herbst, P., "Competing Arguments for the Use of Technology in Mathematics Teaching," *Educational Studies in Mathematics*, vol. 82, no. 1, pp. 1–21, 2013.
- [14] Clark, R. C., and Mayer, R. E., "E-Learning and the Science of Instruction," Wiley, 2016.
- [15] Van der Aalst, W., "Data Science in Education and Learning Analytics," Springer, 2018.
- [16] Hunter, J. D., "Matplotlib: A 2D Graphics Environment," *Computing in Science & Engineering*, vol. 9, no. 3, pp. 90–95, 2007.

- [17] The Manim Community Developers, “Manim Community Documentation,” 2024.
- [18] Perez, F., and Granger, B., “IPython: A System for Interactive Scientific Computing,” *Computing in Science & Engineering*, vol. 9, no. 3, pp. 21–29, 2007.
- [19] Bergmann, T., “BERTopic: Neural Topic Modeling with Transformers,” arXiv preprint arXiv:2203.05794, 2022.
- [20] Priem, J., Piwowar, H., and Orr, R., “OpenAlex: A Fully Open Index of Scholarly Works,” *Scientometrics*, vol. 126, no. 1, pp. 1–15, 2022.