

Performance Analysis and Science Mapping on Technological Pedagogical and Content Knowledge (TPACK) in a Last Decade

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DOI: <https://doi.org/10.20414/ethno-stem.v1i1.15226>

Article Info	ABSTRACT
<p>Article history Received : February 12, 2026 Accepted : June 26, 2026 Published : June 27, 2026</p>	<p><i>This study aims to analyze publications related to Technological Pedagogical Content Knowledge (TPACK) from 2014 to 2024, with a focus on performance analysis and science mapping. This study used a bibliometric analysis method with data sources from Scopus and analysis assistance using VOSviewer and Microsoft Excel. The performance analysis included the distribution of publications by year, country, journal, and author. Meanwhile, the science mapping identified research themes, topic trends, and research clusters. Three main findings were resulted from the analysis. Firstly, after a total of 2,549 publications were analyzed, a significant increase occurring in 2021 was detected, peaking in 2023, with 358 publications. Secondly, the highest number of publications was detected in The United States, Indonesia, and China, while the Journal of Physics Conference Series and Computers and Education had the highest number of publications and citations. Lastly, the science mapping revealed five main clusters: technology integration in education, application of technology in the curriculum, teacher competency development, scientific research, and digital competencies and online learning. This study also recommends more explorations in the application of TPACK in other disciplines, its impact on student learning outcomes, and the development of teachers' digital competencies in post-pandemic online learning. This research provides important insights into TPACK's trends and developments over the past decade and future research directions.</i></p>
<p>Keywords <i>Bibliometric; Performance Analysis; Science Mapping; TPACK</i></p>	
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How to Cite:

Example: Gifari, M. K., et al. (2026). Performance Analysis and Science Mapping on Technological Pedagogical and Content Knowledge (TPACK) in a Last Decade. *Journal of Ethnoscience and STEM Education*, 1(1), 53-64 <https://doi.org/10.20414/ethno-stem.v1i1.15226>

INTRODUCTION

The effective use of technology in learning plays an important role in helping teachers fulfill the various needs of learners, such as concepts, principles, and procedures (McFarlane & Sakellariou, 2022; Rodrigues, et al., 2003; Rogers, 2004; Sahidin, et al., 2022). The rapid development of technology requires every teacher to improve their skills in integrating technology into learning. Teachers must be able to recognize and have good knowledge of what kind of content can be integrated with technology in learning. While there are options for technologies that can be integrated into learning, 21st-century technology is closely related to digital technology. Digital technology has a great influence on the field of education because of its effectiveness, efficiency, and attractiveness (Hanik, et al., 2022).

Therefore, the integration of technology can also help teachers create a creative, interactive, fun, and meaningful learning atmosphere while paying attention to the connection between materials, media, learning methods, and students' initial abilities (Ariani, 2015). This requires teachers to have the necessary skills and knowledge in delivering learning content to learners. Skills in organizing learning content are usually referred to as pedagogical competence (Veronica, et al., 2022). Meanwhile, knowledge related to technology, pedagogy, and content is called Technological, Pedagogical, and Content Knowledge (TPACK).

TPACK is a framework used to design a modern learning model by combining technology, pedagogical, and knowledge components (Hanik, et al., 2022). This Pedagogical Content Knowledge model includes technological knowledge as part of the teacher's knowledge structure, thus producing a theory known as Technological, Pedagogical, and Content Knowledge, which later became TPACK (Mishra & Koehler, 2006; Shulman, 1986). The Association of Colleges of Teacher Education Committee (AACTE) on Innovation and Technology changed the original abbreviation TPCK to TPACK, where the 'A' indicates the interdependence of technological, pedagogical, and content knowledge (Koehler & Mishra, 2016).

The TPACK framework can help teachers master professional, personality, pedagogical, and social competencies (Veronica, et al., 2022). In addition, TPACK can also provide flexibility and optimize teacher performance in designing and implementing the learning process. The integration of TPACK can improve mastery of content, technology, and pedagogy and increase teachers' confidence in designing learning (Doering, et al., 2009).

TPACK is a framework for understanding the knowledge teachers need to use technology effectively in learning (Koehler & Mishra, 2013; Mishra & Koehler, 2008). This knowledge includes (Kamysbayeva, et al., 2021; Mishra & Koehler, 2006; Schmidt, et al., 2009): (1) Technological Knowledge (TK) is knowledge related to simple technology such as whiteboards or digital such as computers, knowledge related to the ability to use technology, and mastery in using technology as a means of communication, goal achievement and problem solving; (2) Pedagogical Knowledge (PK) is knowledge related to learning methods and procedures as well as mastery of student learning strategies, classroom mastery, and the ability to design learning and evaluate learning; (3) Content Knowledge (CK) is knowledge related to learning materials which include facts, concepts, theories and procedures; (4) Technological Pedagogical Knowledge (TPK) knowledge of learning strategies and procedures integrated with technology; (5) Technological Content Knowledge (TCK) is knowledge related to the use of technology to make new representations of learning materials and help students understand the material, knowledge related to how to choose the best technology that

can be used to achieve learning goals, and knowledge related to the effectiveness of the use of technology on learning materials and vice versa; (6) Pedagogical Content Knowledge (PCK) knowledge related to learning development strategies by combining learning materials and pedagogy. This framework of thinking resulted in the concept of TPACK which includes knowledge of (Koehler, et al., 2013; Muhuri, et al., 2019): (1) strategy of presenting concepts through learning technology; (2) the use of technology to learn material with pedagogical techniques; (3) the use of technology to help students understand difficult concepts; (4) students' initial abilities; and (5) the use of technology to strengthen students' initial abilities and construct new knowledge.

The usefulness of TPACK in the world of education encourages researchers to conduct studies on TPACK, including investigations into research trends. Suprpto et al. (2019) revealed a significant trend in TPACK research during the period 2015–2019, marked by an increase in the number of publications, especially journal articles, reflecting growing interest in this topic. The United States and Singapore emerged as the dominant countries in TPACK research, followed by significant contributions from Indonesia, particularly Sebelas Maret University and Indonesian Education University. Additionally, the study identified four main clusters in TPACK research: TPACK as a system, TPACK at scale, TPACK in relation to quantitative parameters, and TPACK in the context of trust, intent, and acceptance of technology. These findings provide valuable insights into recent developments in the field of TPACK and serve as a reference for future research.

Meanwhile, based on the trend of publishing articles about TPACK in science learning indexed by Scopus and SINTA during the 2012–2022 period (Bahtiar, et al., 2023), publications significantly increased from 2016 to 2020, followed by a decline in subsequent years. The article "Examining the Technological Pedagogical Content Knowledge of Singapore Pre-Service Teachers with a Large-Scale Survey" is the most cited publication on TPACK in 21st-century learning. The Journal of Educational and Information Technologies and Computers & Education are identified as the primary publication platforms for this topic. Density map analysis from the study indicates that themes such as ICT investigation, curriculum, effectiveness, teacher knowledge, foreign languages, teacher education, and TPACK instruments are still under-researched.

Jin Yao and Bhattacharyya (2022) systematically examined the literature on TPACK in the Scopus database during the period 2018–2022, with a specific focus on TPACK in learning English as a foreign language (EFL). Their analysis showed increasing interest in the application of technology in language teaching and learning. The study identified four main clusters of research, including TPACK as a system for pre-service and in-service teachers, platforms and approaches, and e-learning. The focus on platforms and approaches highlights the need for further research on the use of specific technologies and teaching methods to improve TPACK competencies. Furthermore, the emphasis on e-learning reflects a growing interest in using technology for distance education. Overall, the study underscores the importance of addressing different contexts and audiences in TPACK research, while identifying knowledge gaps to guide future investigations.

The three studies concur that interest in TPACK research has increased significantly in recent years, highlighting its growing importance in technology-based education. These studies primarily use the Scopus database as their main data source and rely on bibliometric methods. Despite slight differences in naming and grouping, all studies identified several key clusters within the TPACK framework, indicating the field's progression into more specific sub-topics.

The rapid development of information and communication technology has significantly transformed the educational landscape. Teachers are now required not only to master their subject matter but also to integrate technology into the learning process. The concept of TPACK provides a relevant framework for understanding teachers' abilities to integrate technology, pedagogy, and content knowledge (Mishra & Koehler, 2008). Although prior research has demonstrated increased interest in TPACK, a comprehensive understanding of its research trends over specific periods, particularly during major digital transformation periods such as 2014–2024, remains limited. This study seeks to fill this gap by conducting a performance analysis and science mapping of TPACK research during this period.

METHOD

This study used a bibliometric analysis. Bibliometrics is an established technique for measuring specific publication areas (Borregan-Alvarado, 2020; Garousi, 2015) and can be used to detect the most prominent and productive topics and fields (Cobo, et al., 2011; Muhuri, et al., 2019). The bibliometric stages in this study follow the process described by (Donthu, et al., 2021), which includes: (1) defining the aims and scope of the bibliometric study; (2) choosing the techniques for bibliometric analysis; (3) collecting the data for bibliometric analysis; and (4) running the bibliometric analysis and report the findings (performance analysis and science mapping).

This study aimed to conduct an in-depth performance analysis and science mapping of TPACK research during the 2014–2024 period. The study employed the keyword TITLE-ABS-KEY ("TPCK" OR "technological pedagogical content knowledge" OR "TPACK" OR "technological pedagogical and content knowledge") to identify relevant publications during this period, accessed on October 17, 2024, in Scopus. Data related to performance analysis was derived from Scopus analysis results and additional evaluations conducted in Microsoft Excel using .csv files extracted from Scopus. Data related to science mapping was analyzed using VOSviewer, a software tool capable of providing valuable insights into network metrics and groupings (McAllister, et al., 2022; Van Eck & Waltman, 2013).

RESULT AND DISCUSSION

Performance analysis focuses on the year, country, journal, and the most productive and influential authors, while science mapping analyzes the research themes, changes in topic trends, and the distribution of clusters. These results are presented in the findings section.

Performance Analysis

Distribution Analysis of TPACK Research

The distribution of the number of publications included in the study by year is shown in Figure 1. A significant increase in the number of publications occurred in 2021, while the highest number of publications was recorded in 2023, with a total of 358 publications. The development of the number of publications during the 2014–2024 period tends to fluctuate, with a decrease of 8.66% in the final year.

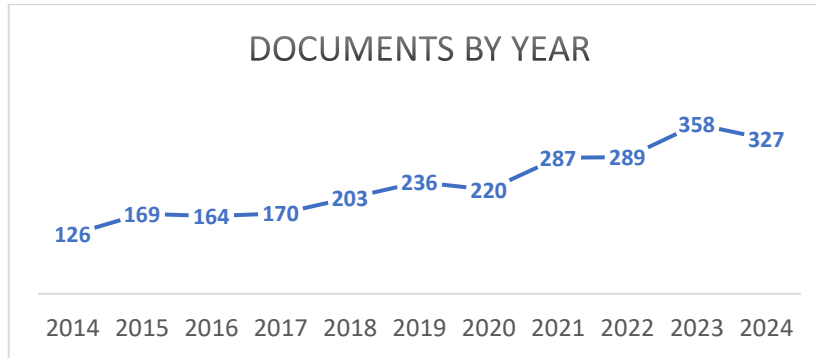


Figure 1. Distribution number of publications by year

The publications on TPACK-related research were identified across 106 countries. Table 1 and Figure 2 present data on the top 10 countries producing TPACK-related publications. The United States, Indonesia, and China are the top three countries, contributing 497 (19.5%), 287 (11.3%), and 255 (10.0%) publications, respectively.

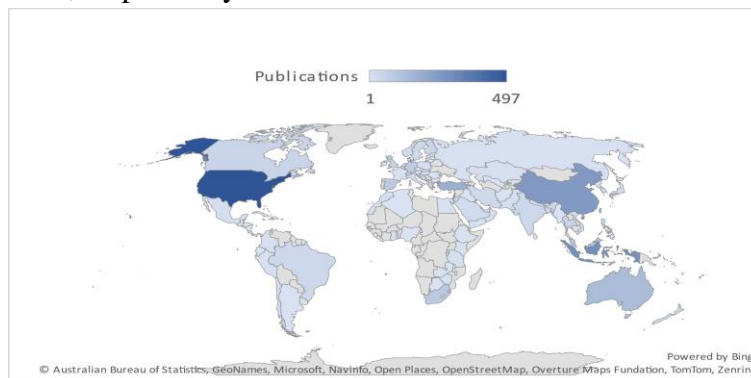


Figure 2. Distribution of Publications by Country Category

Publications from these 106 countries included contributions from 160 affiliations. Table 2 highlights the top 10 affiliations producing TPACK-related research. National Taiwan Normal University, Yogyakarta State University, and Nanyang Technological University emerged as the top three institutions, publishing 46 (1.8%), 45 (1.7%), and 40 (1.6%) publications, respectively.

Most Productive and Cited Journals

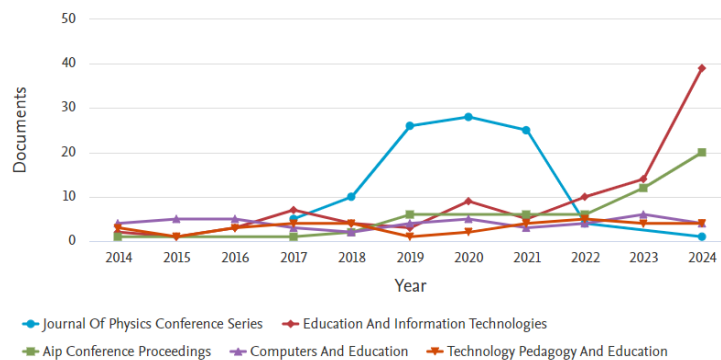


Figure 3. Most relevant sources

The journals with the highest number of TPACK-related publications are presented in Figure 3. The Journal of Physics Conference Series (n=99), Education and Information Technologies (n=97),

AIP Conference Proceedings (n=54), Computers and Education (n=45), and Technology, Pedagogy, and Education (n=35) are the top sources. The Journal of Physics Conference Series held a significant position in TPACK research but saw a dramatic decline in 2022, while Education and Information Technologies experienced a significant increase in 2024, reflecting growing interest in information technology education.

The most influential journals, measured by citation count, are shown in Figure 4. The top three are Computers and Education (n=2446), Education and Information Technologies (n=1320), and Educational Technology and Society (n=1111). Other journals in the top ten include the Australasian Journal of Educational Technology (n=1048), Computers in Human Behavior (n=1018), and Educational Technology Research and Development (n=892). The list continues with Journal of Digital Learning in Teacher Education (n=850), Technology, Pedagogy and Education (n=756), Handbook of technological pedagogical content knowledge (TPCK) for educators (n=686), and Journal of Research on Technology in Education (n=676).

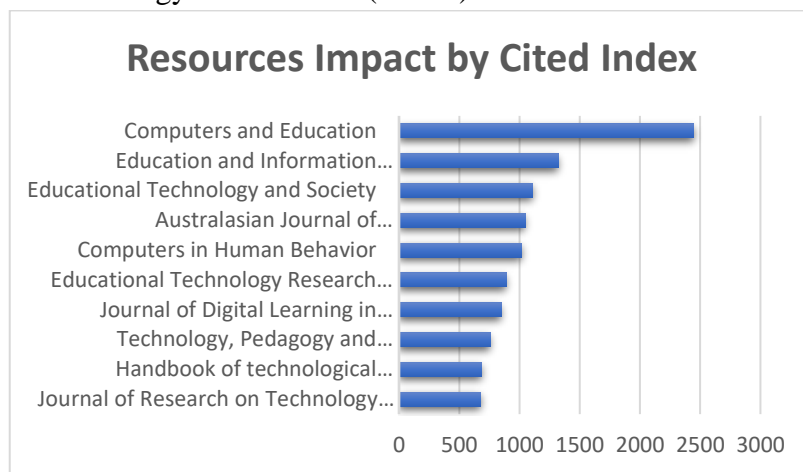


Figure 4. Most cited journals by research on TPACK

Most Productive Cited Authors

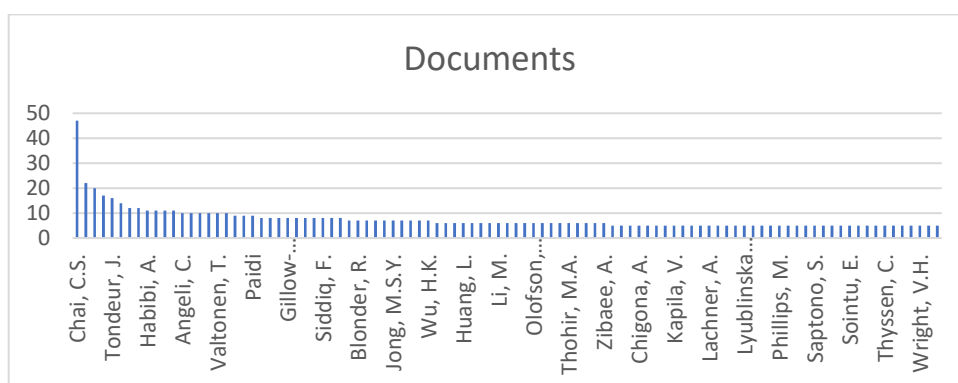


Figure 5. Most productive authors

The productivity of authors is measured by the number of publications, while influence is measured by the number of citations. Figure 5 shows the most productive authors, with at least five articles published. Chai Ching Sing from Hong Kong is the most prolific, with 47 articles. Among

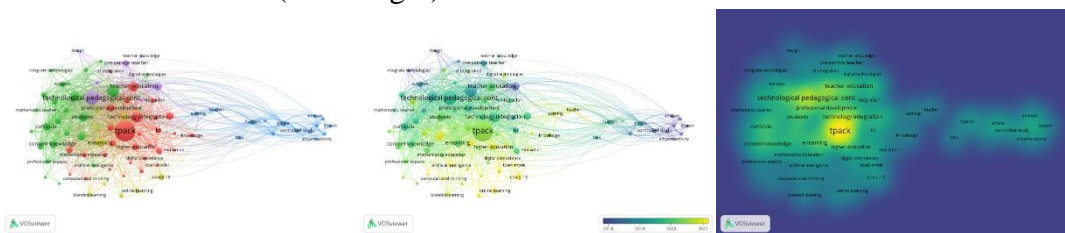
the most influential authors are Matthew J. Koehler and Punya Mishra, whose seminal work "Introducing TPACK" has been cited 483 times in the Scopus database.

Figure 5 shows the most prolific authors, defined as those who have published at least five journal articles. At the top of the list is Chai Ching Sing from Hong Kong, who has published 47 journal articles related to TPACK. Meanwhile, the most influential authors in the field of TPACK are Matthew J. Koehler (Michigan State University, East Lansing, United States) and Punya Mishra (Mary Lou Fulton Teachers College, Phoenix, United States), recognized for their seminal work titled "Introducing TPACK." This document has been cited approximately 483 times in the Scopus database, reflecting its significant impact on TPACK-related research.

Science Mapping

Figure 6 illustrates the keyword network obtained through bibliometric analysis using VOSviewer. The visualization highlights the co-occurrence frequency of keywords. The size of each circle correlates positively with the frequency of keyword usage (Van Eck & Waltman, 2013; Wong, 2018). Color-coded clusters represent interconnected themes, while lines between circles denote the strength of relationships between keywords. Out of 7756 keywords analyzed, 84 met the minimum occurrence criterion (n=20) and were included in the visualization.

Figure 6. Network visualization, overlay visualization, and density visualization of keywords' co-occurrence in VOSviewer (left to right)



The visualization image shows five main clusters. Cluster 1 (red) focuses on TPACK and technology integration in education, with keywords such as "technology integration", "e-learning", and "higher education". Cluster 2 (green) highlights the application of technology in curriculum and teaching, especially in mathematics education, with keywords such as "content knowledge" and "mathematics education". Cluster 3 (purple) focuses on teacher education and development, including "teacher education" and "teacher knowledge". Cluster 4 (blue) is related to scientific research, with topics such as "controlled study" and "enzyme activity". Cluster 5 (yellow) emphasizes the importance of digital competence and online learning, especially in the context of the COVID-19 pandemic, with keywords such as "digital competence" and "online learning". This visualization shows a variety of research related to TPACK and educational technology.

After completing the network visualization, the next step involves mapping and grouping research trends based on the year of publication. The data obtained from the overlay visualization results, as shown in Figure 6, can serve as a guideline for identifying and detecting the latest developments (state-of-the-art) in TPACK-related research. This information is crucial for providing insights into the direction of research development and assisting researchers in identifying areas that require further exploration.

The visualization highlights the historical development of research based on keywords, represented by the color of the nodes. Green-colored keywords, such as "TPACK," "technological pedagogical content," and "technology integration," indicate topics that have been discussed for a long time but remain relevant. Meanwhile, yellow keywords, such as "online learning" and "COVID-19," represent newer topics associated with the rise of online learning during the pandemic. Purple nodes on the right-hand side, such as "controlled study" and "animals," reflect topics that have been part of research for an extended period but are not directly linked to recent trends in technology-based education. This visualization demonstrates how research in technology education evolves, with TPACK at its core, while new topics emerge over time.

The analysis proceeds with density visualization, using VOSviewer. The results, as shown in the figure, reveal areas with high density between nodes, indicating frequently researched topics. These areas are marked in yellow, signifying regions extensively studied. For example, the keywords "TPACK," "technological pedagogical content knowledge," and "technology integration" are among the most commonly researched terms in TPACK-related studies. Conversely, nodes marked in dark colors and located farther from lighter regions—such as "design," "controlled study," "enzyme activity," and "animals"—represent topics that have not been widely explored in relation to TPACK. These gaps present opportunities for further research and innovation.

Discussion

There are no established guidelines for conducting keyword analysis in bibliometric studies (Wilden, 2017). This research explores various configurations to produce a logical interpretation of keyword groupings. The minimum threshold for keyword occurrences was set at 20 out of 7756 keywords, resulting in 84 keywords meeting the criteria. Based on the generated clusters, several key themes were identified. First, TPACK and technology integration in education highlights how this framework is becoming an essential tool for understanding how teachers combine technology with content and pedagogy (Malik, et al., 2019; Archambault & Barnett, 2010; Benson & Ward, 2017). The implementation of TPACK ensures that teachers are not only proficient in technology but also understand how it can enhance teaching and learning (Martin, 2015; Saubern, et al., 2020). Second, the application of technology in curriculum and learning demonstrates that technology is not merely an aid but an integral part of teaching strategies designed to strengthen students' comprehension of specific content (Hanik, et al., 2022; Ertmer, et al., 2012; Kirkwood & Price, 2014). Third, the education and development of teacher competence underscore the importance of teacher training focused on the pedagogical application of technology (Rodríguez, et al., 2019; Papanikolaou, et al., 2017; Wang, et al., 2018). Teachers' ability to use technology effectively is critical to ensuring that it genuinely supports student learning, rather than being a superficial addition (Jimoyiannis, et al., 2013; Foulger, et al., 2017). Fourth, scientific research continues to make significant contributions by showcasing how technology can improve learning, particularly in STEM (Science, Technology, Engineering, and Mathematics) disciplines (Gonzalez & Kuenzi, 2012; Becker, & Park, 2011; Altan, et al., 2019). Finally, digital competencies and online learning have emerged as increasingly relevant topics, especially in the context of the COVID-19 pandemic, which emphasized their importance in contemporary education (Pranckutė, 2021; Kamysbayeva, 2021; Sá & Serpa, 2020).

CONCLUSION

This study comprehensively analyzed TPACK-related publications from 2014 to 2024, uncovering substantial growth in research, with the highest output recorded in 2023, predominantly contributed by the United States, Indonesia, and China. The analysis identified key themes, including technology integration in education, digital competencies, curriculum applications, teacher competency development, and scientific research. Notable trends, such as the rising importance of online learning and digital skills in the post-COVID-19 era, were also highlighted. Prominent journals like *Computers and Education* and influential authors such as Ching Sing Chai and M.J. Koehler have played pivotal roles in advancing TPACK research. Recommendations for future studies include examining TPACK's application across diverse disciplines, assessing its impact on student learning outcomes, and investigating the development of teachers' digital competencies within hybrid and inclusive education environments.

ACKNOWLEDGMENTS

With full respect and humility, the author would like to express his gratitude to previous researchers in Bibliometric Analysis, Artificial Intelligence, Coding, and TPACK who have become the scientific foundation in compiling the background, theoretical basis and academic references in this research.

AUTHOR CONTRIBUTIONS

MK, RA, and AP contributed to the drafting, development, provided additional content and completed the final refinements of the manuscript.

FUNDING

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CONFLICTS OF INTEREST

"The authors declare no conflict of interest."

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