



# Systematic Review of Students' Attitudes and Motivation Using Dynamical System Models

A. Maryati<sup>1\*</sup>, N. Anggriani<sup>2</sup>, A. K. Supriatna<sup>2</sup> and E. Carnia<sup>2</sup>

<sup>1</sup> *Doctoral at the Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, Bandung, Indonesia.*

<sup>2</sup> *Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, Bandung, Indonesia.*

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**Abstract:** The study investigates students' negative attitudes toward learning mathematics, often linked to low motivation, anxiety, and disinterest. These issues are widespread and influenced by factors such as misinformation and avoidance of challenging math courses. To understand the spread of such attitudes, the research uses mathematical modeling through a Systematic Literature Review (SLR) covering studies from 2013–2023, using databases including Scopus, Science Direct, Google Scholar, and Dimensions. Analysis follows the PRISMA method and uses bibliometric tools such as VOSviewer. The findings reveal that since 2020, very few studies have focused on mathematical models analyzing students' attitudes toward mathematics learning, and none have addressed both attitudes and motivation simultaneously—highlighting a significant research gap.

**Keywords:** *mathematical model; dynamic analysis; optimal control; anxiety; hostility towards mathematics; motivation; interest.*

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\* Corresponding author: <mailto:nursanti.anggriani@unpad.ac.id>

## 1 Introduction

Mathematics holds significant potential in cultivating highly competent human resources suited for the demands of the globalization era. This potential can be realized when mathematics education effectively equips students with a strong grasp of mathematical concepts and the ability to apply and integrate them in other scientific disciplines. The advancement of science and technology, along with the economic progress of various nations, is inseparable from the foundational role of mathematics, which is essential for understanding a wide array of fields including science, technology, business, social sciences, engineering, and the arts [1]. Despite its importance, mathematics education faces considerable challenges. Factors such as students' attitude, teaching methods, and teacher competence greatly influence educational quality. One key issue is student anxiety during mathematics lessons, which acts as a psychological barrier to achievement [2]. This anxiety can lead to avoidance and disengagement from math learning. In more severe cases, students may develop outright hostility towards mathematics [3]. Such negative attitudes are often associated with the so-called Strawberry Generation—young people known for their potential, but also for their psychological fragility and difficulty in coping with academic and life pressure [4].

Nonlinear dynamics provides a robust framework to capture the feedback loops, thresholds, and stability conditions inherent in such educational phenomena, allowing researchers and educators to understand not only how negative attitudes propagate, but also how timely interventions can shift the system toward a more motivated and engaged student population. Hence, integrating nonlinear dynamical systems into this educational context enables a deeper, quantitatively grounded insight into the evolution and control of students' attitudes and motivation in mathematics learning.

The persistence of students' negative attitudes toward learning mathematics is a longstanding concern that significantly impacts their motivation and interest in the subject [5]. These attitudes are shaped by various factors, including personal motivation, teacher influence, and social interactions such as peer support [6]. When students lack motivation or experience negative emotions—such as anxiety, fear, hatred, or discouragement—these psychological conditions can spread and hinder the mathematics learning environment. Addressing this issue requires teachers to foster a classroom atmosphere that nurtures positive emotions and encourages student motivation [7]. Situational factors greatly influence emotional experiences, which in turn affect students' attitudes and confidence levels during math learning. By implementing effective teaching strategies, educators can stimulate the transmission of positive emotions and motivation not only between teachers and students but also among peers. This interaction builds students' emotional resilience in facing challenges in learning mathematics. Research also indicates that emotional contagion—especially in close-knit social environments—is more likely to spread positive feelings than negative ones [8].

The approach of mathematical modeling using deterministic methods is a scientific effort to connect and discover real-world situations [9]. A mathematical model is a model that consists of mathematical concepts such as coefficients, constants, variables, functions, equations, and so on. The mathematical model of epidemics in the spread of students' negative attitudes toward mathematics learning is one part of applied mathematics which discusses various aspects of epidemics of psychological diseases, and mathematical modeling is the knowledge to translate a problem into mathematical language [10]. Mathematical modeling is a tool that can be used to analyze the spread of students'

learning attitudes and motivation towards learning mathematics. This research aims to identify future research gaps regarding mathematical modeling in analyzing the dynamics of students' attitudes and learning motivation in mathematics learning.

This study employs the Systematic Literature Review (SLR) method to analyze research on mathematical modeling related to the spread of students' attitudes and motivation in mathematics learning, using data from Scopus, ScienceDirect, Google Scholar, and Dimensions databases from 2013–2023, and analyzed through the PRISMA method and bibliometric visualization. Deterministic mathematical models have long been used to study the spread of physical and psychological phenomena such as diseases in humans and plants, racism and corruption and cultural dissemination [11, 12]. These variations in modeling arise from differing assumptions, making each model unique [13]. Given the limited studies focusing specifically on the dynamics of students' attitudes and motivation in mathematics, this literature review seeks to identify research gaps and encourage future developments in modeling approaches and methodologies in this field.

## 2 Methodology

### 2.1 Data search strategy

The PRISMA method is an analytical technique used to identify elements of papers in a database. This method explores papers related to the research topic to uncover gaps as novel aspects of this study. In the PRISMA method, the first step is to collect related papers for this research using keywords ("Stability analysis" OR "Mathematical model" OR "Mathematical modeling" OR "Dynamical Analysis" OR "Dynamical System") AND "Optimal Control" AND (("motivation" OR "animosity" OR "anxiety") AND "towards mathematics") across four databases: Scopus, ScienceDirect, Google Scholar, and Dimensions. Based on these keywords, papers are obtained from each database, as detailed in Table 1.

Database	Scopus	ScienceDirect	Dimensions	Google Scholar
Number of Papers	2	1	2	18

**Table 1:** Number of papers collected from each database.

### 2.2 Selection of relevant papers

Database	Scopus	Science Direct	Dimensions	Google Scholar
Number of Papers	2	1	2	16

**Table 2:** Contribution of papers from each database after duplicate selection.

As shown in Table 1, a total of 23 papers were initially identified as related to the study of mathematical modeling concerning the spread of students' motivation and interest in learning mathematics. The next step involved filtering these papers to remove duplicates and retain those relevant to the research topic. Using Scopus as the primary reference, duplicates across ScienceDirect, Google Scholar, and Dimensions were identified and

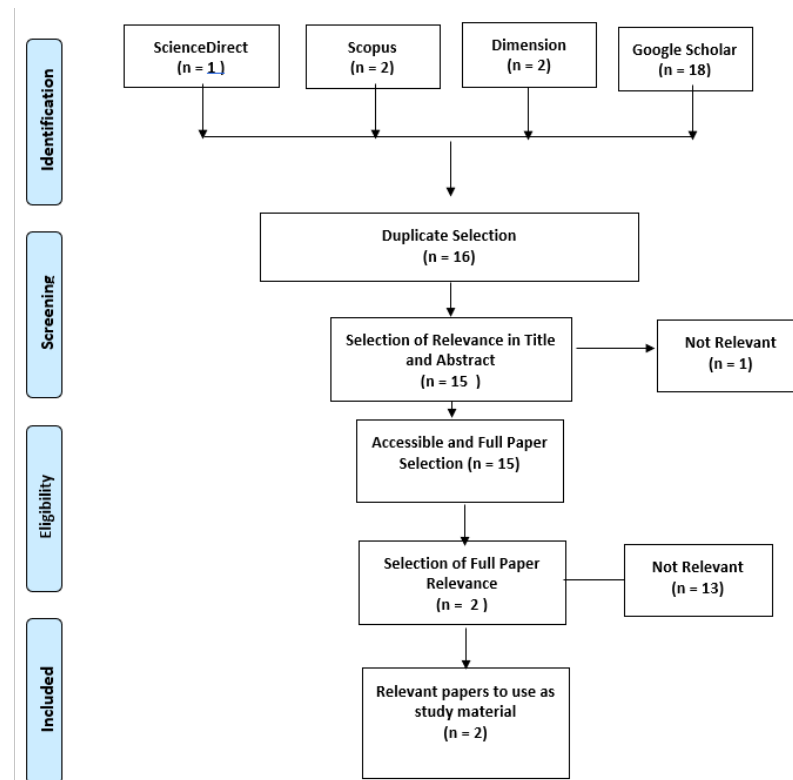


Figure 1: PRISMA analysis flowchart.

excluded, resulting in 15 papers, as presented in Table 2. The selection process continued by evaluating the relevance of the papers titles and abstracts, narrowing the list to 15 papers that matched the specified keywords. A more detailed relevance check was then conducted by skimming these papers to determine alignment with the research scope, which focuses on continuous dynamic systems and the application of optimal control [14]. This rigorous filtering ultimately led to two unique papers deemed most relevant to the study. The PRISMA-based selection process is summarized in the flowchart, see Figure 1.

### 2.3 Data analysis

The data analysis was carried out in four stages: first, by examining mathematical representations related to the distribution of students' attitudes and motivation toward learning mathematics to identify potential areas for model development; second, by reviewing the findings from previous studies; third, by pinpointing aspects that require further exploration in the context of mathematical models addressing students' attitudes and motivation; and finally, by conducting a bibliometric analysis to assess the novelty of the research, providing insight into existing literature and highlighting gaps within the field.

### 3 Results

#### 3.1 Previous model overview

The outcome of paper selection based on the use of specific keywords (“Stability analysis” OR “Mathematical model” OR “Mathematical modeling” OR “Dynamical Analysis” OR “Dynamical System”) AND “Optimal Control” AND (“motivation” OR “animosity” OR “anxiety”) AND “towards mathematics”) shows that after duplicative selection, there are 15 relevant papers. A summary of the papers in question can be seen in Table 3. From the initial 15 papers, only 2 were deemed relevant after the screening, eligibility, and inclusion process, and these were used as key references. Their models, detailed in Table 4, represent the earliest efforts to apply mathematical modeling to analyze the transmission of students’ attitudes toward mathematics learning.

As illustrated in Table 4, the researchers employed several subpopulations and parameters to build their mathematical models. In the model proposed in [2], the vulnerable subpopulation, denoted by  $P(t)$ , consists of students who either have the potential to perform well academically or are at risk of developing anxiety related to mathematics. On the other hand, Teklu and Terefe [7] identify their vulnerable group, represented by  $S(t)$ , as college students who initially do not possess a strong aversion to mathematics—some of whom may even show interest in the subject—but may develop animosity upon interaction with already affected peers. Regarding the exposed subpopulation, Nathan and Jakob [2] do not include this category in their model. However, Teklu and Terefe [7] introduce an exposed group, denoted by  $E(t)$ , comprising students who are currently enrolled in mathematics courses and have frequent contact with those expressing negative sentiments about the subject. These exposed individuals may or may not become negatively influenced. Furthermore, in Nathan and Jakob’s model, the group of students who have developed anxiety toward mathematics is categorized as the infectious subpopulation, represented by  $A_x(t)$ .

Meanwhile, in the Teklu and Terefe model [7], students are infected with animosity towards mathematics. A group of students who strongly dislike or display hostility towards mathematics and tend to perform poorly in university are denoted by  $A(t)$ . Subpopulation that recovered due to treatment, in the Nathan and Jakob model [2], students who recovered due to efforts or treatments to become students with the potential to perform well, are denoted by  $A_a(t)$ . Meanwhile, in the model of Teklu and Terefe [7], the students who recovered, that is, those who received treatment aimed at eliminating hostility towards mathematics, namely a group of students who received different psychological guidance and treatments from their mentors and professors, are referred to as treated students and denoted by  $T(t)$ .

In comparing the models by Teklu and Terefe [7] and Nathan and Jakob [2], key differences in parameter usage are evident. The  $\eta$  parameter, which governs the return of treated individuals to the vulnerable group, appears only in the Teklu and Terefe model. Both models utilize the parameter  $\beta$  to describe transmission, but in Teklu and Terefe’s model, it represents the transition from vulnerable to exposed, while in Nathan and Jakob’s model, it signifies the transition from vulnerable to infected. The parameter  $\gamma$  also differs in meaning: it defines the transition from exposed to infected in Teklu and Terefe’s model, and that from infected to recovered in Nathan and Jakob’s one. Similarly,  $\delta$  denotes the transition from infected to recovered in the Teklu and Terefe model, whereas in Nathan and Jakob’s model, it indicates the transition from vulnerable to recovered.

No	Writer	Research Topics	Summary	Method/model	Description
1.	Kendall (2013) [1]	Estimated Future Trends in the Development Of Mathematics and of its relations with the Non-Mathematical world	Classify the branches of Mathematics into (1) which is rarely or never used in statistics; (2) which is used occasionally but not in depth; (3) things that are important to the subject and adding a fourth category;(4) categories that must be discovered or developed by statisticians	-	The development of mathematics and its relationship with the non-mathematical world Not relevant
2	Nathan & Jackob. (2020) [2]	Mathematical Modeling and Analysis of Mathematics Anxiety Behavior on Mathematics Performance in Kenya	Constructing a deterministic model that describes the dynamics of students who have abilities to perform well on mathematics tests and engage in careers that require its application and the negative influence of individuals with mathematics anxiety on student potential	Model: Susceptible- Infectious- Removed (SIR) Method: Dynamic Analysis	Students who have abilities for achievement and the influence of negative attitudes, namely anxiety towards learning mathematics, on student potential.
3.	Teklu & Terefe (2022) [3]	Mathematical modeling analysis on the dynamics of university students animosity towards mathematics with optimal control theory	Formulate a new SEATS compartmental mathematical model with optimal control theory to analyze the dynamics of student animosity towards mathematics	Model: Susceptible- Exposed- Animosity Infectious- Treated-susceptible (SEATS) Method: Dynamic Analysis	university students animosity towards mathematics
4.	Kotola & shewafera (2022) [4]	A Mathematical Modeling Analysis of Racism and Corruption Codynamics with Numerical Simulation as Infectious Diseases	Formulate the dynamics of racism and corruption that coexist in society, using a deterministic compartmental model to analyze and suggest appropriate control strategies to stakeholders	Deterministic compartment model	Racism and corruption co-exist in society,full paper is not suitable.
5.	Terefe (2022) [5]	Mathematical Model Analysis on the Diffusion of Violence	Formulate and test a mathematical model of direct violence with five different classes of human populations (vulnerable, exposed to violence, violent, negotiated, and reconciled)	Model: Susceptible, exposed, Violently infectious, Negotiated, reconciled SEPHR	Violence against humans full paper is not suitable
6.	Teklu & Mamo (2022) [6]	A nonlinear system dynamics and simulation analysis of fractional order modelling on employees negative attitude towards their workplace with intervention strategies	Formulate and analyze the Caputo fractional order mathematical model with intervention strategies for employees' negative attitudes towards the workplace.	Model: susceptible, protected, exposed, employees who have ordinary negative attitude, employees who have permanent negative attitude, employees recoverd from negative attitude (SPEAQR)	Employee negative attitudes towards the workplace. Full paper is not suitable.
7.	Teklu & Terefe (2022) [7]	Mathematical Modeling Investigation of Violence and Racism Coexistence as a Contagious Disease Dynamics in a Community	Developing and testing a new mathematical model of the coexistence of violence and racism with eight different classes of human populations (vulnerable, violence-infected, negotiated, racist, violence-racism co-infected, recovering from violence, recovering against racism, and recovering from co-infection)	Model:SVUR1,2,3.	Violence and racism full paper is not suitable.
8.	Teklu (2023) [8]	Analysis of fractional order model on higher institution students' anxiety towards mathematics with optimal control theory	Formulate and analyze the Caputo fractional order mathematical model with optimal control strategies for college students' anxiety towards mathematics.	SPEAQR Method: caputo fractional order	College students' anxiety about mathematics.
9.	Teklu et al. (2023) [9]	Analysis of tinea capitis epidemic fractional order model with optimal control theory	Formulating the transmission dynamics of tinea capitis infection using Caputo's fractional derivative approach.	Model : susceptible, exposed, infected, recoverd (SEIR)	Transmission of tinea capitis infection full paper is not suitable.
10.	Asih et al. (2023) [10]	Weights Optimization Using Firefly Algorithm for Dengue Fever Optimal Control Model by Vaccination, Treatment, and Abateseae	Optimal control model for minimizing the spread and cost of dengue fever transmission in Indonesia using the Firefly Algorithm	Model: vaccination, treatment, and larvicide (abateseae) strategies	Examining the dynamics of Dengue Fever in the vaccination phase. full paper is not suitable.
11.	Quedraogo & Guiro (2023) [11]	Analysis of Dengue Disease Transmission Model with General Incidence Functions	analyze a nonlinear dengue fever transmission model involving general incidence functions that describe interactions between humans and mosquito vectors	Model: SIRSI	Dengue fever transmission model full paper is not suitable.
12.	Baba et al. (2023) [12]	A fractional order model that studies terrorism and corruption codynamics as epidemic disease	Formulate a fractional order mathematical model to study the dynamics of the coexistence of terrorism and corruption in society.	Model: SCDRT	Terrorists and corruption full paper is not suitable.
13.	Olaniyi et al. (2023) [13]	Lyapunov Stability and Economic Analysis of Monkeypox Dynamics with Vertical Transmission and Vaccination	Formulate a new nonlinear mathematical model to understand the dynamics of monkeypox disease	-	Monkeypox disease Full paper cannot be opened
14.	Teklu (2023) [14]	Investigating the Effects of Intervention Strategies on Pneumonia and HIV/AIDS Coinfection Model	Formulate a compartment epidemic model on the dynamics of the spread of HIV/AIDS and pneumonia coinfection to investigate the impact of protective and treatment intervention mechanisms on the spread of coinfection in the community	Model: SCHPT	HIV/AIDS and pneumonia full paper is not suitable.
15.	Mamo & Mengstie (2023) [15]	Racism Dissemination Model and Simulation Analysis Considering Crowd Classification with Intervention Strategies	Analyze compartmental mathematical models to understand how racists spread their opinions and influence society with intervention strategies	Model: S-H-R-C-I	Racist full paper is not suitable.

Table 3: Summary of relevant papers.

	$\frac{dP}{dt} = \eta - \beta P(t)A_x(t) - \delta P(t) - \mu P(t)$
4*Model 1 (Nathan and Jakob, 2020) [2]	$\frac{dA_x}{dt} = \beta P(t)A_x(t) - \gamma A_x(t) - \mu A_x(t)$
	$\frac{dA_a}{dt} = \gamma A_x(t) + \delta P(t) - \mu A_a(t)$
	$\frac{dS(t)}{dt} = \eta + \alpha T(t) - \beta S(t)A(t) - \mu S(t)$
4*Model 2 (Teklu and Terefe, 2022) [3]	$\frac{dE(t)}{dt} = \beta S(t)A(t) - (\mu + \gamma)E(t)$
	$\frac{dA(t)}{dt} = \gamma E(t) - \mu + \delta A(t)$
	$\frac{dT(t)}{dt} = \delta A(t) - \mu + \alpha T(t)$

**Table 4:** Model of the distribution of attitudes towards previous mathematics learning.

### 3.2 Results that have been achieved in previous studies

In [2], the mathematical models represent the first attempts to apply mathematical modeling to examine the transmission of students’ attitudes toward mathematics learning. In the first model, the student population is categorized into three groups: vulnerable students, students experiencing anxiety related to learning mathematics, and high-achieving students. In contrast, the second model divides the population into four compartments: vulnerable students, those exposed to hostility toward mathematics, students infected with such hostility, and students undergoing tutorial interventions to recover from negative attitudes. Both models employ dynamic systems approaches, including analysis of equilibrium points, calculation of the basic reproduction number, and assessment of system stability. Additionally, the second model incorporates optimal control strategies using Pontryagin’s maximum principle to evaluate the effectiveness of intervention efforts.

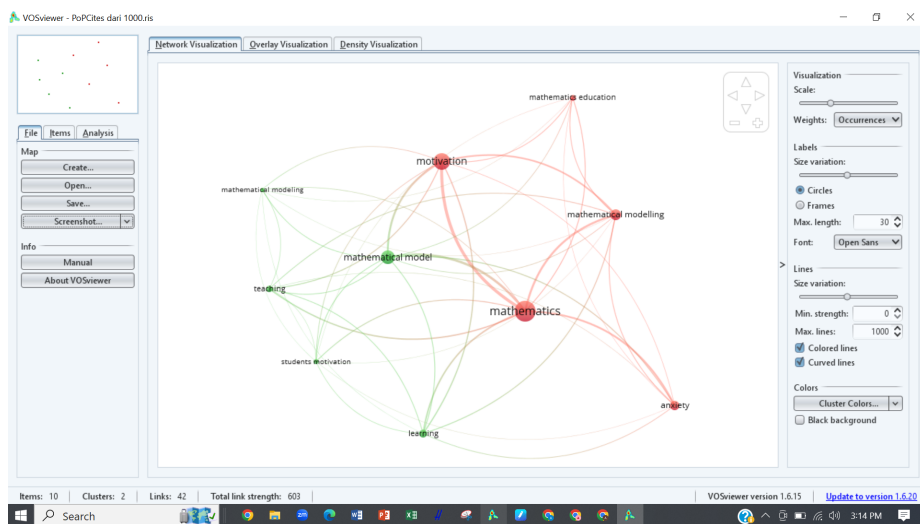
Based on the models developed in [2], several limitations have been identified. Notably, both models focus solely on negative attitudes such as anxiety and hatred toward mathematics, without incorporating motivational variables or the positive influence of teachers as motivators in implementing interventions. Furthermore, the preventive strategies used are implicitly limited to subgroups of students receiving treatment, lacking comprehensive mitigation involving the broader student population. Additionally, the interventions applied are general in nature and do not incorporate STEM-based quantum teaching-learning strategies, which have the potential to significantly boost students’ motivation and engagement. A comparative overview of the elements within both models and their alignment with the research context on the dissemination of students’ attitudes and motivation toward mathematics learning is provided in Table 5.

### 3.3 Research gaps that may be developed

After reviewing studies related to the modeling of the spread of students’ attitudes and motivation toward learning mathematics, it becomes apparent that compartmental models are still rarely applied in this context. This is supported by the identification of only two relevant papers, indicating a significant research gap despite the increasing application of compartmental modeling in various fields. Existing studies primarily focus on modeling the dissemination of negative attitudes such as anxiety and hostility toward mathematics, without addressing the positive aspects of motivation and student interest. Furthermore, prior research has yet to incorporate control strategies involving specific learning approaches aimed at enhancing students’ motivation in mathematics education. The development of Model 1 and Model 2 involves constructing a modified model that

No.	Author	Research Topics	Summary	Method/model
1.	Nathan & Jakob. (2020) [2]	Students who have the ability to achieve and the negative influence of individuals with mathematics anxiety on student potential	Constructing a deterministic model that depicts the dynamics of students who have the ability to excel in mathematics exams and are involved in careers that demand its application, and the negative influence of individuals with mathematics anxiety on student potential.	Model: Susceptible-Infectious-Removed (SIR) Method: Dynamic Analysis
2.	Shewafera & Birhanu (2022) [3]	Student animosity towards mathematics	Formulating a new SEATS compartmental mathematical model with optimal control theory to analyze the dynamics of student animosity towards mathematics.	Model: Susceptible-Exposed-Infectious-Treated-Susceptible (SEATS) Method: Dynamic Analysis

**Table 5:** Summary of papers.



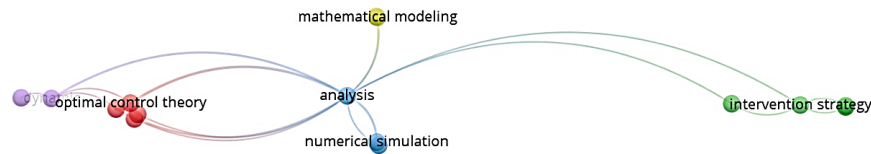
**Figure 2:** Research mapping the distribution of students' attitudes.

incorporates the spread of both negative and positive student attitudes toward learning mathematics, while also taking into account the application of a motivating learning strategy. This modification aims to decrease the number of students with negative attitudes and reduce the presence of unmotivating teachers, while simultaneously increasing the population of students with positive attitudes and teachers who actively motivate mathematics learning. Additionally, the model includes control strategies designed to enhance student motivation and engagement in mathematics while minimizing the associated implementation costs.

### 3.4 Bibliometric analysis

Based on the keywords outlined in Section 2.2, a total of 16 papers were identified after duplicate removal, and additional 15 papers were selected based on the relevance of their references. The bibliometric network visualization of these selected papers, generated using VOSviewer software, is shown in Figure 2.

Figure 2 shows that the nodes representing students' attitudes and motivation to



**Figure 3:** Visualization of the interrelationships among all reference papers.

ward learning mathematics in the context of mathematical modeling are relatively small, indicating that only a limited number of researchers have explored this area. Additionally, the figure reveals a lack of connections between models addressing the spread of negative and positive attitudes, students' learning motivation, and mathematics learning strategies. This gap highlights a valuable opportunity for future researchers to develop comprehensive mathematical models that integrate these aspects to better predict and understand the dynamics of students' attitudes and motivation toward mathematics learning.

Based on Figure 1, the mapping results in Figures 2 and 3, and the summary of papers in Table 5, it is evident that no existing research has integrated a mathematical model of the spread of students' attitudes and learning motivation toward mathematics with optimal control to predict these dynamics. This represents a novel and promising opportunity for future research in this area. Additionally, all reference papers were mapped using VOSviewer to visualize their interconnections, as illustrated in Figure 3.

#### 4 Discussion

The current study highlights a significant gap in the application of mathematical modeling to the dynamics of students' attitudes and motivation toward mathematics learning. Despite the extensive use of compartmental models in fields such as epidemiology, social sciences, and psychology, their application to educational contexts particularly modeling students' emotional and motivational dynamics—remains limited. Only two relevant studies were identified, both focusing predominantly on the spread of negative attitudes such as anxiety and animosity. These models employed classical deterministic approaches, including stability analysis and basic reproduction number calculations, and in one case, optimal control theory to explore intervention strategies. However, neither model incorporated variables that capture positive psychological constructs such as motivation or interest in mathematics.

This limited focus presents a critical shortcoming, as motivation plays a crucial role in shaping students' learning experiences and academic performance. The exclusion of motivational factors and teacher influences from previous models results in a narrow representation of the learning environment. Furthermore, while both existing models introduced control strategies, they were mostly limited to generic psychological treatments or tutorials, without considering pedagogical innovations such as STEM-based or quantum learning approaches. These omissions suggest that current mathematical models may underestimate the potential for positive intervention and support systems

in reversing negative attitudes and promoting long-term engagement with mathematics.

The bibliometric analysis further supports this conclusion, revealing a fragmented research landscape with few interconnections between studies modeling emotional and motivational dynamics in mathematics education. There is an urgent need for comprehensive models that not only capture the spread of negative emotions but also account for the diffusion of positive attitudes and motivational interventions. Future models should integrate dynamic interactions between students, peer groups, and educators, and evaluate the effectiveness of specific teaching strategies through optimal control frameworks. Such advancements would provide a more holistic and actionable understanding of the emotional and motivational factors influencing students' success in mathematics.

## 5 Conclusions

This study reveals a significant research gap in the application of nonlinear dynamical models to analyze the dynamics of students' attitudes and motivation toward mathematics learning. Through a systematic literature review and bibliometric analysis, we identified that existing models have primarily focused on negative psychological responses such as anxiety and animosity, while largely neglecting the role of motivation and positive learning influences. The novelty of this work lies in highlighting the absence of integrated models that simultaneously account for both negative and positive student attitudes, including the impact of motivational strategies within a control-theoretic framework. By synthesizing findings from recent mathematical modeling efforts and mapping their limitations, this paper offers a new research direction: the development of more comprehensive, optimally controlled compartmental models that incorporate emotional contagion, teacher influence, and motivational interventions. These models are crucial for predicting, understanding, and managing the evolving psychological dynamics in mathematics education from a nonlinear systems perspective.

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