MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2023, 19(5), em2260
ISSN:1305-8223 (online)
OPEN ACCESS Review Article https://doi.org/10.29333/ejmste/13153

Professional development for science teachers: A bibliometric analysis from 2001 to 2021

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Received 07 January 2023 ▪ Accepted 27 March 2023

Abstract

The context of innovation education has made policymakers and researchers more and more interested in professional development (PD) for teachers. Along with that, the development of science and technology also leads to changes in the teaching of science subjects in schools, and thus affects the science teachers' PD in many countries. Analysis of publications related to this topic will create a picture of important trends and contributions of scientists and the scientific community and will have many implications for policymakers and researchers. This study uses bibliometric analysis to analyze 431 documents extracted from the Scopus database related to PD for science teachers. The results show a sharp increase in the number of studies on this topic, especially from 2018 to 2021 and mainly from research in the US and developed countries. Moreover, the issues of most interest are PD for in-service science teachers in terms of training, fostering and teacher competence related to sciences; various aspects of the science teaching process are student, curriculum and pedagogical content knowledge; and the belief of teachers, and inquiry in teaching science subjects. Policymakers and scholars can find great authors, research centers, influential studies and frequently published journals on this topic to read and research. Further studies based on the combination of bibliometric analysis with other methods may help paint a more profound picture of research findings on this topic.

Keywords: bibliometric analysis, professional development, science teacher, Scopus

INTRODUCTION

The growing unification of the world's economic, political, and cultural hierarchies has been underlining the requirements for a more competent and knowledgeable workforce in the education field so as to tackle challenges posed by learners in the classroom. As teaching becomes more complicated with increasing responsibilities, teachers encounter external complex challenges brought into the classroom by the learner through various channels (Koda, 2018). In the context of ever-changing education, there is a research gap for studies to highlight the historical characteristics as well as the directions and trends in professional development (PD) for science teachers in the upcoming future.

Policymakers, researchers, and educators have been paying more attention to the roles of PD for teachers in the implementation of educational innovation. Teachers' PD is regarded as the premise of all effective educational innovation forms (Desimone, 2009; Fore et al., 2015). The

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Contribution to the literature

- This article has drawn an overview of the research status on professional development for science teachers from 2001 to 2021.
- This study has shown that prominent authors, works, and journals have a lasting impact on the research trend on this issue.
- This study has pointed out the main research directions on professional development for science teachers and recommendations.

objectives of PD are to improve teachers' knowledge, alter their beliefs and teaching practice, and better learners' academic achievements (Capps et al., 2012). There has been consistent evidence from a range of domains for the effectiveness of PD in deepening teachers' professional knowledge and innovating their teaching methods (Timperley et al., 2007).

In the current scientific innovation, PD is assigned with great significance as a means to improve learners' academic outcomes in science subjects (Supovitz & Turner, 2000). Furthermore, many previous studies highlight the positive influence of PD on science teachers, including

(1) reinforcing teachers' perception and standpoints on science teaching and enriching professional knowledge (Nadelson et al., 2012),

(2) promoting teachers' application of student-centered approach and improving their lesson planning and delivering skills (Du et al., 2019),

(3) building up teachers' willingness and confidence for inquiry-based teaching, and

(4) changing teachers' beliefs and granting teacher autonomy (Dori & Herscovitz, 2005).

The term STEM, the initials of science, technology, engineering, and mathematics, which is widely used in different education levels to refer to career options in those domains, has become utterly prevalent in international discourses in the recent time (Marrero et al., 2014). The US's National Science Foundation (NSF) officially coined this term in 2001 (Donahoe, 2013; Sanders, 2009) in the hope to offer their children an education, where science, technology, engineering, and mathematics (STEM) are emphasized (Thibaut et al., 2018). Notwithstanding potential benefits and increased attention, STEM education still encounters certain challenges in the process of implementation (Nadelson & Seifert, 2017). To implement STEM integration effectively, teachers must have extensive knowledge of the science, technology, engineering, and math content they teach (Eckman et al., 2016). However, many teachers say they feel inadequately prepared to use STEM apps with their students in the classroom (El-Deghaidy & Mansour, 2015). To address these opportunities and challenges, it is recommended that teachers participate in continuous PD (Morrison et al., 2008; Tsai, 2006). Consequently, STEM education can be identified as an influencing factor in teachers' PD in recent times.

PD for teachers, especially science teachers, has been proposed and studied by researchers all over the world using a range of settings and approaches (Avraamidou, 2014). Some previous studies focused on the context for teachers' PD, especially for science teachers (for example, Postholm, 2012; Van Driel et al., 2012). Nevertheless, there has been no comprehensive review of the existing literature on PD for science teachers.

To provide a general overview of PD for science teachers in the period from 2001 to 2021, in this research study, we involve the authors, universities/research institutes and countries with long-term influential research works within this research trend. Also, the study aims to point out the current research trends in professional development for science teachers (PDST) and potential research directions. To fulfill these objectives, the researchers used the bibliometric methods with the Scopus database, one of the world's largest academic databases. Specifically, our study aims to answer these research questions:

1. *What were the volume, growth patterns and geographic distribution of the world's PDST publications in the period in question?*
2. *Who were the prominent authors and publications on PDST in the world in the period in question?*
3. *What were the prominent journals on PDST in the world in the period in question?*
4. *What were the key topics in the existing international literature on PDST in the period in question?*

Subsequently, the bibliometric analysis methods and data collection and screening procedure are presented in the methodology section. Then the result section discusses the findings in response to each research question above, followed by the discussion and recommendations based on the research findings. In the final section of the article, the conclusion and, of course, the limitations of the research are presented.

RESEARCH METHODOLOGY

Bibliometric Analysis

This study employed bibliometric analysis methods, originally proposed by Pritchard in 1969 (Osareh, 1996). Bibliometric analysis is the quantitative study of

bibliographic materials, which is capable of providing a paranormal overview of a specific research area based on the analyses with important features of a publications including titles, abstracts, keywords, references together with authors and author biographies (D. B. Pham et al., 2021; P. T. Pham et al., 2022; Senel & Demir, 2018).

Of all the research methods of analyzing scientific publications, bibliometric analysis methods are the most well-regarded thanks to its effectiveness and popularity among the scientific community (Bar-Ilan, 2008; Hallinger et al., 2016). This approach has been increasingly employed in research reviews in a wide range of areas including operations research and management science (Merigó & Yang, 2017); economics (Bonilla et al., 2015), safety culture (Van Nunen et al., 2018), human resources training (Danvila-del-Valle et al., 2019), computers & industrial engineering (Cancino et al., 2017), especially education (Cao et al., 2020; Do et al., 2021; Nguyen et al., 2020; D. B. Pham et al., 2020). However, this research study is supposedly the very first one to use bibliometric methods to look into the topic of PDST in schools.

In this study, we used descriptive statistics to list the relevant authors, authors' countries, authors' affiliations, sources, and documents in PDTS. Next, analytical techniques such as co-authorship analysis, citation analysis, and co-occurrence author keywords were used to determine the relationship between relevant objects, which related authors, countries, sources, affiliations, and documents in PDTS subject. Like many other studies (Hallinger & Nguyen, 2020; D. B. Pham et al., 2021; H. H. Pham et al., 2021), this study used VOSviewer software to analyze the data.

Database

This research study utilized one of the world's most popular databases currently, the Scopus database, similar to a number of previous studies including Pham et al. (2021b), Nguyen et al. (2020), Phan et al. (2022). Created by the reputable Elsevier Co, Scopus database possesses uniqueness in characteristics with more than 14,000 indexed journals belonging to a variety of domains (Mohamed et al., 2020).

It is considered as a substantial scientific database with the consistency in publication selection criteria (Hallinger & Nguyen, 2020); and the superiority in publication diversity compared with Web of Science regarding the education and social science fields (Mongeon & Paul-Hus, 2016). Given these advantages, the Scopus database was selected as the target index for this study. To determine the publications for the current research, the research group followed the steps in preferred reporting items for systematic reviews and meta-analyses (PRISMA) process (**Figure 1**).

To commence with, to find and identify the relevant publications to the research topic, the researchers

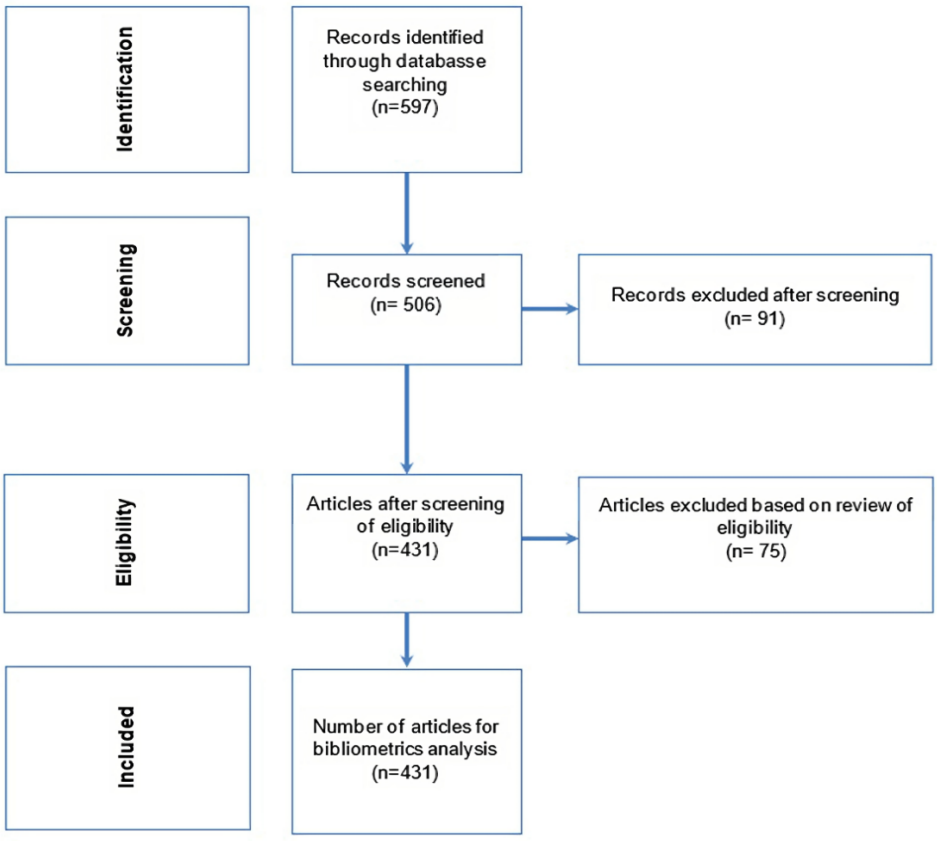

Figure 1. PRISMA process of determining publication dataset related to PDST (Source: Authors' own elaboration)

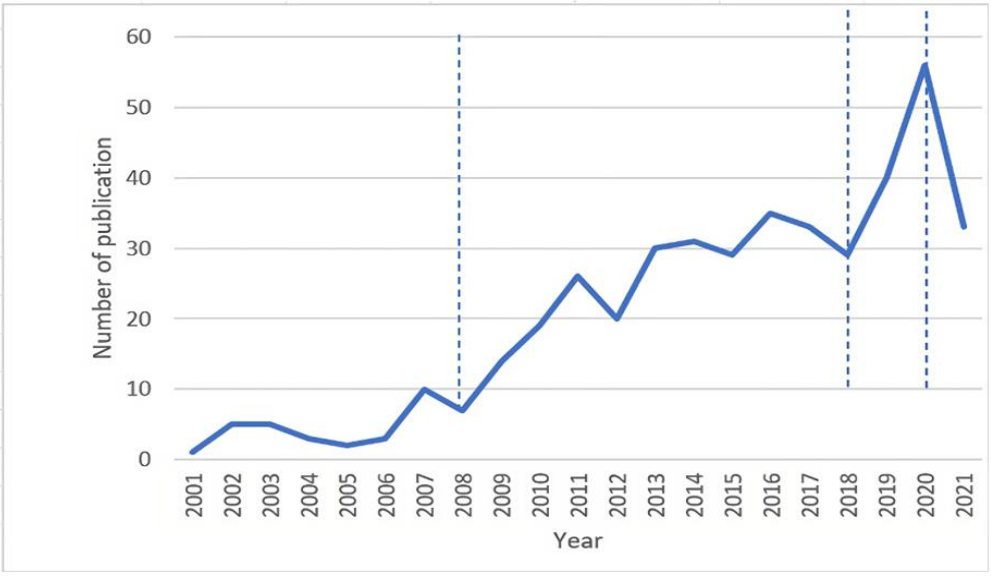

Figure 2. Volume growth of publications on PDST in the world from 2001 to 2021 (Source: Authors' own elaboration)

focused on two searching keywords namely 'professional development' and 'science teacher' and excluded all the publications with the keywords 'higher education' or 'HE' within the period from 2001 to the end of 2021. The pair of selected keywords is similar to that in Van Driel et al. (2012). The search on Scopus database was conducted with the following commands with which 597 publications were identified:

TITLE-ABS-KEY (("Professional development*") AND ("Science teacher*") AND NOT ("Higher education*") AND NOT ("HE*")) AND ((PUBYEAR>2000) AND (PUBYEAR<2022)) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (SUBJAREA, "SOCI")) AND (LIMIT-TO (LANGUAGE, "English")).

In the following screening step, the data would be proofread by the research members to exclude the repeated and incomplete documents and finalized for the analysis. After the screening, 91 publications were excluded from the dataset, most of which missed either keywords (Newton, 2009; Winrich & Garik, 2021), or both abstract and keywords (Johnston & Settlage, 2018; Ogawa, 2014).

In the eligibility phase, the research members were assigned specific publications that they were required to read and then discussed with the team the eligibility of those publications regarding the research topic based on their titles, abstracts and keywords. This phase resulted in a total of 75 publications being excluded from the data collection due to some reasons, including irrelevant topics (Shaw et al., 2014; Sofianidis & Kallery, 2021; Vekiri, 2013), mismatching research subjects, either computer science teachers specifically (Nakajima & Goode, 2019; Ravitz et al., 2017) or higher education teachers/students (Pekdag et al., 2021).

Finally, at the included step, we compiled a data set in the form of a Microsoft Excel file with 431 publications eligible for analysis. Each data line will contain different columns of information, including the author's name(s), link(s) of the author(s), document name, source type, document summary, keywords, number of citations of the document, year of publication and references.

RESULTS

Volume, Growth Pattern, & Geographic Distribution of PDTS Publications

The visual representation of the growth pattern of PDTS publications from 2001 to 2021 is illustrated in **Figure 2**.

Based on the growth directions of PDTS publications, the development pattern of PDTS publications can be divided into three periods:

1. From 2001-2008: *Insufficient interest:* In this period, the topic of PDTS seemed to be neglected by scholars with only 36 publications, accounting for 8.4% of all the publications over the whole period)
2. From 2008-2018: *Early development*: The topic of PDST initially attracted the attention of scholars around the world with 266 publications in this period, making up 61.7% of all identified published works.
3. From 2018-2021: *Large-scale development*: The PDST topic withdrew considerable interest from scholars with 129 publications in this period, constituting 29.9% of all examined publications.

The first and one-time published work included in the dataset is entitled "Spinning a web (case) around professional standards: Capturing the complexity of science teaching", introduced in 2001. This study accompanied a web-based situation development project in which a group of experienced high school science teachers worked together for a few months to

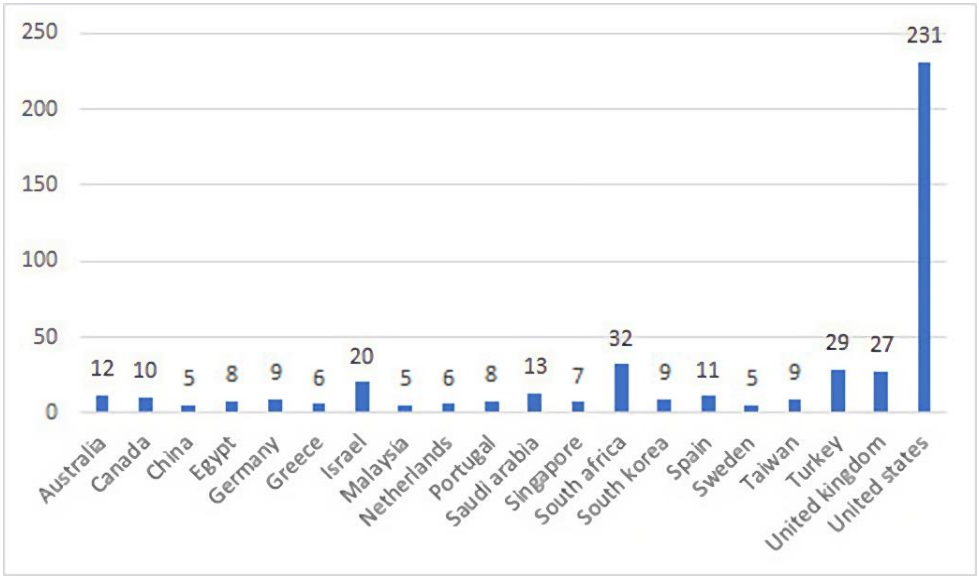

Figure 3. Countries with the greatest number of PDST publications in the world from 2001 to 2021 (Source: Authors' own elaboration)

film their own classes and gather video and audio comments on their lessons based on a rubric of science teaching. This project is evaluated as a resourceful PD experience for the participants (Louden et al., 2001).

The values on the vertical axis show that in the first period, there were an average of 4.5 publications per year, which increased to 24.2 and 32.3 publications in the second and third periods respectively. Overall, the annual number of publications over the whole 20-year time span was 20.5. In particular, the last four years, from 2018 to 2020, witnessed an annual value of 41.3 publications, more than doubling the overall annual value. However, as shown in **Figure 2**, even in the large-scale development period, the year-on-year growth of PDST publications was not stable. For instance, number of PDST publications in 2020 was 55, dramatically increasing from the value 40 in 2019; however, this value dropped to only 33 in the next year, 2021.

Next, we looked into the distribution of PDST publications over the world. It can be seen from **Figure 3** that of all 57 countries with research on this topic in the examined time span, there were 20 countries possessing a significant volume of PDST publications. The US, South Africa, and Turkey were the three most prolific nations with 231, 32, and 29 publications, respectively. Subsequently, the United Kingdom followed with 27 publications and Israel with 20 publications. The US contributed more than half of the publications in the dataset (accounting for 53.6%), which was 7.2 times larger than that of the second most prolific country.

Regarding the international collaboration network, a co-authorship analysis was carried out to determine the transnational research collaboration on the PDST topic in the period in question. After selecting authors with more than three publications on PDST, the co-authorship analysis was conducted, resulting in a visual representation of the countries with considerable co-author link strengths with others as presented in **Figure 4**. Specifically, the US had the greatest co-authorship link strength with a total link strength of 32, followed by the United Kingdom with 22, Saudi Arabia (19), Egypt (15), and Turkey (15). Another noteworthy point is that research collaboration through co-authorship between the US and Turkey was found to be the strongest with 12 co-authored publications; while the United Kingdom and Saudi Arabia research link strength came next with eight co-authored publications; and then the United Kingdom-Egypt (seven publications) and Saudi Arabia-Egypt (seven publications).

Moreover, the color of the node indicates the mean year of publication (of all the selected publications) of a country. The more recent the publications on PDST of a country were, the lighter is the color of the node. Thus, it can be implied that Turkey (with 29 publications, mean year of publication: 2017.10), China (with five publications, mean year of publication: 2018), Malaysia (with five publications, mean year of publication: 2018) are the relatively new names in the research field of PDST. In contrast, the countries marked with dark blue, including Australia (with 12 publications, mean year of publication: 2012.17), Israel (with 20 publications, mean year of publication: 2013.40), Netherlands (with six publications, mean year of publication: 2012.67), Trinidad and Tobago (with three publications, mean year of publication: 2009), seem to halt their interest in PDST topic at some point in the past with fairly limited publication volumes. Noticeably, while identified as the most prolific country on target topic, the US's mean year of publication was 2014.79, which implies that issue of PD for science teachers has been of constant interest among their scholar community for a long time.

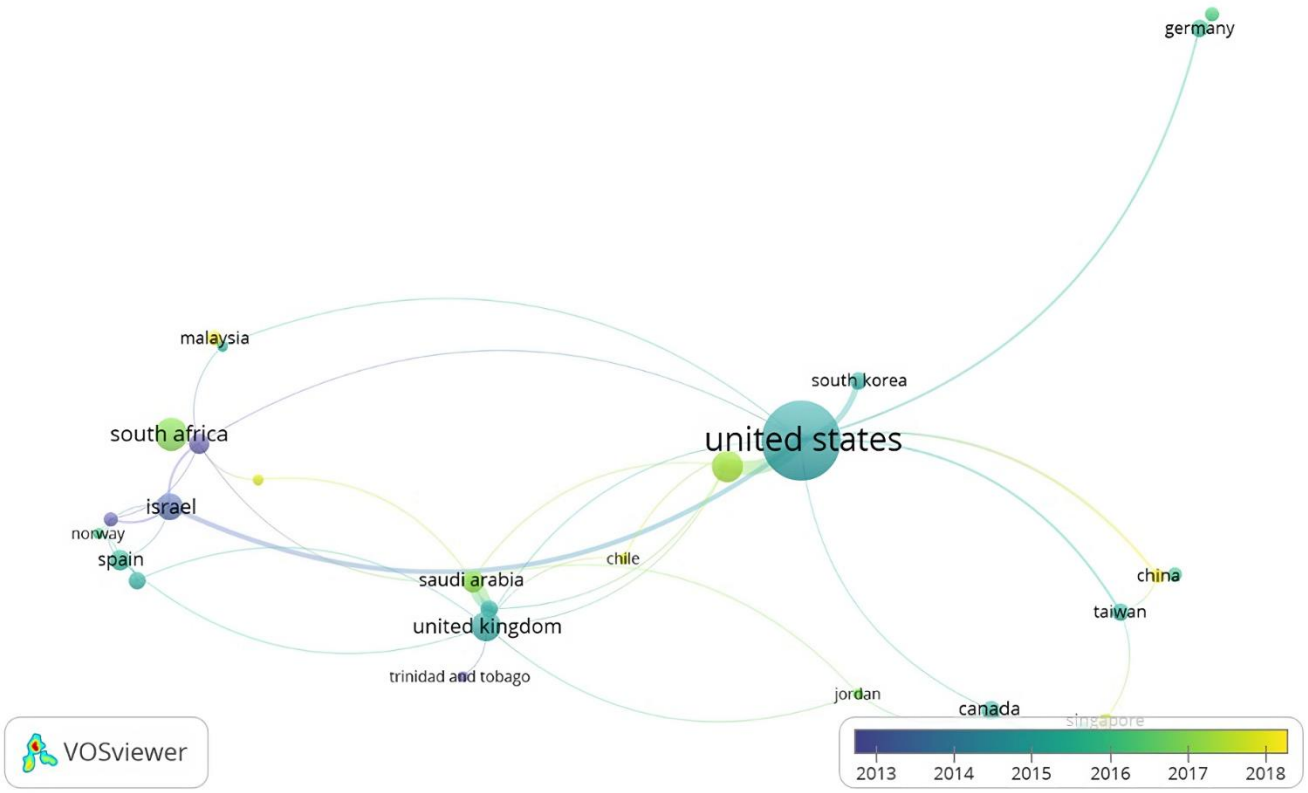

Figure 4. Visual representation of inter-nation co-authorship research collaboration in PDST publications (57 countries, minimum number of documents of an author: 3, 28 meet thresholds) (Source: Authors' own elaboration, using VOSviewer software)

Table 1. 12 most prolific authors on PDST

Rank	Author	Affiliation	Nationality	NP	TC
1	Mansour, N.	Qatar University	Qatar	9	179
2	Campbell, T.	University of Connecticut	The US	5	49
3	Maeng, J. L.	University of Virginia	The US	5	38
4	Johnson, C. C.	NC State University	The US	5	254
5	El-Deghaidy, H.	American University in Cairo	Egypt	5	128
6	Pringle, R. M.	University of Florida	The US	4	50
7	Bantwini, B. D.	Walter Sisulu University	South Africa	4	35
8	Bell, R. L.	Oregon State University	The US	4	28
9	Bancroft, S. F.	Southern Illinois University Carbondale	The US	4	30
10	Southerland, S. A.	Florida State University	The US	4	63
11	Saka, Y.	Bülent Ecevit University	Turkey	4	52
12	Alshamrani, S.	King Saud University	Saudi Arabia	4	56

Note. TC: Number of citations according to Scopus database & NP: Number of publications

The Most Prominent Authors & Publications in the Research Area of PDST

In the 20 year period from 2001 to 2021, as recorded in the Scopus database, there were 1,079 authors, coming from many different countries in the world, publishing their research works on the topic of PDST. 964 authors only had one publication on this topic, making up 89.3% of all the identified authors. Only 12 authors published more than four research works on PDST, whose biographical information is presented in **Table 1**.

Meanwhile, the influence of an author was also measured by the researchers using citation counts.

Table 2 shows that the majority of the most-cited authors in the list were cited with only one or two publications. Combining the two metrics (number of publication and total citation count), there were only three authors appearing in both of the lists, namely Carla C. Johnson, Nasser Mansour, and Heba EL-Deghaidy. Subsequently, the researchers pinpointed the most influential journal articles on this topic.

Table 3 presents the top-10 most-cited publications (all of them are journal articles) on PDST based on the Scopus database.

Table 2. 12 most cited authors

Rank	Author	Affiliation	Nationality	TC	NP
1	Jimoyiannis, A.	University of Peloponnese	Greece	254	2
2	Johnson, C. C.	NC State University	US	254	5
3	Eberhardt, J.	College of Natural Science	US	195	3
4	Mansour, N.	Qatar University	Qatar	179	9
5	Zhang, M.	Amazon.com, Inc.	US	177	2
6	Koehler, M. J.	Michigan State University	US	177	2
7	Lundeberg, M.	Michigan State University	US	157	1
8	Franklin, T.	Ohio University	US	151	1
9	Behrendt, M.	Ohio University	US	151	1
10	Makinster, J. G.	Hobart and William Smith Colleges	US	149	2
11	El-Deghaidy, H.	American University in Cairo	Egypt	128	5
12	Fargo, J. D.	Utah State University	US	125	2

Note. TC: Number of citations according to Scopus database & NP: Number of publications

Table 3. Top-10 most cited publications on PDST based on Scopus database from 2001-2021

Rank	Author(s)	Title	YP	Source	TC	SQ
1	Jimoyiannis (2010)	Designing and implementing an integrated technological pedagogical science knowledge framework for science teachers professional development	2010	Computers & Education	186	Q1
2	Zhang et al. (2011)	Understanding affordances and challenges of three types of video for teacher professional development	2011	Teaching & Teacher Education	157	Q1
3	Behrendt and Franklin (2014)	A review of research on school field trips and their value in education	2014	International Journal of Environmental & Science Education	151	Q3
4	Barab et al. (2003)	Designing system dualities: Characterizing a web-supported professional development community	2003	The Information Society	108	Q1
5	Tan (2011)	Mathematics and science teachers' beliefs and practices regarding the teaching of language in content learning	2011	Language Teaching Research	101	Q1
6	Lakshmanan et al. (2011)	The impact of science content and professional learning communities on science teaching efficacy and standards-based instruction	2011	Journal of Research in Science Teaching	97	Q1
7	Chinn (2007)	Decolonizing methodologies and indigenous knowledge: The role of culture, place and personal experience in professional development	2007	Journal of Research in Science Teaching	95	Q1
8	Greenleaf et al. (1998)	Integrating literacy and science in biology: Teaching and learning impacts of reading apprenticeship professional development	2011	American Educational Research Journal	89	Q1
9	Christodoulou and Osborne (2014)	The science classroom as a site of epistemic talk: A case study of a teacher's attempts to teach science based on argument	2014	Journal of Research in Science Teaching	85	Q1
10	Sato et al. (2008)	Improving teachers' assessment practices through professional development: The case of national board certification	2008	American Educational Research Journal	83	Q1

Note. TC: Number of citations according to Scopus database; YP: Year of publication; & SQ: Scopus quartile

The most-cited publication was "Designing and implementing an integrated technological pedagogical science knowledge framework for science teachers professional development" (Jimoyiannis, 2010), which discussed designing and implementing model of technological pedagogical science knowledge (TPASK)–a new model of PDST devised on integrated framework. This study aims to address the need for PD of science teachers in order to integrate information and communication technology to their in-class teaching practice (Jimoyiannis, 2010).

The earliest dated publication in the list was "Designing system dualities: Characterizing a web-supported professional development community" (Barab et al., 2003). This research study analyzed the challenges when designing and implementing a web-based PD system to facilitate a practitioner community of math and science teachers.

Table 4. Most prominent sources by number of publications & citation count

Rank	Source	TC	NP	SQ
Sources with largest numbers of publications				
1	Journal of Science Teacher Education	974	71	Q1
2	Journal of Research in Science Teaching	872	27	Q1
3	International Journal of Science Education	279	24	Q1
4	Research in Science Education	274	22	Q1
5	Journal of Science Education & Technology	288	21	Q1
6	Professional Development in Education	253	16	Q1
7	EURASIA Journal of Mathematics, Science & Technology Education	148	16	Q2
8	Journal of Baltic Science Education	35	12	Q2
9	International Journal of Science & Mathematics Education	92	12	Q1
10	African Journal of Research in Mathematics, Science a& Technology Education	34	11	Q3
11	Teaching & Teacher Education	344	9	Q1
Sources with largest numbers of citations				
1	Journal of Science Teacher Education	974	71	Q1
2	Journal of Research in Science Teaching	872	27	Q1
3	Teaching & Teacher Education	344	9	Q1
4	Computers & Education	299	4	Q1
5	Journal of Science Education & Technology	288	21	Q1
6	International Journal of Science Education	279	24	Q1
7	Research in Science Education	274	22	Q1
8	Professional Development in Education	253	16	Q1
9	Journal of Teacher Education	199	6	Q1
10	American Educational Research Journal	172	2	Q1
11	International Journal of Environmental & Science Education	172	5	Q3

Note. TC: Number of citations according to Scopus; NP: Number of publications; & SQ: Scopus quartile

The Most Prominent Journals/Publishers in the Area of PDST

Table 4 presents the leading sources (scientific journals) regarding the productivity and citation in the topic, most of which fell into the domain of education and received high rankings in the Scopus database. Journal of Science Teacher Education and Journal of Research in Science Teaching were the two sources with both the greatest publishing productivity and the highest number of citations among the seven sources appearing in both lists. Interestingly, some journals received many citations notwithstanding their limited number of publications, which underlined the great impact of their research issues or their reputation, such as Teaching and Teacher Education Journal and Computers and Education Journal.

Figure 5 shows a map of citation levels among journals that publish PDST. There were 19 journals with the minimum of five publications on PD, among which

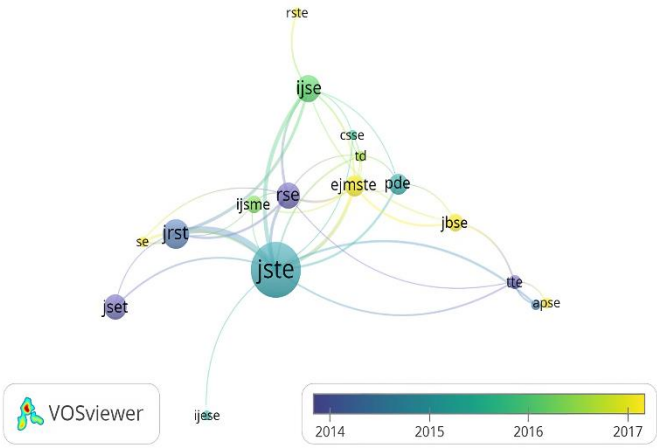

Figure 5. Visual representation of journal cross-citation network in research area of PDST from 2001-2021 (minimum number of documents of a sources: 5) (Source: Authors' own elaboration, using VOSviewer software)

Table 5. Abbreviations of the journal names

Journal title	Abbreviation
Asia-Pacific Science Education	APSE
African Journal of Research in Mathematics, Science & Technology Education	AJRMSTE
Cultural Studies of Science Education	CSSE
EURASIA Journal of Mathematics, Science & Technology Education	EJMSTE
International Journal of Environmental & Science Education	IJESE
International Journal of Science Education	IJSE
International Journal of Science & Mathematics Education	IJSME
Journal of Baltic Science Education	JBSE
Journal of Geoscience Education	JGE
Journal of Research in Science Teaching	JRST
Journal of Teacher Education	JTE
Journal of Science Teacher Education	JSTE
Journal of Science Education & Technology	JSET
Professional Development in Education	PDE
Research in Science Education	RSE
Research in Science & Technological Education	RSTE
Science Education	SE
Teaching & Teacher Education	TTE
Teacher Development	TD

Journal of Science teacher education were the most-cited journals by others regarding this topic.

Table 5 lists the abbreviations of the journal names.

Key Topics in the Existing Publications on PDST

Table 6 lists 15 keywords mentioned in the publications on PDST, which demonstrates different aspects in those publications, including pedagogical content knowledge (PCK) and professional aspects of teaching and learning, together with considerable attention to in-service teacher training.

Table 6. 15 keywords with the most co-occurrences in the publications on PDST

Rank	Keywords	n	TLS
1	Professional development	230	215
2	Science education	52	62
3	Science teachers	39	67
4	Teaching	30	88
5	Student	23	67
6	Pedagogical content knowledge	22	32
7	Teacher education	20	30
8	Professional aspects	19	69
9	Curriculum	18	48
10	Inquiry	17	31
11	Science teaching	16	27
12	Teacher learning	16	19
13	Science teacher education	14	21
14	Self-efficacy	14	20
15	In-service teachers	11	16

Note. n: Number of occurrences & TLS: Total link strength

Figure 6 visually presents the result of the author's keywords co-occurrence analysis given the minimum of 10 occurrences per keyword with which 16 keywords/noun phrases were identified.

During the analysis, some keywords with the same meaning or simply a shorter display were replaced; for example, 'teacher professional development' changed to 'professional development', 'curricula' changed to 'curriculum', 'students' changes to 'student', and 'science teacher professional development' changes to 'science teacher PD'. The size of the node represents the frequency of the keyword, while the width of the link between two keywords implies the co-occurrence count of the pair. Due to the complexity of the topic, the specific aspect of research in each publication greatly varied. Nevertheless, as shown in **Figure 6**, there were three main sub-topics: PD for in-service science teachers in terms of training, fostering and teacher competence related to sciences; various aspects of the science teaching process are student, curriculum and PCK; and a smaller aspect is the belief of teachers, and inquiry in teaching science subjects.

In **Figure 7**, the frequency of the keyword over time, including the second and third period from 2008 to 2021) is represented by different colors. As seen in **Figure 7**, the most recently mentioned keywords were "pedagogical content knowledge", "STEM education", "collaboration", "next generation science standards", "formative assessment" (five and three). Moreover, most of the listed keywords were mentioned in the more recent time span, which implies that the target topic of the research has gained more popularity recently.

DISCUSSION

The number of publications on PDST has rapidly increased in recent years, especially since 2018. This trend may be explained with the introduction of new policies emphasizing the roles of teachers in education innovation. From 2005 to 2014, UNESCO (2005) led a

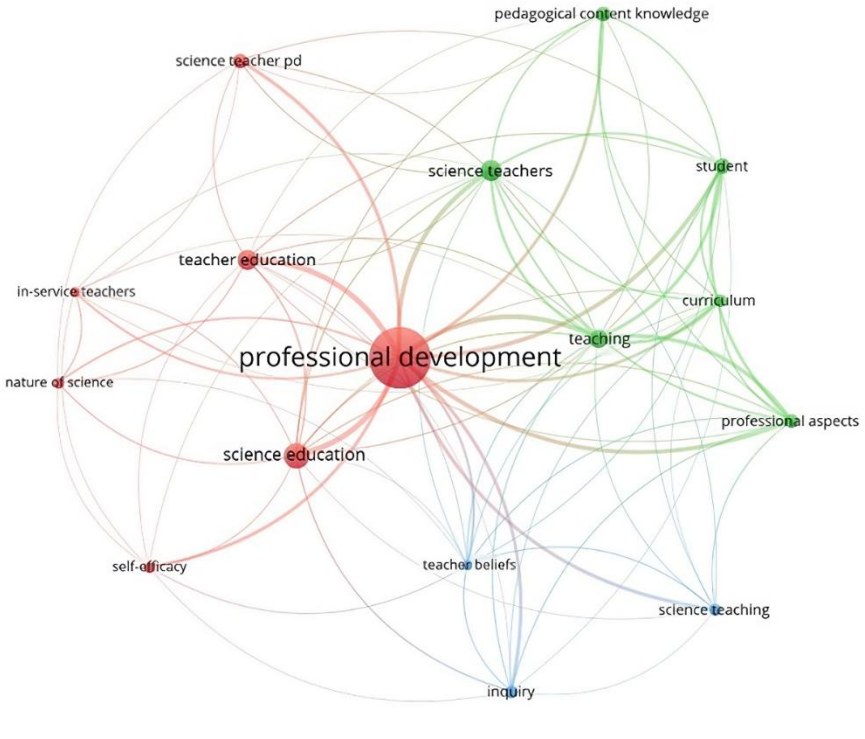

Figure 6. Visual representation of all keywords co-occurrences in publications on PDST (minimum of occurrence of a keyword: 10; 16 thresholds) (Source: Authors' own elaboration, using VOSviewer software)

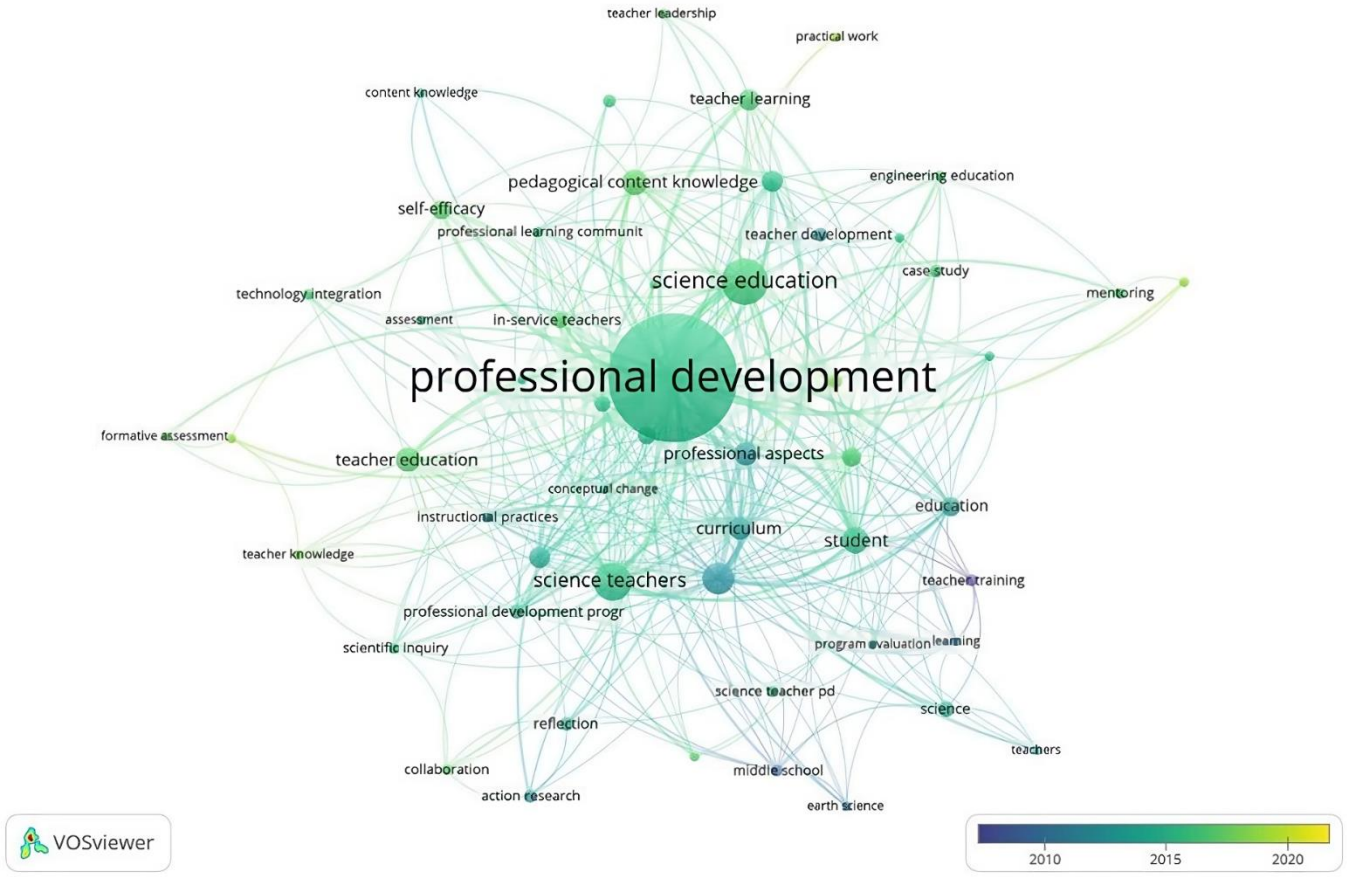

Figure 7. Visual representation of all keywords co-occurrences in publications on PDST in the second period over time (from 2008-2021, minimum number of occurrences of a keywords: 5, 54 thresholds) (Source: Authors' own elaboration, using VOSviewer software)

global effort to promote education for sustainable development. A United Nations report pointed out the extent of changes in policies in that direction (Buckler & Creech, 2014). However, it is reported by the United Nations that there was very limited empirical evidence for the changes related to pedagogical approaches. This organization also announced the primary objectives and expected outcomes by 2030; and suggested taking the challenge as opportunities for suitable career development (Bascopé et al., 2019). This is the driving force for research on PD for teachers in recent years.

Noticeably, the number of publications on PDST in 2021 was 33, significantly smaller than the values in 2019 and 2020, which can be explained with the impact of the COVID-19 pandemic. The outbreak of COVID-19 pandemic in 2020 severely interrupted education due to school closure requirements, causing negative influence on research activities as researchers' capacity to deliver their research was restrained (Onyema et al., 2020).

It is revealed that publications on PDST in developed countries are superior in terms of volumes compared to developing countries. This situation is rational due to the wide gap between developed and developing nations regarding teacher training practice under the great influence from domestic educational policies, in particular the US–the country with the greatest volume of PDST publications in the examined time span. In this country, National Board Certification is the driving force behind teacher PD (Park & Oliver, 2008). The US Federal Government has invested heavily in PD for science and math teachers in the past decade (Doyle et al., 2020). Thus, the topic of continuing teacher PD has been placed in the center of educational research over the last few decades by many educators, researchers, policy makers not only in the US but also in other countries in the world (Bayar & Kostereliogl u, 2014). The Government, education institutions, and teacher training centers are recommended to consult the teacher PD models of influential countries with profound research experience on this topic for an appropriate model for their own context.

It can be concluded that publications on PD have been published in high-quality journals. The most -cited documents generally belong to prestige journals with Q1 rankings in the education domain.

In the recent time, publications on PDST mainly focus on STEM education, which can be rationally justified by the fact that K-12 education's focuses have gradually

shifted to STEM to effectively prepare learners for the requirements of modern society. In some countries, this objective is also aligned with competency-based teaching approach in STEAM teaching, also known as integrated STEM education (Dare et al., 2021). The past decade has witnessed the combination of STEM education with arts to create STEAM in a new trend of contemporary education in fulfillment of the requirement for high-quality labor force with designing competency and creativity of the 4th Industrial Revolution (Keane & Keane, 2016). In the aim of effective development of STEM education programs, K-12 teachers' fundamental professional knowledge and STEM integrated teaching methods are necessarily improved (Ring et al., 2017). This requirement is particularly significant with researchers in PDST in the following stages of development.

PCK is another appealing topic with many researchers. PCK is the knowledge developed with the intersection of teaching content and pedagogical methods, which is demonstrated through teachers' understanding of the ways to organize and present different topics and issues of the subject in line with learners' varied preferences and levels. This knowledge is then exploited to attract learners in the teaching process (Shulman, 1987). From another perspective, Kind (2009) pinpointed the ways to utilize the potentials of PCK in further developing science teacher training practice. She argued that highlighting PCK more clearly in the process of teacher training may facilitate novice teachers in their teaching and support experienced teachers to reinforce more reflective teaching practices (Kind, 2009).

CONCLUSIONS

This paper analyzes the academic research trends in the existing literature on PD for science teachers with bibliometrics analysis methods and the Scopus database. The issue of PD for science teachers has received growing concern from scholars with increasing volumes of publications, yet mainly in a number of developed countries, particularly the US with by far the greatest number of publications. On the contrary, developing countries published a considerably limited number of research works on this topic. Most of the publications in the dataset of the study were introduced by high-ranked educational journals. The specific topics of publications on PDST were varied without any prominent sub-topics of research. Yet, it is possible to highlight some popular research channels with significant publication volumes such as PCK and professional aspects.

Recommendations

The research findings also underline some issues of PDST in the future, including:

Despite the strong interest in PDST seen in many countries, it is still necessary for further research on PDST in developing countries. Also, transnational research collaboration should be strengthened based on the existing research links on this topic between developed and developing nations. It is reasonable to look forward to a positive response to international efforts in order to further promote interest in PDST in developing countries.

It is also suggested that future studies maintain this research direction to propose strategies for sustainable PD for science teachers in satisfaction of STEM education innovation requirements.

In addition, we propose that future research focus on PDST based on information and communication technology given the importance of ICT integration to science education and its increasingly meaningful intervention in PD of science teachers. This has also been mentioned by Fernandes et al. (2020).

Limitations

Limitations are inevitable in any research study regarding the methodology, data or scope of the research. In this study, the first limitation lies in the fact that it does not involve all the documents related to PDST, for example, publications in Web of Science or Google Scholar without Scopus indexes. However, the impact of this limitation has been mitigated somewhat by the use of co-citation analysis, which allows the identification of 'co-cited' documents that fall within the broader literature that are omitted from Scopus.

The next limitation stems from the fact that only documents in English were selected for this study, which may not sufficiently reflect researchers' efforts with this issue. Apart from English, the research topic has been explored in different languages such as Turkish (Karaman & Apaydin, 2014), or Spanish (Cobos & González, 2021). Also, the Scopus database does not consistently list the author's name and affiliation and cannot be corrected manually, which possibly causes imprecision in analysis results as one author may be listed multiple times with different spellings or orders of their full name.

Last but not least, the mere research method of bibliometrics analysis may fail to comprehensively evaluate research quality and trends because the fundamental concepts or theories, and content of proposed, updated, or developed strategies for PD may not be clarified with these methods. In the future, the combination of these methods with others such as systematic analysis or quantitative research methods would be recommended to diminish the drawbacks of bibliometrics analysis methods and obtain additional findings for this current study.

Author contributions: HTP & C-TV: Concept and design, technical or material support, writing. **C-TV:** Editing and writing,

Critical revision of the manuscript, final approval. **T-LN, TN-TV, TH-CL, & H-CN:** Data acquisition, data analysis, statistical analysis. **C-TN:** Writing, editing/review. All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: This study was supported by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under Grant Number: 503.01-2021.19.

Acknowledgments: The authors would like to thank the Vietnam National Foundation for Science and Technology Development for funding this research. The authors also would like to thank Assoc. Prof. Tien-Trung Nguyen (Leader of the Research Group on Educational Sciences and Policies, Vietnam National University, Hanoi) for his excellent suggestions.

Ethical statement: Authors stated that ethical permission was not required for the study because humans and animals were not used. However, ethical guidelines were followed throughout the study.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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