Applications of Augmented Reality in Mathematics Learning: A Bibliometric and Content Analysis

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Abstract. This study aims to comprehensively investigate the current application of augmented reality (AR) in mathematics education through meticulous bibliometric and content analysis of existing academic literature. The primary objectives involve providing an overview of the current landscape and categorizing literature related to AR's role in teaching and learning mathematics. To achieve this, three main research questions are addressed. The first examines prevalent research themes in augmented reality in mathematics learning, shedding light on core focus areas. The second identifies and analyzes emerging research topics, reflecting the evolving nature of AR in mathematics education. The third explores potential future directions, providing insights into unexplored avenues. The study contributes to understanding how AR is utilized in mathematics education, aiding educators, researchers, and policymakers in recognizing key interests and potential areas for exploration. Findings reveal evolving research topics, including geometry, problem-solving skills, apps, and interventions associated with AR. Emerging areas, such as effective approaches and suitable mediums for integrating AR to enhance mathematical literacy skills, are highlighted. The study suggests the dynamic nature of the field, emphasizing the need for continued development in geometry and exploration of affective approaches and tailored AR-based teaching for enhanced mathematical literacy skills.

Keywords: Augmented Reality, Mathematics Learning, Bibliometric, Content Analysis.

1 Introduction

Augmented Reality (AR) is an innovative technology that adds computer-generated information, such as images, videos, 3D models, or data, to the real world[1]. This digital content is viewed through devices like smartphones, tablets, smart glasses, or heads-up displays, and it seamlessly blends with the user's physical surroundings.

AR boosts the user's perception of reality by adding digital elements that can interact with the real world or provide additional context and information[2]. Unlike virtual reality (VR), which immerses users in a completely computer-generated environment, AR merges the virtual and physical worlds.

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AR technology relies on various sensors, cameras, and computer vision algorithms to track the user's environment and position digital objects in the right location and perspective. AR applications are diverse and can be used for gaming, education, navigation, training, data visualization, and many other fields.

AR in education and mathematics learning and teaching

Augmented reality (AR) can be used to improve mathematics learning and teaching in various ways. Firstly, AR can provide new insights and enhance spatial thinking skills in geometry by creating interactive and immersive learning experiences [3]. Secondly, the application of 3D Math AR learning as AR-based mathematics media has been found to be effective in improving learning outcomes and student engagement [4]. Thirdly, AR can increase student motivation and engagement in service mathematics courses, such as calculus for engineering, by providing more engaging learning experiences [5]. Additionally, the integration of AR with intelligent tutoring systems has been shown to be effective in supporting geometry learning and improving learning gains and motivation [6]. Finally, the development of AR-based learning media for geometric materials in elementary schools has been found to be feasible and suitable for enhancing mathematics learning [7].

AR can be used to create engaging and interactive learning experiences for students by leveraging its immersive and interactive features. By overlaying digital content on top of the physical view, AR provides a platform for students to interact with real and virtual elements, enhancing their educational experience [8]. Overall, AR offers the potential to revolutionize education by bridging the gap between traditional teaching methods and the need for more engaging and interactive learning experiences.

As the scholarly investigation of augmented reality in the context of mathematics education continues to expand in terms of both quantity and diversity, there is a crucial need to comprehensively assess the current state of research in this field and identify potential areas for future research. To fulfill this requirement, a quantitative methodology, specifically bibliometric analysis, has been recognized as a suitable approach [9, 10]. However, despite its significance and usefulness, the utilization of bibliometric analysis to study augmented reality in the context of mathematics learning has remained relatively limited, thereby necessitating a more focused examination in this domain.

The main goal of this study is to present a bibliometric analysis of the use of augmented reality in mathematics teaching and learning. To achieve this, we examine, evaluate, and categorize the existing literature on teaching and learning mathematics using AR. We aim to gain insights into the current research themes, emerging research topics, and future research directions in augmented reality as it relates to mathematics learning and teaching. We have formulated the following research questions to address these objectives:

RQ1: What are the current research themes and topics in augmented reality for mathematics learning?

RQ2: What emerging research topics are found in augmented reality for mathematics learning?

RQ3: What is the future research agenda in augmented reality for mathematics learning?

Through investigating these research questions, our study aims to provide a clear and comprehensive representation of the current state and development of AR research in the context of mathematics learning and teaching. Additionally, by combining bibliometric analysis with in-depth content analysis, we aim to identify potential directions for future research and offer valuable insights for researchers and practitioners in AR for mathematics learning.

2 Method

This study employed bibliometric and content analysis which is adapted from Wijaya et al. [11]. Generally, we carried out four-step approaches, first we specified the search database and keywords. Secondly, we carried out an initial examination of the data, subsequently implementing a screening process employing the revised PRISMA protocol to assess the significance [12]. Thirdly, we scrutinized bibliometric networks, encompassing co-occurrence and thematic mapping. Lastly, we executed a comprehensive analysis of the content through a thorough review of the full-text. To perform the analysis, we used Picoportal for screening and VOSviewer for network visualizations.

Bibliometric analysis involves the quantitative analysis of publications, often using methods such as citation analysis, co-citation analysis, and co-authorship analysis. In this study, the authors employed bibliometric analysis by examining bibliometric networks, including co-occurrence and thematic mapping. This type of analysis helps in understanding the patterns and relationships among different publications, authors, and keywords related to the research topic.

Content analysis method involves the qualitative analysis of the content of documents. In this case, the authors conducted a comprehensive analysis of the content through a thorough review of the full-text. Content analysis helps in extracting meaningful insights from the textual data, allowing researchers to identify themes, patterns, and relevant information related to the research topic.

The combination of bibliometric and content analysis provides a comprehensive approach to studying and understanding the research theme and topic of AR in mathematics learning. The bibliometric analysis offers a quantitative perspective by analyzing patterns in the literature, while the content analysis adds a qualitative dimension by delving into the details of the full-text documents. This integrated approach allows us to gain a deeper and more holistic understanding of the subject.

2.1 Database Selection Bibliography Data Collection

We search and collect the literature from three databases: Scopus via publish or perish, ScienceDirect, and Eric Database. The selection of the database was based on its popularity and accessibility. Several steps were taken in collecting data as shown in Fig. 1, beginning with determining the topic and keywords or identification to the record included in the bibliometric analysis.

As illustrated in Figure 1, the data collection procedures undertaken in this study adhere to and are adapted from the PRISMA flow diagram[12]. The data utilized is obtained from the designated database mentioned above, which was acquired on November 2, 2023. The search terms employed pertain to augmented reality and the learning, teaching, or education of mathematics. This search is based on the inclusion of both search terms in the title, keywords, and abstract with publication type journal article. In terms of publication timeframe, this study is restricted to the period between 2014 to 2023. Regarding language, the pulled data is limited to papers written in English. Lastly, a total of n=610 bibliographic data was successfully retrieved, out of which n=56 was deemed suitable after screening using Picoportal. Subsequently, the selected data was processed utilizing VOSviewer [13], a software tool that can be downloaded and utilized at no cost and is effective in conducting bibliometric analysis [14].

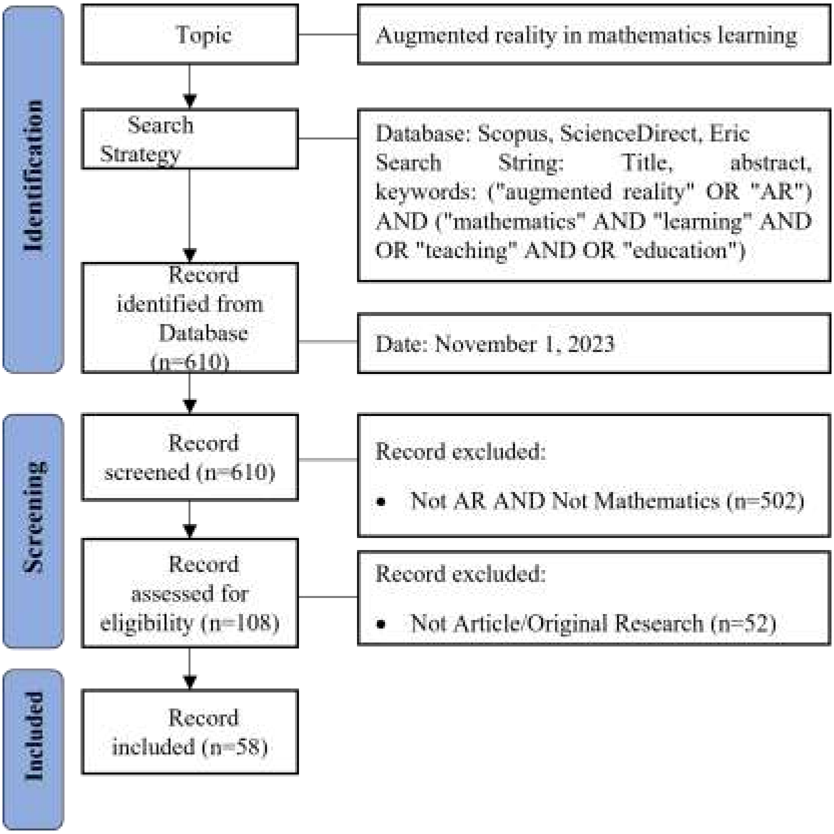

Fig. 1. Search strategy adapted from the PRISMA flow diagram [12]

Bibliometric analysis frequently confronts vast quantities of data, often comprising numerous papers within a specific research domain [15]. In such instances, the application of bibliometric analysis becomes pertinent and defensible due to the magnitude and intricacy of the dataset. Importantly, bibliometric analysis commonly omits the steps of study selection and quality evaluation, which are typically observed in systematic reviews. Instead, the emphasis lies primarily on the selection of appropriate databases, the development of an effective search strategy, and the implementation of relevant filters tailored to the research objectives [15, 16]. By adhering to these guidelines, bibliometric analysis offers valuable insights into research patterns, collaborations, and the impact of publications within a specific field, rendering it a potent and perceptive tool in scholarly research.

2.2 Bibliometric and Content Analysis

Bibliometric analysis was conducted to map and find a theme for the future [9, 17]. Content analysis is carried out to extract as the continuation of the cluster analysis after bibliometric analysis. Based on Fig. 2 three distinct categories of examination are performed to provide a comprehensive response to the RQs. By executing these meticulously planned analyses, a thorough understanding of the respective research inquiries can be attained. Through this meticulous approach, a comprehensive response is formulated, consequently, the research questions can be effectively addressed, leading to a more profound comprehension and exploration of the subject matter at hand. The Descriptive analysis is descriptive-quantitative results of the bibliography data, co-occurrence, and thematic map, and full-text review is a technique for content analysis [11, 18, 19].

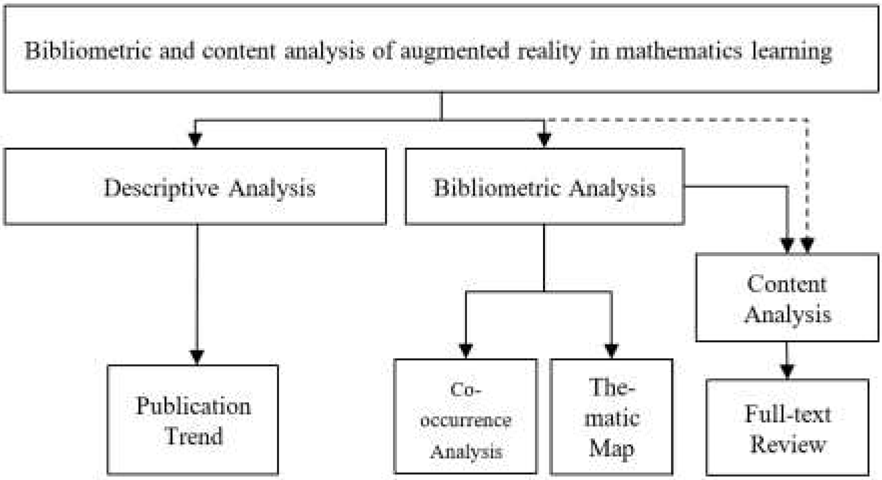

Fig. 2. Research structure to answer RQs adopted from [10]

In the context of content analysis, Figure 2 assumes a vital and indispensable role as a crucial point of reference for the purpose of selecting pertinent papers, a task that is skillfully guided by the mapping derived from the analysis of co-occurrence. This mapping, which is derived from rigorous analysis, offers a highly structured framework that greatly facilitates the identification and retrieval of full-text papers from each cluster, thereby enabling a comprehensive and thorough investigation into the third research question, which specifically concerns the future direction of research in the field of learning style detection. The process of selecting papers is carefully and thoughtfully guided by the identification of trending and influential topics, taking into consideration key factors such as occurrence, and average publication year, as clearly illustrated in the visual output generated by the VOSviewer tool. A thorough and in-depth account of the methodology employed for the purpose of content analysis can be found in Section 3.4.

3 Result and Discussion

Bibliometric analysis was carried out to reveal the current state of research related to augmented reality in mathematics learning. The following is the descriptive results of the quantitative overview of the current state, network analysis modelling from co-occurrence analysis and the thematic map to answer the research questions.

3.1 Descriptive Results

Fig.3 illustrates the publication trends throughout the years, highlighting a significant surge from 2019 to 2020, followed by relatively steady figures from 2020 to 2023. This pattern suggests a period of heightened research or publication activity, succeeded by a relatively consistent level of output.

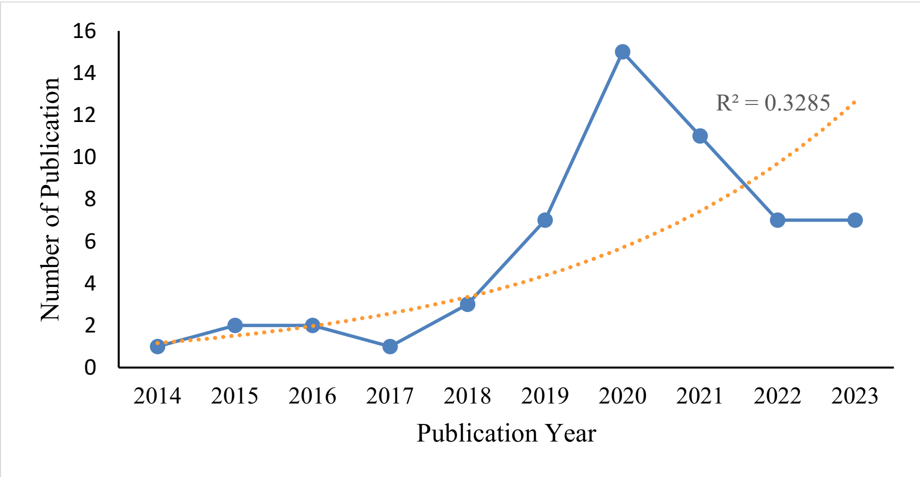

Fig. 3. Annual publication trends (2014-2023): A decade of research output with a blue dotted-line represents the number of documents, while the orange dashed-line represents the exponential trend line

Furthermore, an exponential trend line was fitted to the data, representing a line that exhibits an exponential pattern. The fitting process yielded a positive R-squared value of 0.3285, although it is a relatively weak correlation between the data points and the trend line. This exponential trend line serves as a visual representation, effectively illustrating the sustained and substantial interest in augmented reality (AR) research within the realm of mathematics learning from 2017 to the present day.

The notable upswing in publications during this specific timeframe underscores the continuous and significant growth of interest and attention directed toward the subject within the academic community. It underscores the consistent dedication and enthusiasm the academic community has demonstrated for this topic. Additionally, the substantial increase in publications related to the detection of learning styles, commencing in 2017 and extending onward, further underscores the growing importance and relevance of this specific area of study. This surge in publications reflects an increasing acknowledgment and emphasis on investigating learning styles, laying the groundwork for ongoing advancements and contributions to the field.

3.2 Main Research Themes and Topics

To address Research Question 1, which investigates the current landscape of research on the detection of learning styles, the application of visualizations generated through VOSviewer proves essential. The visual representation resulting from co-occurrence analysis delineates the relationships among research topics, their prevalence, and the emergence of thematic clusters. Consequently, co-occurrence analysis serves as a valuable tool for examining the primary themes, topics, or pivotal concepts within published works [20].

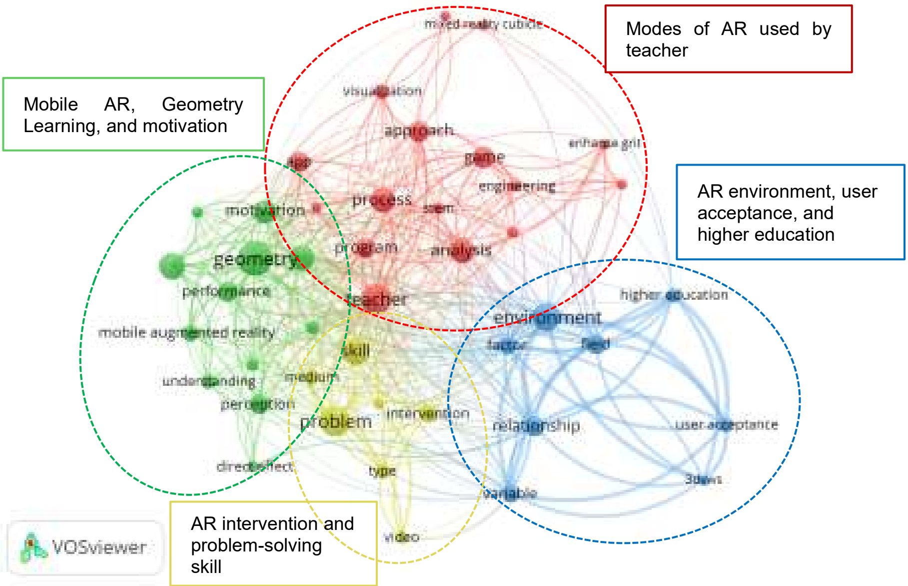

Fig. 4. Network visualization of co-occurrence analysis of keywords and terms

The network visualization derived from co-occurrence analysis, as depicted in Fig. 4, brings to light the presence of four distinct thematic clusters. Each cluster is distinguished by a unique color, where the red, green, blue, and yellow clusters correspond to clusters 1, 2, 3, and 4, respectively. The red cluster concentrates on the utilization of augmented reality (AR) modes by teachers within the realm of mathematics education. The research theme of the green cluster revolves around geometry learning, exploring the impact of mobile AR on motivation, understanding, perception, and performance. Meanwhile, the blue cluster delves into variable factors related to the environment, user acceptance, and the utilization of Three-Dimensional Virtual Worlds (3DVWs) in higher education. The final cluster (yellow) is concerned with the intervention of AR using video as a medium to enhance problem-solving skills.

Cluster 1, identified by red, is dedicated to the examination of the application of Augmented Reality (AR) modes within the realm of mathematics pedagogy. This cluster extensively explores the impact of teacher training in employing mobile AR on the professional advancement of educators involved in STEM subjects. Teachers assume a pivotal role in STEM education, contributing by delivering dynamic learning materials and pertinent content to engage students and foster their skill development. The investigations within this cluster focus on teacher professional development concerning the potential of AR games in educational training, as evidenced by studies conducted by Lasica et al. [21], Pombo & Marques [22], Schutera [23], and Bagossi et al. [24]. These inquiries propose that sustained teacher training can alter perceptions of technology and enhance teacher expertise, encouraging the exploration of AR games in educational settings, as indicated by Marques & Pombo [25].

Cluster 2, denoted by green, is focused on the utilization of AR applications by teachers within the context of mathematics teaching. In this cluster the most popular topic is the application of AR for teaching and learning geometry in supporting students' motivation, understanding, and performance [26–30]. This research area focuses on the advancement of spatial reasoning abilities and comprehension of geometric shapes and their properties. The objective is to improve both the abstract and practical aspects of students' geometric thinking skills. Within geometry education, a crucial component involves the capacity to identify and construct 3D shapes, encompassing the skill to recognize and assemble the nets of such geometric objects. Determining whether to construct an object based on its folded net is part of this process. Pittalis et al. [31] have identified six dimensions of 3D thinking skills, including the ability to recognize and create 3D shapes. Their work establishes a framework for evaluating geometry instruction and augmenting students' proficiency in 3D geometry thinking [30, 32, 33].

Cluster 3 (blue) focuses on the variable aspects of Augmented Reality (AR) in higher education, including environmental factors, user acceptance, and 3D virtual worlds [34–36]. The studies in this cluster emphasize the growing importance of digital e-learning tools in higher education, particularly in the context of the fourth industrial revolution. Higher Education Institutions (HEIs) are increasingly incorporating Virtual Reality (VR), Augmented Reality (AR), and other digital platforms to enhance the learning process. These technologies offer visual and interactive experiences, aiding students in understanding complex concepts and improving learning outcomes. For instance, a mobile VR application was developed for engineering students to learn about induction motor technology [37], while AR technology has shown positive impacts on learning gains and attitudes, especially in subjects like mathematics [38]. Integrating these technologies into higher education presents significant benefits for both students and educators, offering innovative ways to engage with educational content.

Cluster 4 as presented by yellow, the topics are focused on the intervention of AR video towards problem-solving skills. The studies within this cluster investigate topics such as intelligence AR tutoring system for mathematics teaching and learning [39]; mobile AR for remedial teaching of compound-cube-surface area [40]; video-based AR instruction to teach mathematics [41]; and learning mathematical modelling with AR mobile math[42]. Those researchers revealed that students showed a substantial improvement in their performance and supports students in bridging between real-world situations and mathematical concepts in problem-solving after receiving AR interventions.

3.3 Emerging Topics

To answer RQ2 related to emerging research topics in AR for mathematics learning or teaching, the output of a co-occurrence analysis was generated using VOSviewer on an overlay visualization (see Fig. 5).

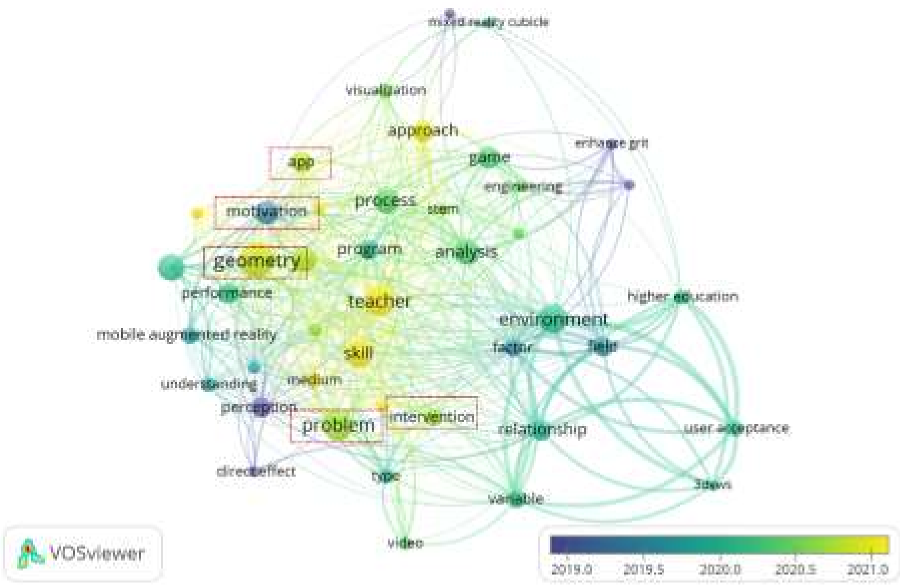

Fig. 5. The overlay visualization combines co-occurrence analysis and average publication year, using green to yellow for emerging topics and blue for declining topics

Fig. 5 depicts average publication years for each research topic through node colors. Green to yellow nodes represent novel publication years, while green to blue nodes signify older publication years. Topics with green to yellow nodes are considered emerging, whereas those with colors closer to blue are deemed declining. Geometry, problem solving skills, app, intervention exhibit green to yellow colors, indicating they are emerging topics. Conversely, motivation has a color close to blue, signifying it is a declining topic.

3.4 Future Works and Directions

To answer RQ3 co-occurrence analysis with overlay visualization and content analysis were conducted for mapping future work and direction. The overlay visualization offers a comprehensive depiction of the research topics that are presently evolving and exerting a notable impact on studies related to the detection of AR in mathematics learning. In the meantime, content analysis is employed to investigate potential areas of future research (see Fig. 6).

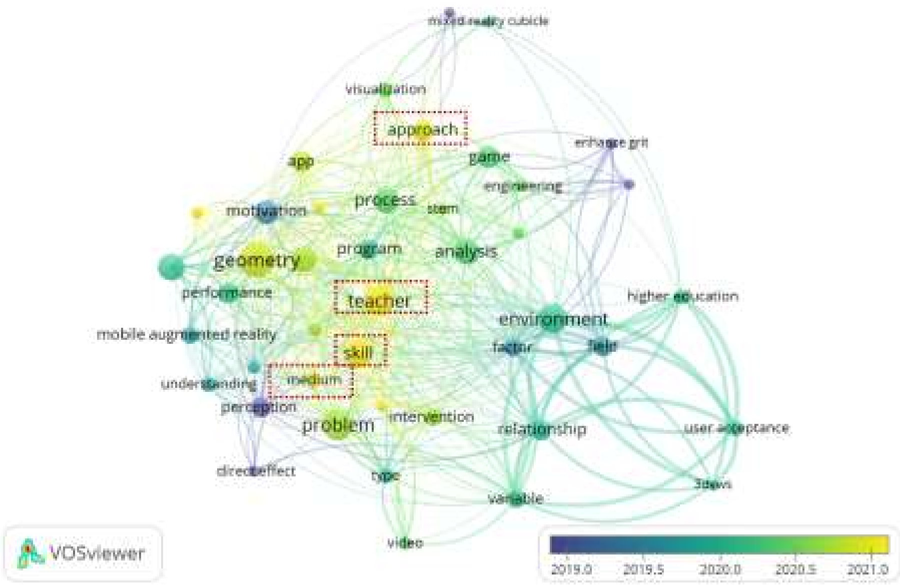

Fig. 6. Overlay visualization of novel/old topics

The examination of Fig. 6 highlights that teacher skill, medium, and approach associated with AR are intriguing subjects warranting further investigation. These areas present potential avenues for in-depth exploration and offer promising directions for future studies.

The need for further exploration is emphasized, particularly in addressing issues related to the integration of AR for mathematics learning. Key challenges include determining effective approaches and suitable mediums for integrating AR to enhance mathematical literacy skills, as noted by Pujiastuti [43]. Additionally, it is crucial to develop AR-based teaching materials tailored to specific education levels, as indicated by Koparan [44] and Ozcakir & Cakiroglu [45], and to provide guidelines for teacher training, as emphasized by Pombo & Marques [22]. These aspects collectively underscore the importance of continued research and development in the field to fully harness the potential of AR in mathematics education.

The finding of this study identified key challenges, emphasizing the need for exploring effective approaches, suitable mediums, and tailored AR-based teaching materials to enhance mathematical literacy skills. The study underscores the importance of continued research to fully leverage AR's potential in mathematics education.

4 Conclusion

This study utilized bibliometric analysis to assess the current state of AR research in mathematics learning. Additionally, guided by insights from the bibliometric analysis, a content analysis was conducted to identify future research directions. Through co-occurrence and thematic map analysis, the study elucidated evolving research topics, including geometry, problem-solving skills, apps, and interventions associated with AR. Emerging research areas, such as effective approaches and suitable mediums for integrating AR to enhance mathematical literacy skills, were also highlighted, indicating the dynamic nature of the field.

While geometry topics have seen continuous development, attention to future research directions is warranted. Specifically, exploring affective approaches and tailored AR-based teaching to enhance mathematical literacy skills is essential.

In conclusion, this study provides insights into the current landscape of AR in mathematics learning and highlights areas for future exploration. Addressing these research gaps and advancing methodologies can contribute to the growth of AR research in mathematics education, fully leveraging its potential.

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