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Review Article

Examining the relationship between TPACK and STEAM through a bibliometric study

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ABSTRACT

This research is a bibliometric study that focuses on publications containing both terms "technological pedagogical content knowledge" (TPACK or TPCK) and "science, technology, engineering, arts, and mathematics" (STEAM). The former addresses knowledge that teachers are expected to gain, whereas the latter addresses a new integrating subject field. Both terms dominate contemporary education research, especially in relation to technology and its impact on education. These two terms have been researched individually by bibliometricians. The aim of this research is to examine articles that combine these terms, as there seems to be a lack of such studies. With the help of the Scopus platform, 2,608 articles published since 2007 were collected and analyzed.

Keywords: STEAM, TPACK, bibliometrics, research trends

INTRODUCTION

Bibliometrics is used as an approach that can provide information on various media of communication or publications, including journal articles, in specific fields of study. Journal articles, in particular, are considered the basic unit of bibliometrics. This method allows for the collection and analysis of a large number of articles as well as their associated data, such as keywords, scientific disciplines, publication dates, and countries of origin. This, in turn, can assist in gaining insights into these fields. Those insights can be research trends, developments, or the main interests, challenges, and focus of research groups (Pacheco-Mendoza et al., 2020; Pritchard, 1969).

The application of bibliometrics has been significantly helped by the progress of information and communication technologies (ICT). The use of the Internet has led to new methods of research dissemination and article publication, such as electronic books and journals. Aside from that, it has facilitated access to these articles and relevant resources. Moreover, it has expanded and simplified complex quantitative or statistical analysis on which bibliometrics is based. In addition, online search engines and platforms, such as Scopus, have been established that can carry out functions that assist bibliometricians. For these reasons, there has been an increase in bibliometric studies during the last two decades, which has provided significant findings (Donthu et al., 2021; Glanzel, 2003; Pacheco-Mendoza et al., 2020).

This applies in many areas of study, including the education sciences. Education research has expanded recently. There has been a surge in studies on topics that had been well-investigated in the past. There has also been a surge in new themes that may address new institutions or trends in education and teaching. The reasons for these phenomena are complex. They can be associated with general reforms, including the expansion of the Internet and modern technologies. Indeed, educators and researchers are dealing with new challenges and conditions that they have to respond to in order to improve schools and teaching. An example is technological pedagogical content knowledge (TPACK or TPCK), which addresses a set of qualities that teachers need (Mishra & Koehler, 2006). Another example is science, technology, engineering, arts, and

mathematics (STEAM), which addresses a new teaching subject (Allina, 2018; Perignat & Katz-Buonincontro, 2019; Shatunova et al., 2019).

Bibliometrics can provide significant information regarding the research trend around those new themes, either individually or combined. This research aims to examine, through a bibliometric approach, whether there is a relationship between TPACK and STEAM in publications. In doing so, it is important to examine each of these terms, their definition, content and previous bibliometric studies around them. This approach will shed light to trends around the relationship between these concepts, which is possible with bibliometrics (Ahadi et al., 2022).

TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE

TPACK or TPCK, which stands for technological pedagogical content knowledge, is a term attributed to Mishra and Koehler (2006). The authors used it to encompass a body of knowledge and qualifications that effectively combine three different fields, which are pedagogy, technology, and the content of teaching units. It has evolved from previous approaches around topics such as content knowledge, technological knowledge, and pedagogical content knowledge. TPCK goes beyond individual disciplinary knowledge or expertise. The main innovation and rationale behind it are that it entails not only the sum of these fields but also the way they can be combined so that contemporary teachers can use technology in their work effectively. The fundamental components of TPCK are: understanding technology and technological representations of concepts and knowledge; teaching practices and techniques that are based on technology and promote the active participation of learners in the session, during which they will be encouraged to construct knowledge; estimating the level of difficulty of knowledge to be understood and the ways in which technology can assist and facilitate; epistemological knowledge and theory; appreciation of learners' prior knowledge and practices to use it; mastery of practices that lead to rejection of misconceptions and incorrect knowledge as well as practices that lead to the strengthening of the correct ones, with the help of technology; and development of attitudes that aim for new epistemologies and paradigms as an ultimate goal. Through all this, the teachers will be able to teach different topics in various subjects using up-to-date advanced technology and achieve the best educational outcomes (Mishra & Koehler, 2006; Setiawan et al., 2019).

The development and expansion of the Internet and its use have affected the conditions under which teachers work in many ways. For example, they increased access to information regarding any topic that has to be taught. Moreover, thanks to new ways of communication, they have laid the groundwork for new pedagogical modes and institutions. If teachers and schools want to respond to these new conditions and challenges, they should be in a position to appreciate the interwoven relationships between technology, pedagogy, content, and their progress. The philosophy of TPCK relies on identifying complex relationships that occur within a teaching classroom or context. There is no single solution regarding how to teach a concept or knowledge with the help of technology. Each classroom might require a unique approach or lesson plan. In order to identify which is the appropriate one for a specific case, the teachers must consider different factors. They also have to decide what their main goal or starting point will be. Some teachers can start with the content. This implies that they specify the new knowledge they want their students to acquire before they start planning. As soon as they clarify it, they can check which technological applications and pedagogical approaches can help. Other teachers, in other cases, might use technology or pedagogy as their starting points. No matter how the teachers decide to work, using TPCK, they can achieve better results (Mishra & Koehler, 2006; Peruski & Mishra, 2004).

TPCK has attracted the interest of bibliometrics researchers during the last few years. Suprapto et al. (2021) have investigated 2,075 papers published from 2015 to 2019 that emphasized this concept. Most of them were journal articles, but there were also conference proceedings. They concluded that there is growing interest in it, mainly in education journals. However, there were articles in journals of other fields as well, such as Physics, Science, and Technology. The majority of these articles came from English-speaking countries, such as the USA, the United Kingdom, and Australia. There were a considerable number of articles from other countries, such as China, Turkey, and Indonesia.

Simultaneously, Lee et al. (2022) carried out a bibliometric study on 700 publications, disseminated between 2011 and 2020, in an effort to achieve science mapping. They also concluded that there is an

increased emphasis on TPCK. They also pay attention to co-occurrences; they point out that there is a correlation between this concept and teacher education, skills, the integration of science subjects, and pre-service and in-service training. Most likely, this happens because researchers believe that there is a strong link between these topics and TPCK. They stress, though, that TPCK is approached mainly as a body of knowledge, whereas competencies are not given adequate attention.

Soler-Costa et al. (2021) carried out a thorough and detailed bibliometric study on 556 articles that researched TPCK and were published from 2006 to 2017. They clarify that the surge in articles over the last few years is mainly due to technological development and the expansion of ICT, which influence education functions and institutions. Apart from justifying the findings of other researchers, the authors have associated TPCK with sustainability issues in the fields of professional development and education. They point out that research on this concept can and should have a more profound and long-lasting impact. It may lead to new educational paradigms and modes of learning.

In a bibliometric study that examined 910 articles published between 2012 and 2021, Putri et al. (2022) investigated the relationship between TPCK and science teaching. Their primary finding is that many articles on science education seem to include TPCK. Many of the keywords in these articles are common to the elements of TPCK. From this study, the researchers concluded that there is a relationship between these two topics. In other words, the researchers believe that TPCK can help science teachers achieve better results. In particular, they observe a co-occurrence with TPCK and concepts such as scientific inquiry, STEM, and higher education.

Irwanto (2021) examined 106 papers published from 2010 until 2021 that researched TPCK. While justifying the accelerating number of publications, the author also points out that the number of authors and affiliations per paper is also rising considerably. This means that there is interest in fostering cooperation between researchers and institutions to carry out research on TPCK and its benefits for teachers and educational foundations. For those reasons, even though English-language countries and institutions still prevail in the number of publications, there is a rise in papers from other countries too. All these lead to the assumption that the rise in the number of publications around TPCK is likely to continue.

SCIENCE, TECHNOLOGY, ENGINEERING, ARTS, AND MATHEMATICS

STEAM is an acronym, which stands for science, technology, engineering, arts, and mathematics, refers to an innovative educational field of study. It aims to introduce teaching activities that integrate all these five subjects. It is the successor to STEM, which excluded the art factor, which was later thought to be important. The innovation of STEAM lies in the fact that it aims to develop skills and qualities that assist in problem-solving in actual, real-life situations. Learners that engage in STEAM activities are expected to go beyond the knowledge and skills that are normally taught in mainstream traditional, individual subjects or disciplines. By combining these, learners are expected to get a deeper understanding of contemporary issues relating to scientific and technological progress and become more creative. Of course, effective STEAM implementation in the educational context is dependent on teachers. Teachers, therefore, should have the appropriate training to carry out relevant activities, bearing in mind the context where they work (Adebusuyi et al., 2022; Allina, 2018; Lugthart & van Dartel, 2021; Ng et al., 2022; Ozer & Demirbatir, 2023; Perignat & Katz-Buonincontro, 2019; Shatunova et al., 2019).

Specifically, teaching STEAM relies on three primary axes. The first is teaching with hands-on activities, projects, and inquiry-based scenarios. Since it is not restricted to traditional learning outcomes, it cannot rely on traditional practices. Learners will be challenged by questions, themes, or problems that derive from everyday life or authentic context. They will be expected to provide ideas, suggestions, hypotheses, and solutions by using knowledge from the composing disciplines of STEAM. As a result, teachers should be capable of preparing and carrying out activities and sessions that involve problem-based learning. This is not always easy and straightforward for them (Quigley & Herro, 2016).

The second axis is technology-based teaching. Learners are expected to become competent in digital skills and understand the progress of modern technology, the World Wide Web, and its applications. Apart from that, they should be able to collect information and exchange ideas as part of their engineering-oriented, scientifically based thinking and discourse. This includes several competencies such as searching resources,

evaluating their accuracy, thinking critically, observing, stating hypotheses, planning, implementing, and reviewing activities with the help of ICT. Teachers need to have the appropriate training. They should be technologically literate and able to achieve these desired learning outcomes (Perignat & Katz-Buonincontro, 2019; Quigley & Herro, 2016).

The third axis is arts and creativity. Learners should expand their way of thinking in order to respond to challenges that they may face in their lives in the future. They will not be restricted solely to the knowledge they have gained from school. Instead, they will be able to deal with unknown situations. They will also be able to design, express themselves, and find ways to connect fields through artistic patterns. In other words, learners should understand that creativity can lead to innovation. They should work abided by that principle. This, like the previous axes, necessitates appropriate teacher training.

In short, teachers need to possess several qualities in order to teach STEAM. They should appreciate problem-based learning and use it as their main approach. They should be familiar with ICT. Finally, they should develop creative thinking and transfer it to the learners (Quigley & Herro, 2016).

STEAM has piqued the interest of bibliometricians in recent years. Marín-Marín et al. (2021) have studied 1,220 articles published from 2006 until 2021. Their main finding is that there has been a significant increase in STEAM-related publications since 2015. Aside from that, the authors concluded that this term is associated with the teaching of science subjects and computational thinking, as expected. It is also associated with research on teaching different groups, teacher training, and skill development. Arts education is also mentioned, which is important as this differentiates STEAM from the previously existent term, STEM. Lastly, it is concluded that the majority of researchers derive from universities or other centers of institutions in English-speaking countries.

Santi et al. (2021) investigated 174 articles about STEAM published between 2013 and 2020. They concluded that there is a link between STEAM and concepts such as research and development, critical thinking, comparative effectiveness, technological science, educational technology, teacher learning, effectiveness, the flipped classroom, and teaching environments. The subject areas that are involved in STEAM teaching in science education are various. They may be engineering sciences or health sciences, but they are also arts and humanities. The majority of publications came from English-speaking countries, as well as South Korea, Spain, and Indonesia. Finally, there are a considerable number of publications that came from a collaboration between universities and different countries.

At the same time, López-Belmonte et al. (2021) have investigated STEAM and the field of robotics, which is highly related. The articles they collected were published from 1975 until 2019. A total of 926 publications were collected. Most of them were disseminated during the 2010s, with an accelerating tendency observed. For that reason, the authors express the belief that the number of such publications will keep rising in the near future. When focusing on citations, they concluded that the most cited articles are those that emphasize how education technology can enhance teaching practices and help learners develop early programming skills.

Porras et al. (2022) carried out a bibliometric study on the relationship between digital skills and STEAM education. They have collected 214 articles published from 2017 until 2021. This proves that researchers believe that STEAM education can indeed be associated with the development of digital skills. These articles might be in journals relevant to education research, social sciences, arts and humanities, scientific disciplines, mathematics, engineering, and computers. Most of them come from English-speaking countries. However, there are other countries too, such as Taiwan, South Korea, Indonesia, Turkey, Finland, and Spain.

Aguilera and Ortiz-Revilla (2021) have emphasized the STEAM and creativity factors. A total of 304 articles were published between 2010 and 2020. Most of these research studies were done with the help of questionnaires addressing various members of the learning community, such as teachers, learners, or stakeholders. The authors concluded that researchers generally support the idea that STEAM, as well as STEM education, can assist the development of creativity skills in learners. However, there is a need for a more robust framework that teachers can rely on in their work and sessions.

METHODOLOGY

Over the last few decades, bibliometrics has been used as a method to identify trends and interests that guide researchers (Donthu et al., 2021). This is the case in various fields, including education studies and science education, either broadly or in specific themes such as TPACK and STEAM. Several such studies have pointed out that there are articles where these two concepts co-exist. In other words, in studies around TPACK, the concept of STEAM was observed and vice versa (Aguilera & Ortiz-Revilla, 2021; Irwanto, 2021; Kutluca & Merkan, 2022; Lee et al., 2022; Porras et al., 2022; Putri et al., 2022). However, there seems to be a limited number of bibliometric studies that specifically aim to determine whether there are articles that study both of these terms. This is the scope of this research, which can help reveal whether there are researchers who consider that TPACK and STEAM can be interrelated.

For the purpose of the study, the platform Scopus, was used, which is a standard tool for bibliometric studies. This platform was selected for accessibility reasons. In the search engine the appropriate set of words was added to ensure that articles including the two concepts would be identified:

> ALL ("STEAM" OR "STEM" OR "SCIENCE, TECHNOLOGY, ENGINEERING, ARTS, MATHEMATICS" OR STEM AND education OR STEAM AND education)
>
> AND ALL (TPACK OR TPCK OR technological AND pedagogical AND content AND knowledge OR TPCK AND education OR TPACK AND education)

The search came up with 2,713 articles published from 2007 until 2022, including. Further filtering limited this number to 2,608. An analysis of these articles can reveal what research trends exist around the relationship between STEAM and TPACK. These trends can be composed of several parameters, which bibliometrics studies can help to examine and precise. An example of such a parameter is the general interest of researchers. This can be reflected in the number of publications per year. A growing number of publications can reflect a rising interest (Donthu et al., 2021).

A second parameter is the specific fields or specializations of researchers that seem to focus on combining these two terms. This can be reflected in the subject area, the journals, and the number of articles per each. A third parameter has to do with the common sub-themes that TPACK and STEAM have. This can be reflected in the keywords. A final parameter is the country or territory of publication and the language. Generally, in both terms, there was a dominance of certain countries or areas, particularly English-speaking ones (Aguilera & Ortiz-Revilla, 2021; Irwanto, 2021; Lee et al., 2022; Porras et al., 2022; Putri et al., 2022).

These parameters lead to the following research questions:

1. What was the combined publication output of TPACK and STEAM from 2007 until 2022?
2. What areas of study tend to combine these two concepts in their research?
3. What are the common themes between the two concepts?
4. Where do most of these publications come from?

The data were collected and analyzed with the help of Scopus and Microsoft Excel. The findings and data were then represented in figures with the help of the same programs. All these are common methods of bibliometric studies (Donthu et al., 2021).

FINDINGS

With regard to the first question, it is evident that there is a rising tendency in publications to combine the terms STEAM and TPACK.

As shown in **Figure 1**, the number of publications per year is growing rapidly. Indeed, even though before 2010, publications would not exceed the limit of 10, they reached 100 by 2015 and more than 600 by 2022. There is an apparent surge in the number of such articles and papers disseminated. In fact, there have been articles accepted for publication. This increase shows interest on the part of the authors (Donthu et al., 2021).

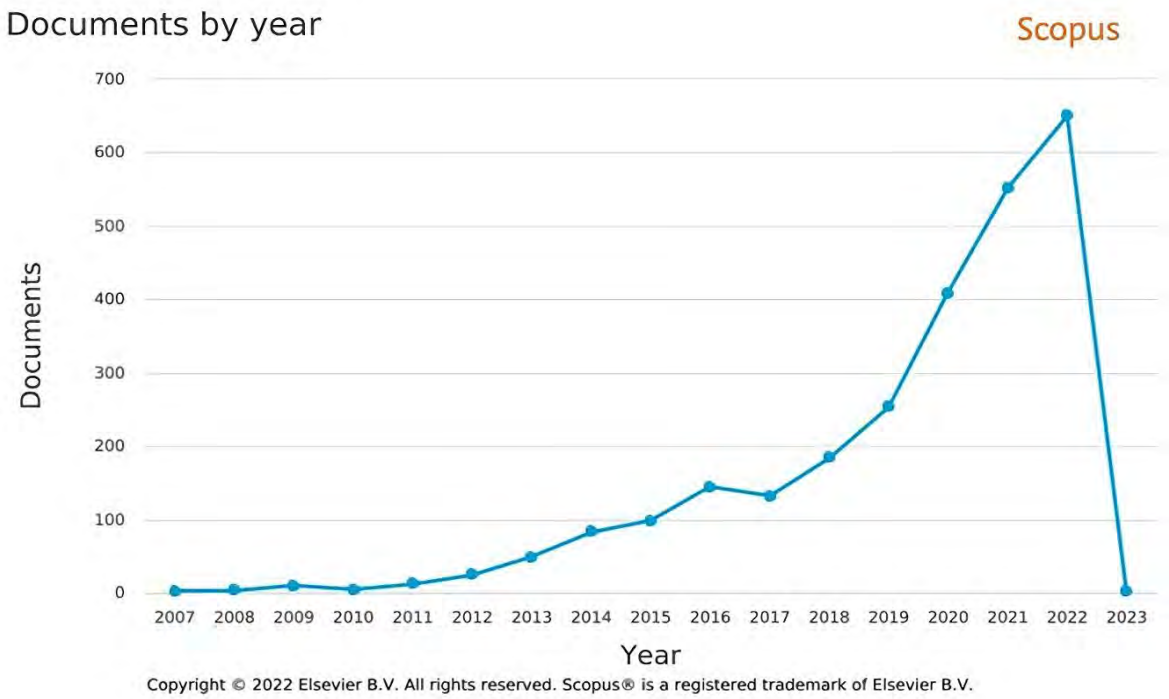

Figure 1. Number of publications per year (Source: https://www.scopus.com/)

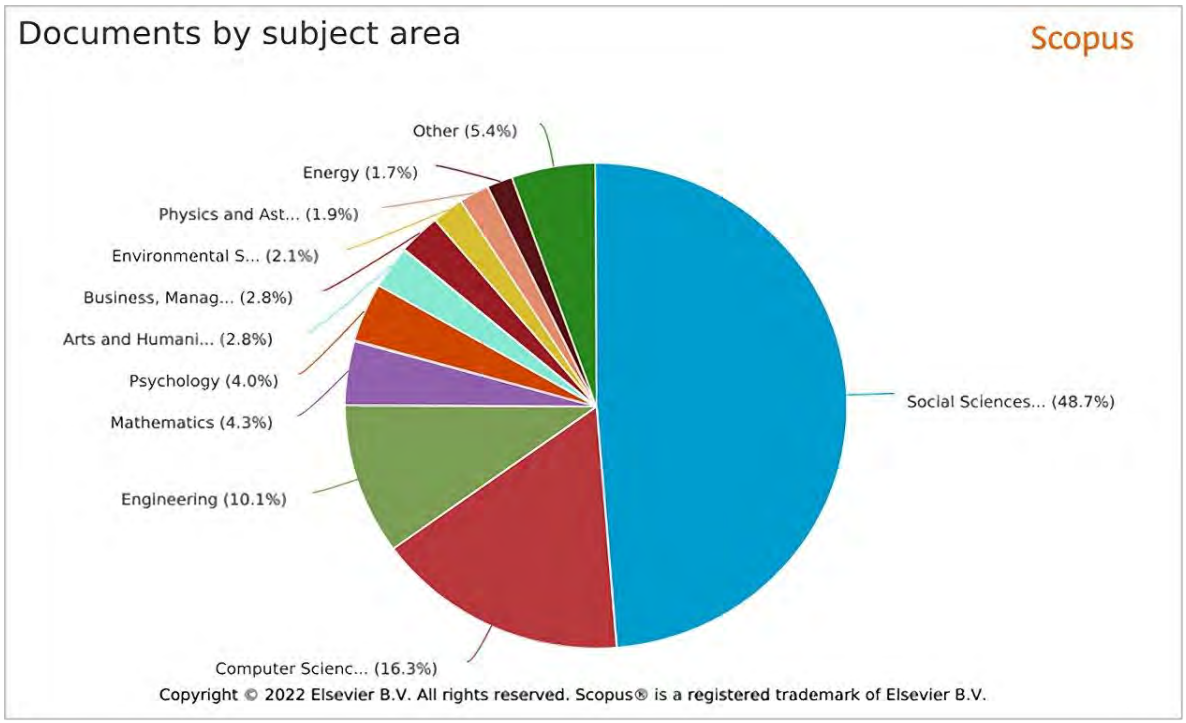

Figure 2. Documents per subject area (Source: https://www.scopus.com/)

With regard to the second research question, it is obvious that the articles published come from a wide range of subjects and study fields. Certainly, as shown in **Figure 2**, the majority of publications are from researchers in the field of social sciences. A considerable percentage of publications are also coming from engineering and computer science. Psychology, physics and astronomy, energy, mathematics, environmental studies, and arts and humanities are among the fields that have come up in the search, even if in a smaller percentage. It can be stated that there is a general interest from various fields in how TPCK and STEAM are combined (Aguilera & Ortiz-Revilla, 2021; Irwanto, 2021; Lee et al., 2022; Porras et al., 2022; Putri et al., 2022).

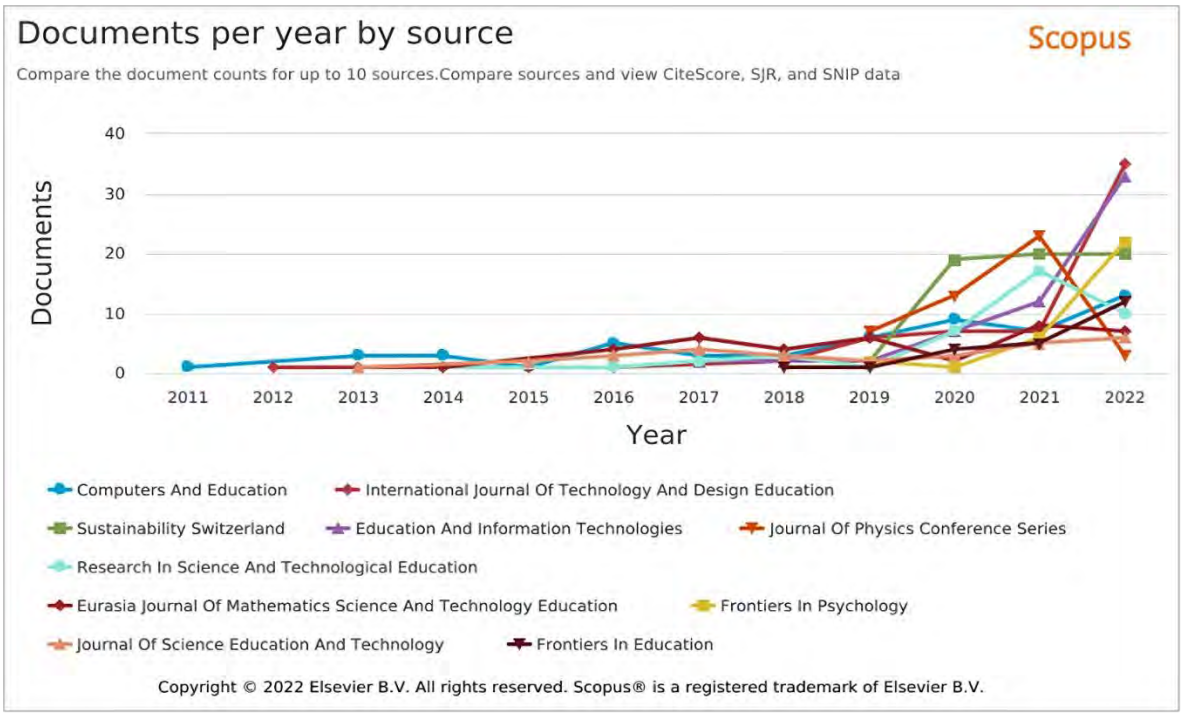

Figure 3. Documents per year by source (Source: https://www.scopus.com/)

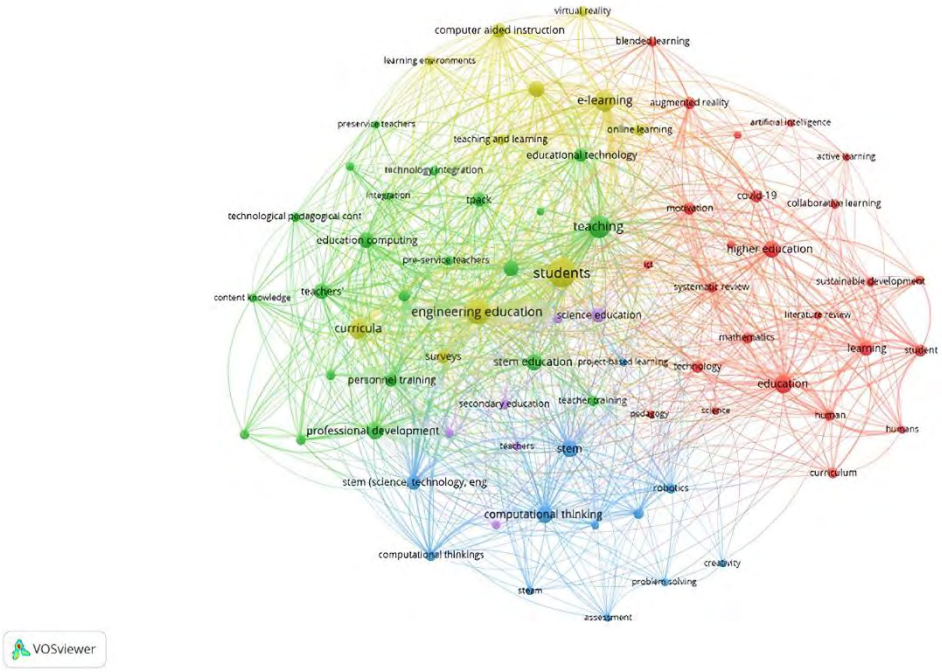

Figure 4. Keywords (Source: https://www.scopus.com/)

As **Figure 3** shows, when looking at the number of publications per year by source, a change in the tendency is observed. During the first years, from 2007 until 2018, the majority of articles were from journals focusing on the field of technology and education. However, from 2018 onwards, journals from other fields, such as science and mathematics education, psychology, and general education studies, seem to have prevailed. The former group of journals still publish relevant articles, though. That tendency can be attributed to a broadening of the rationale of the topic (Donthu et al., 2021).

With regard to the third research question, the keywords (**Figure 4**) that emerged most (**Figure 5**) were students, teaching, engineering education, education, curricula, and e-learning.

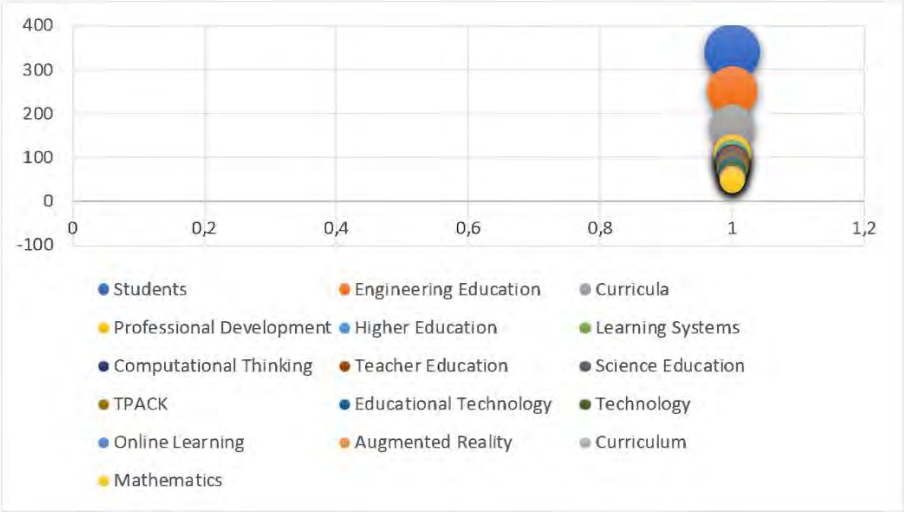

Figure 5. The most frequent keywords (Source: https://www.scopus.com/)

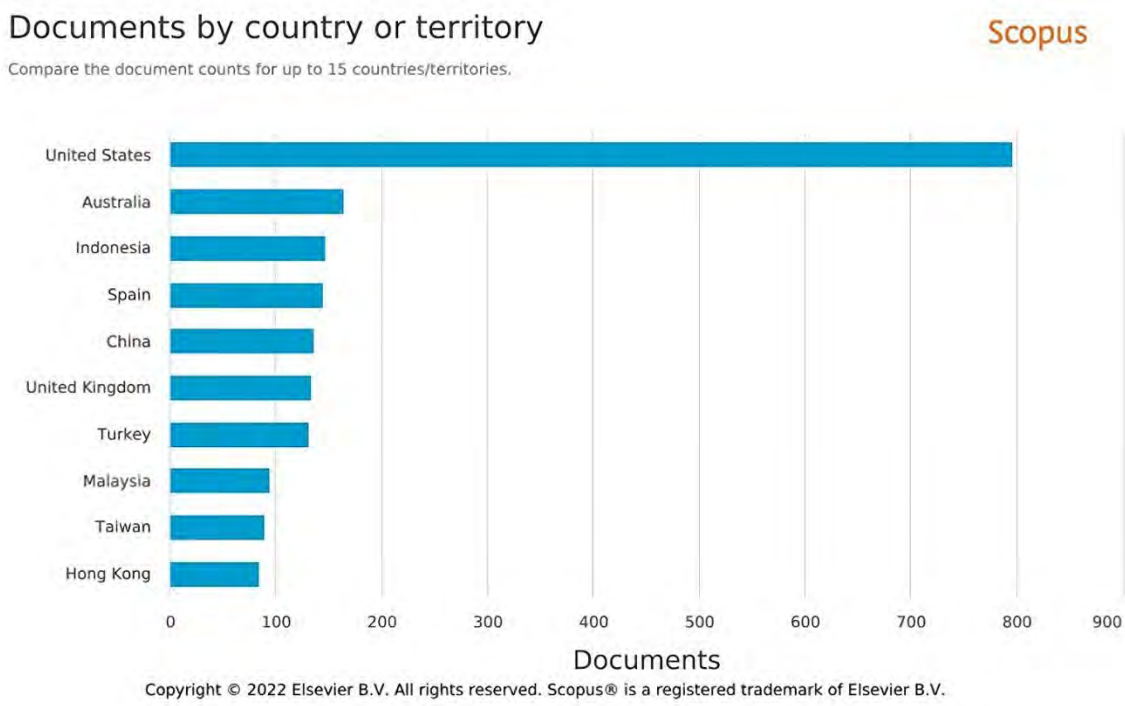

Figure 6. Documents by country or territory (Source: https://www.scopus.com/)

There were several other keywords that came up with considerable frequency, which were professional development, STEM, higher education, education computing, and learning. Lastly, there were others that were observed, but less frequently systems, STEM education, computational thinking, STEM (science, technology, engineering, and mathematics), teacher education, computer aided instruction, science education, learning, TPACK, teachers', educational technology, personnel training, technology, surveys, online learning, student, augmented reality, motivation, curriculum, technology integration, mathematics, and technological pedagogical content knowledge. All these cover a broad range of themes (Mishra & Koehler, 2006; Perignat & Katz-Buonincontro, 2019; Peruski & Mishra, 2004; Quigley & Herro, 2016).

Finally, with regard to the fourth question, as shown in **Figure 6**, the vast majority of the nearly 800 publications come from the USA. Australia, Indonesia, Spain, China, the United Kingdom, and Turkey have between 100 and 200 publications, while Malaysia, Taiwan, and Hong Kong have slightly less than 100. These tendencies are common with the articles focusing on STEAM or TPCK individually (Aguilera & Ortiz-Revilla, 2021; Irwanto, 2021; Lee et al., 2022; Porras et al., 2022; Putri et al., 2022).

DISCUSSION

The findings show that in the literature disseminated, and there is an interrelation between the concepts of STEAM and TPACK. This can probably be attributed to certain beliefs. STEAM teaching requires appropriate training that goes beyond the content knowledge of its components. This training is expected to qualify teachers to use ICT in their work in order to promote hands-on activities, inquiry-based learning, and creativity (Perignat & Katz-Buonincontro, 2019; Quigley & Herro, 2016). A growing number of researchers probably support the idea that these qualities can be developed with the help of TPACK. Indeed, the latter aims to introduce new learning modes, achieve better learning outcomes, and establish new educational environments with help of technology (Mishra & Koehler, 2006; Peruski & Mishra, 2004; Setiawan et al., 2019).

This belief seems to expand among researchers in different fields and areas of study. Of course, the majority of them are from the area of technology or education. However, the fact that researchers from other fields examine topics that combine the two concepts shows that there is a growing interest in seeing how innovative patterns of technological education, or STEAM, can be achieved. In relation to that, they also examine the kind of preparation that educators need in a growing number of areas, including Mathematics, Sciences, Social Sciences, and Arts. In other words, there seems to be a general tendency in various fields to see how students can be better educated and obtain qualifications to deal with contemporary challenges thanks to the appropriate use of technology. Similar conclusions have been stated in relevant previous studies (Aguilera & Ortiz-Revilla, 2021; Mishra & Koehler, 2006; Setiawan et al., 2019).

As can be understood from the common keywords, the cross points are related to the different points. Keywords such as “students” and “curriculum” address school functions, elements, and foundations. The emphasis on such keywords might imply that researchers believe that thanks to the implementation of STEAM and the promotion of TPCK, there is a need to revise curricula and the role of students (Allina, 2018; Perignat & Katz-Buonincontro, 2019; Shatunova et al., 2019). Simultaneously, the keywords such as “engineering education,” “teacher education,” and “professional development” might imply the belief that teacher training needs to adopt appropriate practices, which is also supported by previous studies (Mishra & Koehler, 2006; Setiawan et al., 2019). Apart from that, the keywords such as “augmented reality,” “learning systems,” “computational thinking,” and “online learning” might imply that there is a general idea that through STEAM and TPCK, new approaches in education can be promoted, as previously suggested (Mishra & Koehler, 2006; Quigley & Herro, 2016). Finally, the findings show that the same countries and contexts that examine STEAM or TPACK individually, such as English-speaking countries along with Spain, Turkey, and Asian countries, are generally the ones that move further to examine how they can be interwoven (Aguilera & Ortiz-Revilla, 2021; Irwanto, 2021; Lee et al., 2022; Porras et al., 2022; Putri et al., 2022; Santi et al., 2021; Suprapto et al., 2021).

CONCLUSIONS

The scope of this research is to identify whether the two terms TPACK and STEAM are associated, with the prism of research trends. The former refers to an accumulation of knowledge, skills, and qualities that educators should conceive in order to carry out effective pedagogical approaches with the help of technology in subjects of specific content (Mishra & Koehler, 2006). The latter addresses an innovative subject. This is an integration of several composing subjects: science, technology, engineering, arts, and mathematics. The activities of STEAM are expected to be based on inquiry-based approaches topics that rely on everyday topics and problem-solving (Quigley & Herro, 2016).

Research trends can be analyzed with the help of bibliometrics (Donthu et al., 2021). Both TPACK and STEAM have grabbed the attention of bibliometricians. The number of such studies has been increasing vastly over the last few years. TPACK is found to be related to topics such as technologies, computers in education, science education, teaching practices, teacher training, and professional development. The majority of these articles came from specific countries, particularly English-speaking, along with Asia, Spain, and Turkey (Irwanto, 2021; Lee et al., 2022; Putri et al., 2022; Soler-Costa et al., 2021; Suprapto et al., 2021). STEAM has also been linked to education innovations, skills, teacher training, education technologies, and science teaching, as well as education in other composing areas, such as mathematics and arts. The countries that disseminated most of the relevant articles were also mainly English-speaking or Asian, along with Spain or

Turkey (Aguilera & Ortiz-Revilla, 2021; López-Belmonte et al., 2021; Marín-Marín et al., 2021; Porras et al., 2022; Santi et al., 2021). There are, therefore, some common points between the two terms and some common findings of bibliometric studies around them (Aguilera & Ortiz-Revilla, 2021; Irwanto, 2021; Lee et al., 2022; Porras et al., 2022; Putri et al., 2022). There seems to be limited bibliometric research on articles that examine both of them. This was the aim of this study. Through the platform of Scopus, which is commonly used, a number of 2608 articles were collected. The trends examined were the rate of publications per year, areas of study, keywords, and countries of origin (Donthu et al., 2021).

The findings showed that there is an accelerating number of relevant publications. Most of them come from areas of technology or education. However, there are publications from other fields, such as Sciences, Arts and Humanities. The common points, as identified from keywords, are about education and teacher training, subject teaching, and education technologies. The countries that prevail are mostly English-speaking and Asian, along with Turkey, and Spain, in a smaller frequency. Those conclusions seem to be compatible with the ones of studies that focus on each of the two terms separately (Aguilera & Ortiz-Revilla, 2021; Irwanto, 2021; Lee et al., 2022; Porras et al., 2022; Putri et al., 2022).

It would be interesting if, in the future, further similar studies were carried out that might pay attention to other parameters of the bibliometric study, such as the examination of abstracts or data from more platforms (Donthu et al., 2021).

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Declaration of interest: The author declares no competing interest.

Data availability: Data generated or analyzed during this study are available from the author on request.

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