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ARAŞTIRMA MAKALESİ / RESEARCH ARTICLE

Bibliometric Analysis of Mathematical Modeling Research in Mathematics Education

Matematik Eğitiminde Matematiksel Modelleme Araştırmalarının Bibliyometrik Analizi

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Abstract

In the field of mathematics education, as in many other fields, comprehensive and summative review studies are an important part of the research that needs to be done in the field. In this way, researchers can manage their research processes with greater efficacy by accessing the most studied topics and studies published in SSCI and SCI-Expanded indexed journals from a single source. This study presents a bibliometric map of qualified studies on mathematical modeling between 2003 and 2023. After searching Web of Science, 178 articles and reviews were identified. According to the results, studies on mathematical modeling in mathematics education have increased over the years. It was found that most of the studies were research articles. One of the key results of the study is that research on the mathematical modeling process is more prevalent than research on problem-posing. The results suggest that there is a need for review studies such as systematic reviews, meta-analyses, and bibliometric analyses. In addition, it can be suggested that problem-posing studies should be included more in research articles.

Keywords: Bibliometric analysis, Literature review, Mapping review, Mathematics education, Mathematical modeling

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Öz

Birçok alanda olduğu gibi matematik eğitimi alanında da kapsayıcı ve özetleyici derleme çalışmaları bu alanda yapılacak çalışmalar için önemli bir yere sahiptir. Böylelikle araştırmacılar özellikle en çok çalışılan konular ve SSCI ve SCI – Extended indeksli dergilerde yayınlanan çalışmalara tek bir kaynaktan erişerek araştırma süreçlerini daha etkin yönetebilmektedir. Bu çalışmada da 2003-2023 yılları arasında matematiksel modelleme konusunda yapılan nitelikli çalışmaların bibliyometrik haritası sunulmuştur. Web of Science veritabanında taranan araştırma ve derleme çalışmaları belirlenen kriterler çerçevesinde incelenmiş ve 178 dokümana ulaşılmıştır. Sonuçlara göre matematik eğitimindeki matematiksel modelleme çalışmaları giderek artmaktadır. Çalışmaların büyük bir bölümünün araştırma makalesi olduğu tespit edilmiştir. Araştırmanın ortaya koyduğu önemli sonuçlardan biri matematiksel modelleme süreci üzerine yapılan çalışmaların problem kurma çalışmalarına nazaran daha yoğun olmasıdır. Sonuçlar sistematik derlemeler, meta-analizler ve bibliyometrik analizler gibi derleme çalışmalarına ihtiyaç olduğunu göstermektedir. Bununla birlikte araştırma makalelerinde problem kurma çalışmalarına biraz daha yer verilmesi önerilebilir.

Anahtar Sözcükler: Bibliyometrik analiz, Literatür taraması, Haritalama incelemesi, Matematik eğitimi, Matematiksel modelleme

Geniş Özet

Giriş

Matematiksel modelleme yaklaşımı son yıllarda birçok ülkenin farklı kademelerinde öğretim programlarını doğrudan ya da dolaylı olarak etkilemektedir. Bazı ülkelerde (Almanya, Amerika Birleşik Devletleri gibi) ilkokuldan liseye kadar öğretim programlarının zorunlu bir parçası iken bazı ülkelerde (Türkiye, Çin, Güney Kore gibi) öğretim programlarını etkileyen önemli faktörlerden biridir (Schukajlow vd., 2018; Borromeo Ferri, 2023). Örneğin, Türkiye'de doğrudan öğretim programında yer almasa da 2018'den itibaren öğretmen eğitimi programının bir parçasıdır (Yükseköğretim Kurulu, 2018a ve 2018b). Bu durum yakın zamanda bu ülkelerde de matematiksel modellemenin öğretim programının bir öğesi olacağının bir göstergesi şeklinde değerlendirilebilir.

Matematiksel modelleme araştırmaları son birkaç on yılda hatırı sayılır nitelikte artan bir ivmeye sahiptir. Çalışılan konuların matematiksel modelleme yeterlikleri, matematiksel modellemenin öğretimi, sınıf içi uygulamalar üzerinde yoğunlaştığı görülmektedir. Akademik çalışmalardaki artış yeni çalışma alanlarının ve farklı teorik çerçevelerin ortaya çıkmasına olanak sağlamaktadır. Araştırma alanının genişletilmesi de matematiksel modellemenin daha iyi anlaşılmasını, matematiksel modellemenin öğretim programları, ders araçları, öğretmen eğitimi programları, hizmet içi programlarına entegre edilmesi açısından önemli katkı sunmaktadır. Bununla birlikte modelleme çalışmalarındaki niceliksel artış maalesef her zaman nitelikli bir etki yaratmamaktadır. Bu alanda yapılan birçok çalışma içinden nitelikli olanları belirlemek için derin bir literatür taraması yapılmalıdır. Kapsayıcı ve özetleyici derleme çalışmaları bu anlamda önemli bir rol üstlenmektedir (örn., Schukajlow, Kaiser & Stillman, 2018; Cevikbas, Kaiser & Schukajlow, 2022). Detaylı ve iyi organize edilmiş bir literatür taraması ilgili alanda yapılacak çalışmalar için bir yol göstericidir. Bir araştırma konusu hakkında literatür taraması yaparken çok sayıda çalışma içinden kaliteli olanları

belirlemek gerekli ancak zor ve zaman alıcı bir süreçtir. Bu anlamda literatür taraması çalışmaları ilgili alanda bir çerçeve sunarak araştırmacıların işini kolaylaştırmaktadır. Böylelikle araştırmacılar özellikle en çok çalışılan konular ve en etkili yayınlara (ilgili alanda önemli araştırmacılar tarafından yürütülen veya en çok atıf yapılan) tek bir kaynaktan erişerek araştırma süreçlerini daha etkin yönetebilmektedir. Bunun yanı sıra literatür taramaları alanda daha az çalışılan konuları tespit etme ve eksikleri belirleme fırsatı sunmaktadır. Araştırma boşluklarını tespit etmek aynı ya da benzer araştırmaların tekrar tekrar yapılmasının önüne geçmek için önemlidir (Snyder, 2019). Birçok konuda olduğu gibi matematiksel modelleme odaklı çalışmaların farklı zaman aralıklarında literatür derlemeleri bulunmaktadır (örn., Sokolowski, 2015; Cevikbas vd., 2022).

Matematiksel modelleme hakkında yapılan araştırmaların oldukça geniş bir bileşen haritası bulunmaktadır. Dolayısıyla her bir bileşen için sistematik literatür taramalarının yapılması mümkün ve hatta gereklidir. Bununla birlikte matematiksel modellemeye daha geniş bir çerçeveden bakabilmek de önemlidir. Bu durum dikkate alınarak bu çalışmanın amacı son 20 yılda nitelikli matematiksel modelleme araştırmalarının etki düzeylerini araştırmak olarak belirlenmiştir. Böylelikle araştırmacıların matematiksel modelleme alanında en etkili dergi, yazar ve yayın bilgilerini toplu halde görmeleri mümkün olacaktır. Bu çalışma araştırmacılar, öğretmen ve öğretmen adayları için bir kılavuz olabilir. Ayrıca etki değeri yüksek çalışmaların bir haritası araştırmacıların alandaki eksikleri görmelerini ve hangi hususlarda literatürü destekleyebilecekleri hakkında fikir üretmelerini sağlayacaktır. Bu gerekçeler doğrultusunda araştırma sorusu "Son 20 yılda matematik eğitimi alanında Social Sciences Citation Index (SSCI) ve Sciences Citation Index – Expanded Indeks kapsamında yayınlanan matematiksel modelleme çalışmalarının etki düzeyleri nasıldır?" şeklinde belirlenmiştir.

Yöntem

İlk olarak Pritchard (1969) tarafından yeni bir sistematik inceleme yaklaşımı olarak tanımlanan bibliyometrik analiz yöntemi, çok sayıda bilimsel verinin incelenmesine ve analiz edilmesine olanak tanıyan bir tekniktir (Donthu vd., 2021). Bibliyometrik analizin nesnel bakış açısı, başlıkların, anahtar kelimelerin, atıf sayılarının ve yayın indekslerinin nicel verilerine dayanmaktadır. Bu çalışmada yukarıdaki bileşenler bağlamında matematiksel modelleme literatürünün bibliyometrik haritası çıkarılmıştır.

Web of Science (WoS), önemli bir bilimsel veri tabanı olması ve bibliyometrik verileri farklı dosya formatlarında sunması nedeniyle bu çalışmanın veri kaynağı olarak seçilmiştir. Bu çalışmada, 2003-2023 yılları arasında Web of Science veri tabanında taranan SSCI ve SCI-EXPANDED indeksli 178 doküman analiz edilmiştir. Veri tabanına son erişim tarihi 20 Mart 2024'tür.

Veriler VOSviewer yazılımı kullanılarak analiz edilmiştir. VOSviewer boyut, mesafe ve renklere dayalı görselleştirme haritaları üretir. Bu özellikler verilerin yorumlanması için bilgi verir. Bir düğüm, yazar, anahtar kelime veya yayın kaynağı gibi belirli bir unsuru temsil eder. Düğümün boyutu sıklık miktarını gösterir. Olay sayısı arttıkça düğümün boyutu da artar. Düğümler arasındaki bağlantı, bağlantılı oldukları anlamına gelirken, düğümler arasındaki mesafe ilişkilerinin yoğunluğunu

yansıtır. Daha kısa çizgiler daha güçlü bağlantıları gösterirken, daha uzun çizgiler daha uzak ilişkileri ifade eder. Her renk ise bir kümeyi temsil eder (Van Eck & Waltman, 2010).

Bulgular

Bulgular, matematiksel modelleme alanındaki çalışmaların nicelik olarak doğrusal bir artış göstermese de 2015 yılından günümüze kadar bu alanda gözle görülür bir yoğunlaşma olduğunu göstermektedir. Matematiksel modelleme konusunda en fazla çalışmanın (35 yayın) 2018 yılında yayınlandığı görülmektedir. En çok çalışma yayınlayan dergiler ise 48 yayın ile ZDM-Mathematics Education ve 29 yayın ile Educational Studies in Mathematics olmuştur.

Anahtar kelime analizine göre, "matematiksel modelleme" 83 atıfla en sık kullanılan anahtar kelime olurken, onu 18 atıfla "modelleme", 13 atıfla "problem çözme" ve 10 atıfla "matematik eğitimi" takip etmektedir. ZDM-Mathematics Education, incelenen tüm çalışmaların dörtte birinden fazlasını (%27) oluşturan 48 yayınla en üretken dergi olmuştur. Educational Studies in Mathematics (29 yayın, %16,3) ikinci sırada, Mathematical Thinking and Learning (17 yayın, %9,5) ise üçüncü sırada yer almaktadır.

Yazarların üretkenlik sıralaması yayın ve atıf sayılarına göre farklılık göstermektedir. Bu çalışmada yazarların üretkenliğini belirleyen faktör olarak yayın sayısını dikkate alınmıştır. Buna göre matematiksel modelleme konusunda en çok yayın yapan ve en çok atıf alan yazar Stanislaw Schukajlow olmuştur (13 yayın, 315 atıf). Onu sekizer makale ile Gabriele Kaiser ve Ayhan Kürşat Erbaş takip etmektedir. Ayrıca, bir yazarın etki faktörü, toplam atıflarının toplam yayınlarına bölünmesiyle hesaplanmış ve etki değerleri en yüksek olan yazarların Lieven Verschaffel ve Wim Van Dooren olduğu tespit edilmiştir (36,5). Ortak atıf analizine dahil edilen 178 yayın için, bir yayın tarafından alınan minimum ortak atıf sayısı 10 olarak belirlenmiştir. Bu eşiği atıf yapılan 6260 referanstan 56'sı karşılamıştır. Aynı yayınlar tarafından ortak atıf yapılan referanslar 4 küme halinde gruplandığı görülmüştür.

Bibliyografik bağlantı analizine dahil edilen 328 yazar için, bir yazara ait minimum yayın sayısı 5 olarak belirlenmiştir. 328 yazar arasından 9 araştırmacı bu eşiği karşılamış ve ortak referans kullanan yazarların 3 küme oluşturduğu görülmüştür. S. Schukajlow diğer yazarlarla en güçlü ortak referans ağına sahip olan yazar olmuştur.

Tartışma ve Sonuç

Matematik eğitimi alanında da diğer disiplinlerde olduğu gibi literatür taramaları özellikle sistematik incelemeler ve meta-analizler oldukça ilgi görmektedir (Cevikbas et al., 2024; Kaiser & Schukajlow, 2024). Bu araştırmada ise matematiksel modelleme alanında yer alan en etkili çalışmaların sadece birinin (Van Dooren et al., 2008) literatür taraması olduğu tespit edilmiştir. Bu sonuç sınıflı dergilerde matematiksel modelleme hakkında daha fazla derleme çalışmalarına ihtiyaç duyulduğunun bir göstergesidir.

Anahtar kelimeler, araştırmayı yansıtma potansiyeli olan makaleye özgü terimlerdir (Tosun, 2022). Bir çalışmanın anahtar kelimeleri ve özeti çalışmanın içeriği ile ilgili genel bir bilgi sunar. Matematiksel modelleme çalışmalarında kullanılan anahtar sözcükler incelendiğinde "matematiksel modelleme"yi merkeze alan bir harita elde edilmiştir. Bu araştırmanın anahtar sözcükler analizi matematiksel modelleme araştırmalarında "problem çözme" odaklı çalışmalara "problem kurma" çalışmalarından daha çok yer verildiğini göstermektedir. Ayrıca veri setinde yer alan çalışmalar incelendiğinde matematiksel modelleme alanında daha çok öğretmen ve öğretmen adaylarının problem kurma becerileri üzerine çalışma yapıldığı tespit edilmiştir (örn. Paolucci & Wessels, 2017; Villarreal et al., 2018). Matematiksel modelleme öğrencilerin fark edilmeyen yeteneklerini ortaya çıkmasını sağlayan, problem kurmaya yönelik güzel bir a-didaktik yaklaşım örneğidir (English, 2020; Lehrer & English, 2018) ancak öğretmenlerin öğrencilerin problem kurma becerilerinin farkındalıklarına ilişkin yeterince araştırma yapılmamıştır (English, 2020). Bu çalışmadan elde edilen sonuç benzer durumun matematiksel modelleme çalışmaları için de geçerli olduğunu göstermektedir. Ayrıca literatürde öğrencilerin problem kurma becerileri üzerine uzun yıllardır birçok çalışma yapılmasına (English, 2020) rağmen bu araştırmanın sonuçları öğrencilerin matematiksel modelleme problemleri kurma yetkinliklerinin henüz incelenmediğini göstermektedir.

Matematiksel modelleme alanında en etkili 10 yazar Almanya, Türkiye ve Belçika'daki üniversitelerde görev yapmışlardır (ya da hala görev yapmaktadır). Toplam yayın sayısı dikkate alındığında Almanya ve Türkiye ilk üçte (Amerika Birleşik Devletleri ilk sırada) yer alırken; Belçika dokuzuncu sıradadır. Bu sonuç matematiksel modelleme çalışmalarında Almanya ve Türkiye'nin oldukça önemli bir rolü olduğu şeklinde yorumlanabilir. Matematiksel modelleme alanında en etkili 10 yazardan ikisi (G. Kaiser ve L. Verschaffel) aynı zamanda Julies ve arkadaşlarının (2021) çalışmalarında matematik eğitimi araştırmalarında 1980-2020 arasında en etkili 20 yazar arasında yer almaktadır.

Bu çalışmada incelenen 178 yayının referans listelerinde birlikte referans gösterilen yayınların tespiti için yapılan ortak atıf analizi bu ikililerin veri setinde yer almadığını göstermektedir. Bu sonuç şu durumu vurgulamak açısından önemlidir: Bibliyometrik incelemelerde çalışmalar araştırmacılar tarafından belirlenen kriterler doğrultusunda veri setine dahil edilir. Dolayısıyla elde edilen tüm sonuçlar bu kriterler dikkate alınarak değerlendirilmelidir. İlgili alanda en etkili yazarlar, dergiler ya da yayınların kriterler (örn., indeks, yayın yılı, yayın türü) değiştirildiğinde sonuçların değişmesi mümkündür. Bu çalışmada kitap bölümleri araştırmaya dahil edilmemiş ve indeks türü SSCI ve SCI-Expanded ile sınırlandırılmıştır. Ortak atıf analizinde ilk üç sırada yer alan ikili çalışmalardan üçü kitap bölümü, üçü ise belirlenen zaman aralığında (2003-2023) henüz SSCI ya da SCI-Expanded indekslerinde taranmayan bir dergide yayınlanmıştır. Bu sonuç sonraki araştırmalarda kriterlerin daha geniş tutularak veya farklı kriterler belirlenerek matematiksel modelleme çalışmalarının bibliyometrik analizinin yapılabileceği anlamına gelmektedir.

Introduction

Mathematical modeling is defined as the process of mathematising real-life problems and solving them (Blum & Niss, 1991; Lesh & Zawojewski, 2007). In this context, the term 'mathematising" refers to the act of whole solving process rather than the transfer of problems to the language of mathematics. Mathematical modeling problems are regarded as a valuable instrument for the cultivation of 21st-century competencies (Galbraith, 2018). For this reason, in recent years, the mathematical modeling approach has exerted a direct or indirect influence on the curricula at different levels in numerous countries. In some countries, such as Germany and the USA, mathematical modeling is a compulsory part of the curriculum from primary school to high school. In other countries, such as Turkey, China, and South Korea, it is one of the important factors affecting the curriculum (Schukajlow et al., 2018; Borromeo Ferri et al., 2023). In Turkey, for instance, although it is not explicitly included in the curriculum, it has been incorporated into the teacher education program since 2018 (Yükseköğretim Kurulu, 2018a, 2018b). This suggests that mathematical modeling may soon become an indispensable element of the curriculum in these countries as well. Qualified academic studies in the field of mathematical modeling could facilitate this process.

Mathematical modeling problems are characterized by several key features, including their open-ended, real-life basis, thought-provoking nature, interpretive flexibility, and capacity to support the emergence of diverse solutions and models. These attributes have led to the recognition of modeling problems as an effective tool in mathematics education (Maaß, 2007; Borromeo Ferri, 2018; Sahin, 2019). Indeed, these are the characteristics that a good mathematical problem should possess (Maaß, 2007). Consequently, rather than perceiving mathematical modeling as a completely novel approach, the focus should be on how it can be integrated into education as a good mathematical problem. However, the fact that mathematical modeling is used in many fields (e.g., mathematics, engineering, medicine, economics) with different contents and purposes in line with different perspectives also affects the determination of its role in education. In the field of mathematics education, the fact that the definition and purposes of mathematical modeling vary according to the perspectives hinders the formation of a common understanding. It is important to note that what is meant here is not to create a uniform understanding of mathematical modeling. According to different perspectives, the purpose of mathematical modeling and modeling processes may vary. It is therefore important to be aware of these differences. One of the main reasons for the confusion in the literature is that the distinctive features of the perspectives are not understood or ignored. Failure to make this distinction leads to uncertainty about how to integrate mathematical modeling into education. There are studies in which the purposes of the perspectives are elucidated and exemplified, and the similarities and differences between them are revealed (e.g. Sahin et al., 2023; Kaiser & Sriraman, 2006). Sahin et al. (2023) delineate the objectives and structures of mathematical modeling activities from diverse vantages, offering illustrative examples from the literature. An understanding of these perspectives will assist in determining the role and purpose of mathematical modeling in education.

There has been a notable increase in the quantity of mathematical modeling research conducted over the past few decades. It can be observed that the subjects under investigation are focused on mathematical modeling competencies, the teaching of mathematical modeling, and the applications

of mathematical modeling in the classroom. The expansion of academic studies is of great significance in terms of the expansion of the field, which is achieved through the introduction of new fields of study and different theoretical frameworks, as well as the integration of mathematical modeling into curricula, course tools, teacher education programs, and in-service programs. Nevertheless, it is regrettable that the quantitative expansion of mathematical modeling studies does not always result in the desired outcome. A comprehensive literature review is necessary to identify the most qualified studies within this field. Comprehensive and summarising review studies play an important role in this context (e.g., Schukajlow, Kaiser & Stillman, 2018; Cevikbas et al., 2022). A comprehensive and well-structured literature review serves as a foundation for subsequent studies within the relevant field. Conducting a literature review on a research topic is a necessary but challenging and time-consuming process, as it involves identifying the most suitable studies from a large number of available ones. In this context, literature reviews serve to facilitate the work of researchers by providing a framework within the relevant field. Consequently, researchers can streamline their research processes by accessing the most studied topics and the most effective (the most cited or studied by important researchers in the relevant field) publications from a single source. Furthermore, literature reviews provide the opportunity to identify less studied topics within the field and identify gaps in the existing literature. It is of paramount importance to identify research gaps to prevent the same or similar research from being conducted repeatedly (Snyder, 2019). As is the case in many other disciplines, there are reviews of the literature on mathematical modeling studies at different time intervals (e.g., Sokolowski, 2015; Cevikbas et al., 2022). Cevikbas et al. (2022) conducted a comprehensive analysis of 75 studies on modeling competencies published in reputable databases over the past two decades. The investigation also considered how modeling competencies were measured and the applications or suggestions made for the development of competencies, taking into account criteria such as the type of studies, methods, participant level, and activities used. As the researchers noted, although a comprehensive search of as many databases as possible was conducted, it cannot be guaranteed that all relevant studies in this field have been identified. This is one of the inherent limitations of systematic literature reviews. Nevertheless, this study provides a comprehensive overview of how mathematical modeling competencies are addressed and in which areas researchers should expand the field in the context of the studies examined. The field of research on mathematical modeling is characterized by a very large component map. Consequently, it is both feasible and imperative to conduct systematic literature reviews for each component. However, it is also important to consider mathematical modeling from a broader perspective. In light of the aforementioned considerations, the objective of this study is to ascertain the impact levels of qualified mathematical modeling research over the past 20 years. Consequently, researchers will be able to identify the most influential journals, authors, and publications in the field of mathematical modeling collectively. This study may serve as a valuable resource for researchers, educators, and those considering a career in education. Furthermore, a map of high-impact studies will enable researchers to identify areas of deficiency in the field and generate ideas about which issues they can support in the literature. In light of the aforementioned considerations, the research question was formulated as follows: "How have the impact levels of mathematical modeling studies published in the last 20 years within the field of mathematics education within the scope of the Social Sciences Citation Index (SSCI) and

the Sciences Citation Index – Expanded Index?" The research will examine mathematical modeling studies published within the scope of SSCI and SCI-Expanded Index in the field of mathematics education in the last 20 years. The answers to the undermentioned questions will be sought.

1. What is the distribution according to years?
2. What is the distribution according to keywords?
3. What is the distribution according to sources (journals)?
4. What is the distribution according to the authors?
5. What is the distribution according to the number of publications and citations?
6. What is the distribution according to countries?

Methodology

The bibliometric analysis method, initially defined by Pritchard (1969) as a novel systematic review approach, is a technique that permits the examination and analysis of substantial quantities of scientific data (Donthu et al., 2021). This method, which has gained considerable traction in numerous disciplines in recent times, is employed to ascertain the prevailing trends in the literature, thereby elucidating the intellectual structure of the pertinent fields (Verma & Gustafsson, 2020). The objective point of view of bibliometric analysis is based on the quantitative data of titles, keywords, the number of citations, and indexes of publications.

The bibliometric analysis method employs two fundamental techniques: performance analysis and scientific mapping. In the context of performance analysis, the vast majority of quantitative data associated with publications can be utilised as criteria. The principal topics under consideration are publication-related measures, citation-related measures, and measures combining both publication and citation data. In performance analysis, the combination of publications and citations is employed to assess the performance of research components (Donthu et al., 2021). Performance analysis can be considered a tag for researchers, publications, or journals. This imprint allows for the contribution of the relevant research components to the field to be revealed descriptively (Cobo et al., 2011; Donthu et al., 2021). Scientific mapping examines the relationship between research components (Cobo et al., 2011; Donthu et al., 2021). The fundamental principles and explanations of scientific mapping are outlined below (Donthu et al., 2021):

Citation analysis. Analyzing the relationships among publications by identifying the most influential publications in a research field.

Co-citation analysis. Analyzing the relationships among cited publications to understand the development of the foundational themes in a research field.

Bibliographic coupling. Analyzing the relationships among citing publications to understand the periodical or present development of themes in a research field.

Co-word analysis. Exploring the existing or future relationships among topics in a research field by focusing on the written content of the publication itself.

Co-authorship analysis. Examining the social interactions or relationships among authors and their affiliations and equivalent impacts on the development of the research field.

It can be argued that the foundations of mathematical modeling studies were established during the period following Polya's (1944) introduction of a novel approach to problem-solving. In light of its historical development, it is evident that this field has experienced a significant growth spurt since the 2000s. Consequently, it is prudent to examine the publications of the past twenty years. The Web of Science was selected as the data source for this study due to its status as an important scientific database and the availability of bibliometric data in different file formats. In this study, 178 SSCI and SCI-EXPANDED-indexed documents scanned in the Web of Science database between 2003 and 2023 were analyzed. The date of access to the database is 20 March 2024. The studies included in the analysis were selected according to the following criteria:

Table 1. Criteria of document selection

Category	Criteria
Publication years	2003-2023
Document types	Article or Review Articles
WoS Categories	Education Educational Research, Education Scientific Disciplines or Social Sciences Interdisciplinary
Citation Topic Meso	Education & Educational Research or Remote Research & Education
WoS Index	Social Sciences Citation Index (SSCI) or Science Citation Index Expanded (SCI-EXPANDED)
Languages	English
Research areas	Education Educational Research

The topic was determined as "mathematical model*" or "modeling" or "modelling" and the keywords "mathematical model*" (298 publications), "mathematical model* competenc*" (13 publications), "model-eliciting" (19 publications), "real-world problems" (15 publications), "mathematics education" (122 publications), which are frequently used in mathematical modeling studies, were searched separately, maintaining the topic criteria constant. A total of 386 publications remained after duplication.

Mathematical modeling is a concept that has different characteristics in many fields. In this study, it is specifically examined in the context of mathematics education. Although the database was searched with customized keywords, the researcher conducted a manual review of all the studies and found that 178 publications out of 386 publications met the specified criteria. A general overview of the included studies is presented in Table 2.

Table 2. Overview of the included studies

Category	Result
Total included documents	178
Publication years	2003-2023
Authors	334
Countries	38
Keywords	532
Sources (journals)	38

The data were analysed using the VOSviewer software. VOSviewer produces visualization maps based on size, distance, and colors. These characteristics give information to the interpretation of data. A node represents a specific element, such as author, keyword, or source of publications. The size of the node indicates the amount of frequency. As the number of occurrences increases, so does the size of the node. The link between the nodes means they are connected, while the distance between nodes reflects the density of their relationship. Shorter lines denote stronger connections, whereas longer lines signify more distant relationships. Each color represents a cluster (Van Eck & Waltman, 2010).

Results

In this study, a bibliometric analysis of mathematical modeling studies with its use in the field of mathematics education between 2003 and 2023 was conducted. Within the preceding two decades, 38 journals published studies on mathematical modeling. Figure 1 shows the top ten journals that have published articles on mathematical modeling, along with the corresponding year of publication.

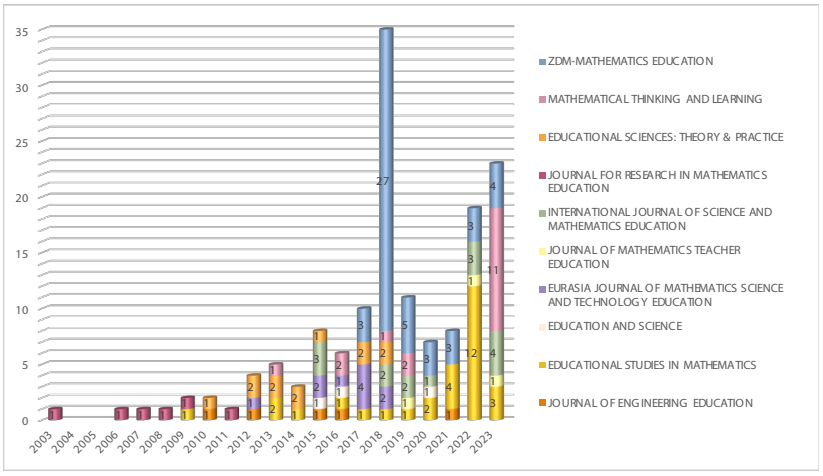

Figure 1. Distribution of studies by journal and year

It is observed that the highest number of studies on mathematical modeling (35 publications) were published in 2018. The most prolific journals to publish the largest number of studies were

ZDM-Mathematics Education with 48 publications and Educational Studies in Mathematics with 29 publications. Although the number of studies in the field of mathematical modeling has not increased linearly, there has been a noticeable intensification since 2015. The maximum number of studies was reached in 2018, followed by a decrease in the following three years (2019-2021). However, there has been a recent increase in the last two years (2022-2023). Considering the years with the highest number of publications, it is possible to talk about the major impact of a certain journal each year. For instance, in 2018, ZDM-Mathematics Education made a significant contribution to mathematical modeling research with 27 publications, and in 2022, Educational Studies in Mathematics made a significant contribution to the field with 12 publications, while Mathematics Thinking and Learning had the same effect in 2023 with 11 publications. It is well documented that these journals published special issues on mathematical modeling in the relevant years.

Keywords and co-word analysis

To understand the thematic content of the studies examined, frequently used keywords were determined and co-word analysis was performed. A total of 532 keywords were used in 178 studies which means an average of 2.99 keywords for each study. The fact that keywords were not used in each study reduced the average. According to the keyword analysis, "mathematical modeling (n=51)", "mathematical modelling (n=32)", "problem-solving (n=13)" and "mathematics education (n=10)" were the most frequently used keywords. Figure 2 shows the co-word analysis of the keywords (34 keywords) used at least 3 times in the same studies. Figure 2 shows that the word "mathematical modeling," which is the most frequently used one is mostly used together with the words "model-eliciting activities", "rate of change", and "quantitative reasoning". Similarly, one of the most frequently used keywords is "mathematical modelling" which is mostly used together with the words "inquiry-based learning", "numeracy", and "stem education". Figure 2 also shows the co-word analysis of keywords composed of 8 clusters.

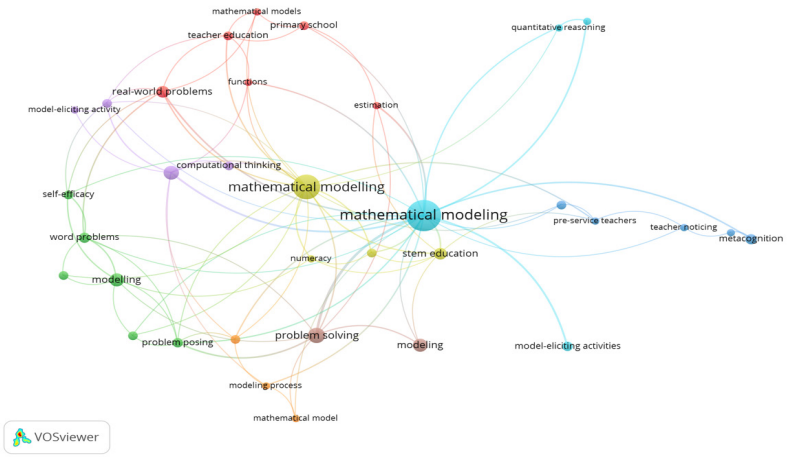

Figure 2. Most commonly used co-words

In studies on mathematical modeling in mathematics education, mathematical modeling is used phonetically in different ways. The biggest discrepancy is between 'mathematical modelling' and 'mathematical modeling'. In addition, depending on the modeling perspective, the name of the activities may differ (e.g. model-eliciting activities). Sometimes only the term "modelling" or "modeling" is used. All "modelling" words in the data file were updated to "modeling" and data re-analysed (Figure 3).

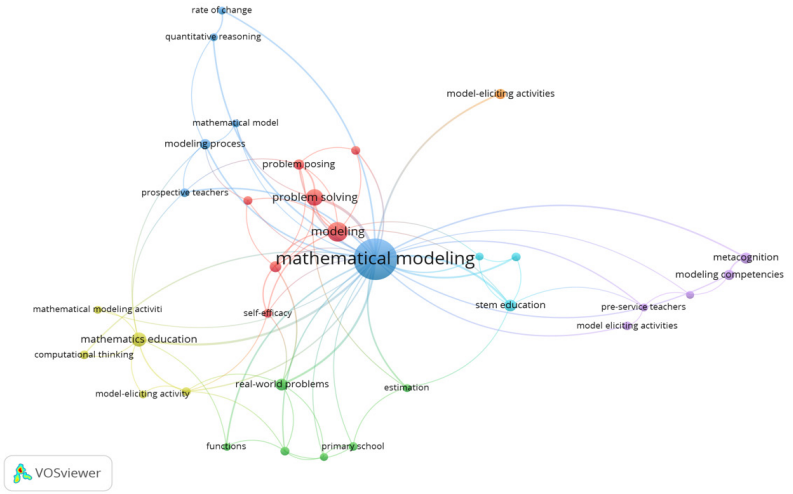

Figure 3. Most commonly used co-words (revised)

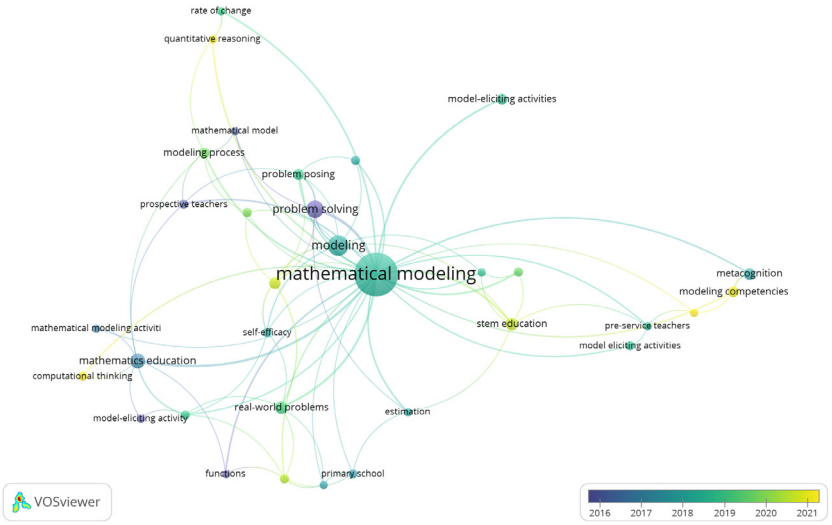

Figure 4. Distribution of the most used co-words by year

According to the new keyword analysis, "mathematical modeling" is the most frequently used keyword with 83 citations, followed by "modeling" with 18 citations, "problem-solving" with 13 citations, and "mathematics education" with 10 citations. The keyword analysis of this study indicates that studies focusing on problem-solving are more prevalent than those focusing on problem-posing in mathematical modeling research.

The distribution of keywords by year is shown in Figure 4. The keywords used in the studies in the dataset change from purple to yellow from old to new. The keyword map shows that prominent keywords in the studies published before 2016 are "professional development" (4 citations), "prospective teachers" (4 citations) and "problem-solving" (13 citations), whereas after 2020 prominent keywords are "STEM education" (7 citations), "teacher noticing" (3 citations), "modeling competenc*" (9 citations), "computational thinking" (4 citations) and "quantitative reasoning" (3 citations).

Most Productive Journals

A total of 38 journals have contributed to the publication of 178 articles on mathematical modeling in mathematics education. Table 3 shows the top 10 productive journals based on total publication (TP) and total citation (TC).

Table 3. Top 10 most productive journals in mathematical modeling

Journal	TP (%)	TC
ZDM-Mathematics Education	48 (27 %)	733
Educational Studies in Mathematics	29 (16.3 %)	394
Mathematical Thinking and Learning	17 (9.5 %)	112
International Journal of Science and Mathematics Education	15 (8.4 %)	77
Educational Sciences-Theory & Practice	12 (6.7 %)	53
Eurasia Journal of Mathematics Science and Technology Education	10 (5.6 %)	73
Journal for Research in Mathematics Education	6 (3.4 %)	299
Journal of Engineering Education	5 (2.8)	77
Journal of Mathematics Teacher Education	3 (1.7 %)	8
Education and Science	3 (1.7 %)	11

Table 3 shows that ZDM-Mathematics Education journal is the most prolific journal, contributing 48 publications, which accounts for more than a quarter (27 %) of the total articles found on mathematical modeling. It is followed by Educational Studies in Mathematics (29 publications, 16.3 %), Mathematical Thinking and Learning (17 publications, 9.5 %), and International Journal of Science and Mathematics Education (15 publications, 8.4 %). Based on the citations, ZDM-Mathematics Education (733 citations) and Educational Studies in Mathematics (394 citations) are the most cited sources. Following them is the Journal for Research in Mathematics, with 299 citations (6 publications, 3.4 %).

Most Prolific Authors

Table 4 presents the top ten authors out of 334 researchers ranked by the number of articles and citations. The ranking of authors' effectiveness varies based on the number of publications and citations.

The study considers the number of publications as the factor in determining the prolific of authors. The author with the highest number of published articles on mathematical modeling and with the highest number of citations is Stanislaw Schukajlow from the University of Munster in Germany (13 publications, 315 citations). Gabriele Kaiser and Ayhan Kursat Erbas follow him with 8 articles each. Additionally, the impact factor of an author was calculated by dividing their total citations by their total publications. When the impact values of the authors are analyzed, Lieven Verschaffel and Wim Van Dooren share the first place (36.5). The studies of these researchers are common and emphasize that the mathematical modeling process is cyclical. In particular, one of the most important features that distinguish mathematical modeling from traditional problems is the problem-solving process. Therefore, it is usual that many researchers working in this field frequently benefit from these studies.

Table 4. Most prolific authors

Author	TP	TC	TC/TP	Affiliation
Schukajlow, Stanislaw	13	315	24.23	University of Munster
Kaiser, Gabriele	8	133	16.62	University of Hamburg
Erbas, Ayhan Kursat	8	67	8.37	Middle East Technical University
Verschaffel, Lieven	6	219	36.50	KU Leuven
Van Dooren, Wim	6	219	36.50	KU Leuven
Krawitz, Janina	5	57	11.40	Universität Paderborn
Kertil, Mahmut	5	45	9	Marmara University
Cetinkaya, Bulent	5	45	9	Middle East Technical University
Vorhoelter, Katrin	5	50	10	University of Hamburg
Maass, Katja	4	127	31.75	University of Education Freiburg

The relationships of the most influential authors with other researchers are determined with co-author analysis (Figure 5).

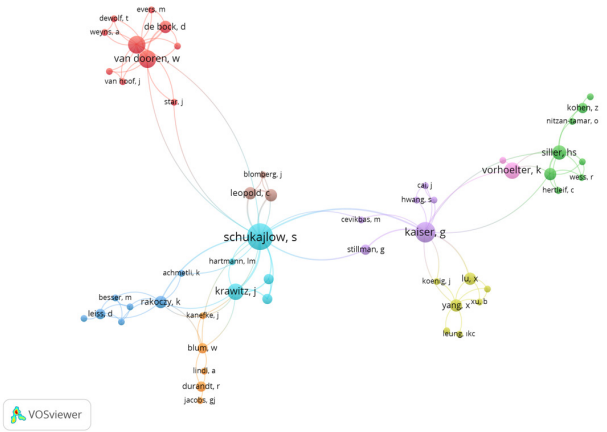

Figure 4. Co-author networks

Figure 5 presents the collaborative networking between authors. Clusters represent groups of authors who frequently collaborate in publishing articles. For instance, G. Kaiser is at the center of the purple cluster and has collaborated with 12 authors, 5 of whom are in the same cluster. The presence of researchers belonging to multiple clusters indicates strong collaboration with authors both within and outside of their respective clusters. According to this analysis, K. Vorhoelter played an important role in promoting mathematical modeling-related research efforts, where the author is involved in three clusters (pink, green, and purple). Additionally, it should be noted that varying sizes of nodes next to each author's name indicate the frequency of collaborations they have participated in.

Most Prolific Documents

Table 5 shows the top ten most-cited articles respectively, which were published by several journals. This more or less indicates that two journals (ZDM-Mathematics Education and Journal for Research in Mathematics Education) have taken the studies of mathematical modeling as important research foci. The table shows that "A modeling perspective on students' mathematical reasoning about data" by Doerr and English (2003) is reported to have the highest number of cited references, leading to 113 citations. The second-highest cited reference is Verschaffel et al.'s (2020) study, "Word problems in mathematics education: a survey" with 95 citations in WoS, followed by Maass et al. (2019), the study titled "The Role of Mathematics in interdisciplinary STEM education" with 85 citations.

Table 5. Most cited documents

Authors	Title	Journal	Citations (WoS)
Doerr and English (2003)	A modeling perspective on students' mathematical reasoning about data	Journal for Research in Mathematics Education	113
Verschaffel et al. (2020)	Word problems in mathematics education: a survey	ZDM-Mathematics Education	95
Maass et al. (2019)	The Role of Mathematics in interdisciplinary STEM education	ZDM-Mathematics Education	85
Van Dooren et al. (2008)	The linear imperative: An inventory and conceptual analysis of students' overuse of linearity	Journal for Research in Mathematics Education	65
Schukajlow et al. (2018)	Empirical research on teaching and learning of mathematical modelling: a survey on the current state-of-the-art	ZDM-Mathematics Education	53
Singer and Voica (2013)	A problem-solving conceptual framework and its implications in designing problem-posing tasks	Educational Studies in Mathematics	49
Van Dooren et al. (2009)	Students' Overuse of Proportionality on Missing-Value Problems: How Numbers May Change Solutions	Journal for Research in Mathematics Education	38

Gainsburg (2007)	The mathematical disposition of structural engineers	Journal for Research in Mathematics Education	38
Rellensmann et al. (2017)	Make a drawing. Effects of strategic knowledge, drawing accuracy, and type of drawing on students' mathematical modelling performance	Educational Studies in Mathematics	37
Yerushalmy (2006)	Slower algebra students meet faster tools: Solving algebra word problems with graphing software	Journal for Research in Mathematics Education	33

Figure 5 displays the bibliometric map of 79 publications that have received at least 5 citations and are linked to other publications.

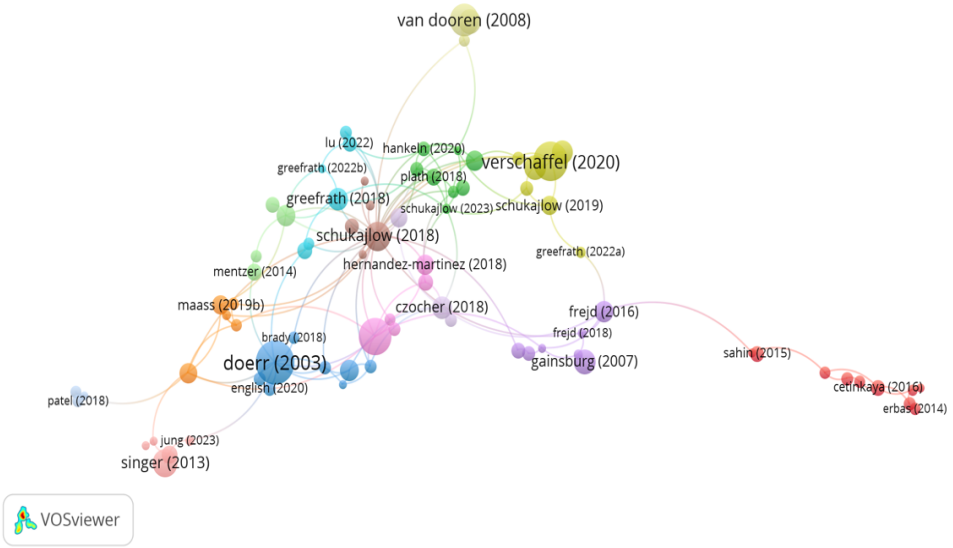

Figure 6. Network of cited documents

Figure 6 illustrates that there are 14 clusters comprising a total of 79 publications that meet the specified conditions. When hovering over each node in the Vosviewer program, the publications to which it is linked are highlighted and other publications remain in the background. By following the linking paths, it is possible to determine which studies are connected (newer studies referencing older studies).

Co-citation analysis establishes a link between two research units if they both appear in another bibliography. A visualization of the co-citation network shown in Figure 7 reveals the most co-cited documents.

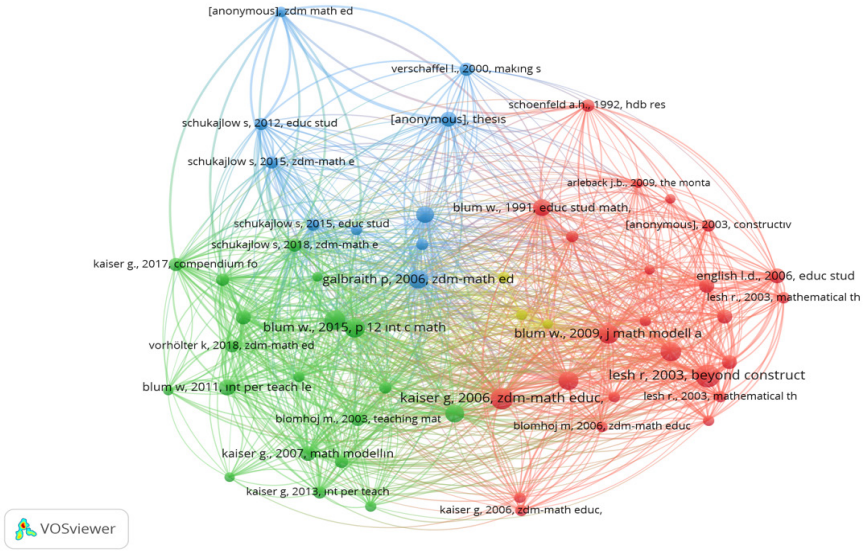

Figure 7. Co-citations of documents

For the 178 publications included in the co-citation analysis, the minimum number of co-citations received by a publication was set at 10. Out of 6260 cited references, 56 references met this threshold to be included in the co-citation network. As can be seen in Figure 7, the references that were co-cited by the same publications were grouped into 4 clusters. Documents that receive more co-citations tend to be closer together in the visualization. Three of the clusters are relatively larger than the yellow cluster in the center of the visualization.

In the documents analysed in this study, the most cited study pairs and the common aspects of the studies are shown in Table 6 together with the link strength.

Table 6. Most strength co-cited documents

Documents	Co-content	Link Strenght
Principles for Developing Thought-Revealing Activities for Students and Teachers (Lesh et al., 2000)	Lesh et al. (2000) describe six principles of model-eliciting activities. In the second study, three model-eliciting activities are presented in which these six principles are put into practice. Both studies are based on the "Model and Modeling Perspective" which is one of the modeling approaches.	21
Foundations of a model and modeling perspective on mathematics teaching, learning, and problem-solving (Lesh & Doerr, 2003).		

A framework for identifying student blockages during transitions in the modelling process (Galbraith & Stillman, 2006)	The first research aims to create, test, and refine a framework that can identify potential obstacles for students during transitions between stages in the modeling process.	20
How do students and teachers deal with modelling problems (Blum & Leiss, 2007)		
A global survey of international perspectives on modelling in mathematics education (Kaiser & Sriraman, 2006)	Kaiser and Sriraman (2006) analyse the debate on modeling from different perspectives and highlighted the similarities and differences between these perspectives. Maass (2006) defined modeling competencies through an empirical study. Although he did not directly emphasize mathematical modeling perspectives like Kaiser and Sriraman (2006), he discussed the theoretical structure of the modeling process according to different approaches.	19
What are modelling competencies? (Maass, 2006)		

Three of the studies listed in Table 6 are book chapters (Lesh et al., 2000; Lesh & Doerr, 2003; Blum & Leiss, 2007). The remaining three studies are included in a special issue of ZDM – The International Journal on Mathematics Education, which has been scanned in Web of Science but not yet in SSCI or SCI-Expanded as of the date of publication. Therefore, the data set for this study does not include any of the most co-cited publications.

Most Prolific Countries

Table 7 presents the distribution of publications related to mathematical modeling in mathematics education across 38 countries. The results indicate that the USA has the highest number of articles on mathematical modeling, with 40 documents and 611 citations. Germany is the second most productive country with 39 TPC and 674 TCC, followed by Turkey (34 TPC, 147 TCC), and Australia (19 TPC, 409 TCC).

Table 7. Most prolific countries

Country	**Total Publications of a Country (TPC)**	**Total Citations of a Country (TCC)**
USA	40	611
Germany	39	674
Turkey	34	147
Australia	19	409
Spain	10	163
China	9	65
Israel	8	75
Sweden	7	98
Belgium	6	219
South Korea	6	36

Referring to Table 7, the total publications of the top-10 countries are 178. It does not necessarily mean that 28 countries that have not been mentioned in Table 7 have no publications. VOSviewer shows that there are 232 publications in total according to the countries. This indicates that 54 publications are joint publications of more than one country. This analysis demonstrates that some studies (max 54) are the product of collaboration between at least two authors, from different countries. For instance, in the study 'The Role of Mathematics in Interdisciplinary STEM Education' published by Maass, Geiger, Ariza, and Goos (2019), four researchers from different countries, and the same study was counted separately for each country during the analysis process. Figure 8 illustrates the bibliometric map of international collaboration between the selected 25 countries (13 countries have no collaboration), clustered per country.

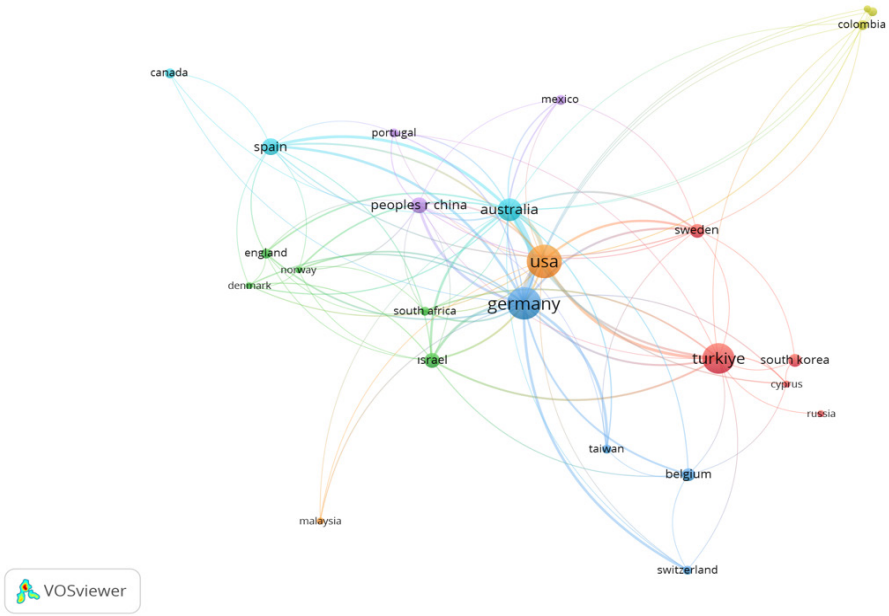

Figure 8. International collaboration between countries

Bibliographic Coupling

For the 334 authors included in the bibliographic coupling analysis, the minimum number of documents of an author was set to 5. Out of 334 authors, 9 researchers met this threshold to have a co-referenced network. Figure 9 shows that the authors who use co-reference form 3 clusters. S. Schukajlow, who has the strongest co-reference network with other authors, is in the red cluster.

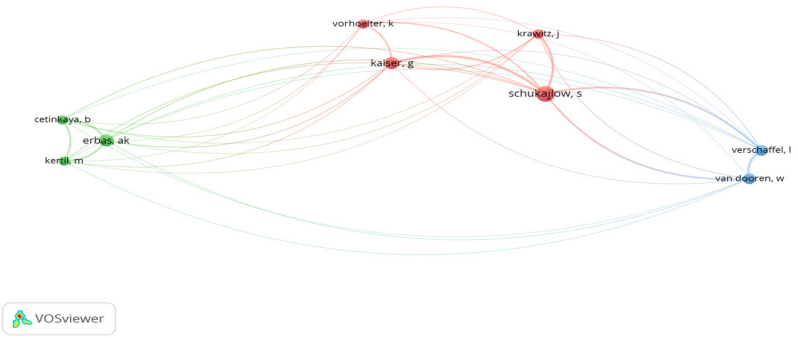

Figure 9. Bibliographic coupling of authors

B. Cetinkaya, A.K. Erbas, and M. Kertil have collaborated on four occasions. In addition, Cetinkaya and Erbas were involved in one study together. A total of three publications were identified in which these three researchers did not collaborate with the other two. The studies conducted by all three of them together or independently of each other are mainly focused on pre-service teachers' mathematical modeling skills. It is therefore unsurprising that the number of common references is high. A similar situation is observed for other researchers with high bibliographic matching levels.

Discussion

This study tried to determine a bibliometric view of the scientific articles on mathematical modeling between 2003-2023. Mathematical modeling is a concept that varies in content and application in many fields. This study examined review and research articles published in SSCI and SCI-expanded indexed journals in the Web of Science Core Collection database in the field of mathematics education. To create the data set, various filters (keyword, field of study, publication language, etc.) as well as a manual review were performed and 178 documents that met the conditions were reached.

The results indicate a growing trend in mathematical modeling studies between 2003 and 2023. The fact that journals include special issues on mathematical modeling is indicative of the importance accorded to this field. ZDM-Mathematics Education, which was the most prolific journal, contributed the greatest number of publications to the literature (48 publications, 733 citations). This journal also boasts the highest number of publications in a single year, with 27 in 2018, including a special issue. The second most prolific journal in terms of both publications and citations is Educational Studies in Mathematics (29 publications, 394 citations), followed by Mathematical Thinking and Learning (17 publications, 112 citations).

Keywords are specific terms that have the potential to reflect the research (Tosun, 2024). The keywords and abstract of a study provide the reader with a general overview of the content of the study. Upon examination of the keywords utilized in mathematical modeling studies, a map centered on the term "mathematical modeling" was generated. The term "mathematical modeling" is subject to variation in phonetic transcription, with alternative forms including "mathematical modelling" and "mathematical modeling". Furthermore, the term is open to interpretation in terms of alternative concepts, with the use of "modelling/modeling" or "mathematical modeling activity" being permitted instead of the original term. The keywords map indicates that a wide range of alternatives should be considered when searching in this field. Nevertheless, the keywords "mathematics education" (10 citations) and "modelling/modeling" (18 citations) are inclusive concepts. Consequently, they fail to provide sufficient commentary on the content of the studies. Although they are used less frequently, the keywords used other than these provide information about the content of the study. The keyword analysis of this study indicates that studies focusing on problem-solving are more prevalent than those focusing on problem-posing in mathematical modeling research. Furthermore, an examination of the studies in the data set revealed that a greater number of studies were conducted on the problem-posing skills of teachers and pre-service teachers in mathematical modeling (e.g. Paolucci & Wessels, 2017; Villarreal et al., 2018). Mathematical modeling represents a case in point of an a-didactic approach to problem posing that enables students to reveal their hitherto unrecognized abilities (English, 2020; Lehrer & English, 2018). However, there has been a paucity of research on teachers' awareness of students' problem-posing skills (English, 2020). The findings of this study indicate that the observed phenomenon is also applicable to mathematical modeling studies. Furthermore, although numerous studies have been conducted on students' problem-posing skills in the literature for several years (English, 2020), the results of this study demonstrate that students' competencies in posing mathematical modeling problems have not yet been examined. In addition, when analyzing the distribution of keywords by year, some keywords come to the fore. For example, in the studies conducted in 2013-2016, studies dealing with teacher competencies with keywords such as professional development, teacher education, and prospective teachers come to the fore. In more recent years, on the other hand, studies with keywords such as modeling competencies, teacher noticing, computational thinking, and quantitative reasoning, which mostly examine students' mathematical modeling processes and cognitive skills, stand out. These findings suggest that keywords play an effective role in determining the trend of mathematical modeling studies.

The top 10 most prolific authors in the field of mathematical modeling were (or still are) from universities in Germany, Turkey, and Belgium. When considering the total number of publications, Germany and Turkey are again in the top three, with the United States topping the list. Belgium is in ninth place. This result can be interpreted as indicating that Germany and Turkey play a pivotal role in mathematical modeling studies. S. Schukajlow, who is the most prolific author, and the researchers with whom he has been in contact are particularly interested in mathematical modeling competencies. Researchers who have conducted systematic literature reviews in this field (e.g., Schukajlow et al., 2018; Cevikbas et al., 2022) have also conducted experimental studies investigating the factors that influence mathematical modeling competencies. For example, the relationship between reading

comprehension and modeling competence (Krawitz et al., 2022), the relationship between problem-posing skills and modeling competence (Hartmann et al., 2021), and the relationship between drawing strategies and mathematical modeling competence (Rellensmann et al., 2023; Rellensmann et al., 2017, 2020) are prominent studies. Among these studies, 'Empirical research on teaching and learning of mathematical modelling: a survey on the current state-of-the-art' (Schukajlow et al., 2018) ranks fifth in the list of most cited publications with 53 citations; 'Make a drawing. Effects of strategic knowledge, drawing accuracy, and type of drawing on students' mathematical modelling performance' (Rellensmann et al., 2017) ranks ninth with 37 citations (see Table 5). S. Schukajlow is then followed by G. Kaiser, who has published eight articles and received 133 citations. Two of the ten most influential authors in the field of mathematical modeling (G. Kaiser and L. Verschaffel) are among the twenty most prolific authors in mathematics education research between 1980 and 2020, as reported by Julie et al. The average number of citations per publication (TC/TP) of the authors is also considered. This reveals that L. Verschaffel and W. Van Dooren rank first with an impact value of 36.5 (six publications, 219 citations) (see Table 4). The studies of these two authors that were analyzed within the scope of this study were all conducted by the same researchers. The fact that they did not limit their studies to mathematical modeling and that they theoretically addressed the transition process from problem-solving to mathematical modeling from many aspects (such as problem types, problem-solving process, and cognitive thinking levels) constitutes an important basis for experimental studies (e.g., Verschaffel et al., 2020; Degrande et al., 2018). These reasons have resulted in them being the authors with the second-highest number of citations in the most influential authors ranking. Indeed, three of their works are among the top 10 most influential publications, as evidenced by the following rankings: Verschaffel et al. (2020), ranked second with 95 citations; Van Dooren et al. (2008), ranked fourth with 65 citations; and Van Dooren et al. (2009), ranked seventh with 38 citations.

As is the case in other disciplines, literature reviews, in particular systematic reviews and meta-analyses, are of great interest in the field of mathematics education (Cevikbas et al., 2024; Kaiser & Schukajlow, 2024). This study identified only one of the most prolific studies in the field of mathematical modeling as a literature review. The detected study was conducted by Van Dooren and his colleagues in 2008. This result indicates a need for further review studies on mathematical modeling in classified journals.

In this study, a search was conducted to identify the publications cited together in the reference lists of 178 publications analyzed in this study. The co-citation analysis revealed that these pairs were not included in the dataset. This result is important to emphasize the following situation: in bibliometric analyses, studies are included in the data set according to the criteria determined by the researchers. Therefore, all results obtained should be evaluated by considering these criteria. The most prolific authors, journals, or publications in the relevant field may change when the criteria (e.g. index, publication year, publication type) are changed. In this study, book chapters were not included and the WoS index type was limited to SSCI and SCI-Expanded. In the co-citation analysis, three of the top three pairs of studies were book chapters and three were published in a journal that was not yet indexed in SSCI or SCI-Expanded indexes during the specified period (2003-2023). This

indicates that future bibliometric analyses of mathematical modeling studies may be conducted by broadening the criteria or by determining different criteria.

Limitations and Conclusion

In spite of its contributions, this study has some limitations. Firstly, the database selected, WoS, is one of the most important bibliographic databases in the world, but this study is limited to articles published in journals indexed in SSCI and SCI-Expanded. Furthermore, the study selected articles and review articles as the document type. A multi-source search among different databases and a wider range of mathematical modeling-related articles, either written in English or otherwise, will make the research more convincing. It is important to note that as mathematical modeling has different definitions and functions in many scientific fields, it was not possible to prevent studies from different fields from being included in the dataset, despite the tailored criteria. For this reason, the author also conducted a manual review of the dataset to identify studies in the field of mathematics education. Despite the care taken in this process, small variations in the number of publications are possible.

In conclusion, I recommend some of the prominent suggestions based on the results of the research as follows:

- The use of either of the terms "modelling" and "modeling" (preferably "modeling") in mathematical modeling studies, which have the same conceptual meaning, may facilitate literature reviews.
- Mathematical modeling problem-posing studies can be focused more on students' problem-posing skills and teachers' awareness of students' problem-posing skills.
- A systematic review, meta-analysis, or bibliometric analysis of the literature focusing on mathematical modeling and specific aspects of modeling (e.g. modeling skills, the role of the teacher in teaching modeling, and the role and importance of mathematical modeling in other disciplines) is required.

Conflict of interest statement

The author has no conflicts of interest to declare. There are no financial interests to declare. I certify that this is an original work and that it is not under consideration for publication elsewhere.

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** Note, the asterisk indicates a study used in the bibliometric-analysis.*

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