Exploring the Research Trends of Technological Literacy Studies in Education: A Systematic Review Using Bibliometric Analysis

Edi Suyanto*, Muhammad Fuad, Bayu Antrakusuma, Suparman, and Ari Syahidul Shidiq

***Abstract*—To date, the development of technological literacy studies representing the dynamics and phenomena of research regarding technological knowledge, technological capacity, and critical thinking-decision making has not been reported in scientific publications. Therefore, the purpose of this study is to present a bibliometric and bibliographic review regarding technological literacy studies. A bibliometric analysis was used to conduct this study in which 83 selected documents from the Scopus database published between 1991 and 2022 were the data. Some analyses, such as performance, citation, co-word, and co-authorship, were carried out to analyze the data supported by VOSviewer and PoP software. Results of this study revealed that the number of studies regarding technological literacy increased gradually, while the progress citations on the studies of technological literacy were not consistent every year. In addition, the most productive and influential documents, authors, countries, institutions, and sources contributed to developing technological literacy research. Furthermore, autonomous technology is expected to be the newly trending research in the technology field. Consequently, the studies about autonomous technology can be directed to further educational studies focusing on technology education. The development of autonomous technology in the future, like a robot for teaching, contributes to educational advancement.**

***Index Terms*—Bibliometric analysis, Scopus, systematic review, technological literacy, VOSviewer**

I. Introduction

Industry 4.0 (the fourth industrial revolution) describes the fast development of science and technology in the 21st century [1]. The rapid and sophisticated progress of technologies requires every individual to adapt to the condition and situation by having 21st-century skills. Binkley *et al*. [2] stated that there are three essential literacies in the 21st century that have to be mastered by each individual: life and carrier literacy, learning and innovation literacy, and information, media, and technological literacy. This shows that technological literacy is one of the essential skills by which each individual has to respond to the emergence of new technologies actively. Moreover, the advancement of various life fields such as economics, education, science, management, health, and agriculture are highly affected by the newly appearing technologies [3–6]. It indicates that technological literacy controlled by individuals has an essential role in developing many life fields.

Technological literacy refers to the individual's skills in understanding, assessing, and managing the technology [4, 7–9]. Moreover, Choresh *et al*. [7] argued that technological literacy involves knowledge and skills, which represents the ability to apply knowledge in solving technological problems in real-world situations. In addition, Avsec and Jamsek [4] defined technological literacy as a fundamental achievement of technology-intensive education that leads the educational system's technological design. Meanwhile, Rupnik and Avsec [10] stated that technological literacy is the primary learning outcome of technology education. Moreover, some literature states that technological literacy consists of technological capacity, critical thinking and decision-making, and technological knowledge [4, 10, 11]. It can be defined as technological literacy refers to the abilities involving knowledge and skills to solve real technological problems through technology education.

The importance of technological literacy in education is due to it can support educational practitioners such as teachers and lecturers in organizing education, specifically in implementing learning [12]. Moreover, it can help them to understand what technological tools are suitable to be utilized in the learning process [9, 13]. In addition, Rupnik and Avsec [10] argued that technological knowledge is one of the components of technological literacy by which refers to teacher or lecturer knowledge related to traditional and new technologies that can be integrated into the curriculum [14–18]. Moreover, Schmidt *et al*. [19] revealed that technological knowledge is related to understanding various technologies, from conventional technologies such as paper and pencil to digital technologies such as software programs, the internet, interactive whiteboards, and digital video. Thus, technological knowledge is one of the technological pedagogical content knowledge (TPACK) frameworks in which these pieces of knowledge simultaneously and cooperatively work in the learning process system [20, 21].

From Shulman's idea related to pedagogical content knowledge emerging in 1986 until the appearance of the technological knowledge idea that became the unity of The TPACK framework [22–24], it indicates that the development of technological literacy concepts has started. To date, however, the development of technological literacy studies representing the dynamics and phenomena of research related to technological knowledge, technological capacity, and critical thinking-decision making has not been reported in scientific publications such as journal articles or

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conference papers. Meanwhile, the reports regarding the development of technological literacy studies are highly needed by many researchers who focus on educational technology to develop and find something new related to technological literacy. Therefore, this study wants to provide the development of technological literacy studies using a systematic review supported by bibliometric analysis.

Bibliometric analysis is a systematic method of exploring and analyzing large volumes of scientific data to show the state of emerging research trends [25–29]. Moreover, Donthu *et al*. [27] stated that bibliometric analysis could support gaining a one-step overview, identifying knowledge gaps, positioning intended contributions to the field, and deriving novel ideas for investigation. To date, many bibliometric analysis studies related to literacy have been carried out by many researchers. Some literature states that literacy categories include finance, information, mathematics and science, media, digital, and technology [30–32]. Many bibliometric analysis literature has studied financial literacy [33–37]. Many bibliometric analysis reports have also studied information literacy [38–48]. In addition, some bibliometric analysis studies related to digital literacy have been conducted [49–52]. Several bibliometric analysis studies regarding media literacy also have been carried out [53–55]. A few bibliometric analysis pieces of literature also have studied scientifical and mathematical literacy [56, 57]. Meanwhile, this bibliometric analysis study focuses on exploring the development of research related to technological literacy.

This current study aims to provide a bibliometric and bibliographic review of the numerous studies related to technological literacy in the Scopus database. The following research questions are directed to the aim of this bibliometric analysis study that is:

1) What is technological literacy studies' publication and citation trend in 1991–2022?
2) Which are the most productive and influential documents, authors, countries, institutions, and sources related to technological literacy studies?
3) What are the most frequently appearing keywords related to technological literacy studies? What is the distribution of the most appearing keywords in 2021–2022?
4) What are the social interactions among authors and countries related to technological literacy studies?

II. Methods

A systematic review using a bibliometric analysis was employed to present a bibliometric and bibliographic review related to technological literacy studies [25, 26, 28]. Fuad *et al.* [58] revealed five stages to carrying out the bibliometric analysis (See Fig. 1).

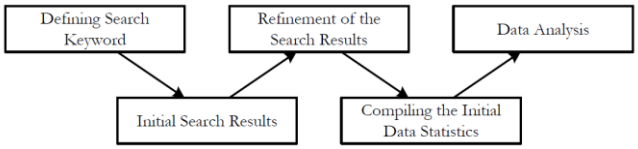

Fig. 1. The stages in conducting bibliometric analysis.

Every stage, in detail, of this current bibliometric analysis study was presented in the following subsection.

A. Defining Search Keywords

The Scopus database was utilized to search and find documents regarding technological literacy studies. Donthu *et al*. [59] argued that Scopus was one of the best scientific databases that provided many well-qualified documents, so it was selected to help search the qualified documents related to technological literacy studies. A particular keyword, "technological literacy" was used to explore the documents. In addition, the search process for documents regarding technological literacy studies was carried out on August 17, 2022, particularly at 7.29 AM.

B. Initial Search Results

An initial search using the keyword "technological literacy" found 3,434 documents published between 1965 and 2023. Some documents were still in the press, but many documents were published finally. The documents obtained were written in English, Spanish, Portuguese, Russian, German, Chinese, Turkish, Croatian, Lithuanian, French, Italian, Japanese, African, Persian, Bosnian, Dutch, Estonian, Norwegian, Serbian, Slovak, and Slovenian. In addition, the source type of documents, such as journals, conference proceedings, books, and book series. The document types obtained were the article, conference paper, book chapter, review, book, conference review, editorial, note, short survey, and erratum. Furthermore, most document titles did not contain the keyword "technological literacy".

C. Refinement of Search Results

Several inclusion criteria were established to find relevant documents related to technological literacy studies. Firstly, the title of the documents had to contain the keyword "technological literacy". Secondly, the status of the documents' publication stage was finally published. Thirdly, the documents were only written in English. Fourthly, the source type of documents was only journals. Fifthly, the document type was only an article. Lastly, the documents were published from 1991 through 2022. Furthermore, there were four stages in selecting the documents systematically that were: 1) identification, 2) screening, 3) eligibility, and 4) inclusion [60–63]. The document selection process for this bibliometric analysis study is presented in Fig. 2.

D. Compiling the Initial Data Statistics

The included documents were downloaded from the Scopus database in some formats, such as Comma Separated Values (CSV) and Research Information System (RIS). These formats consisted of bibliometric information, bibliographic information, and abstract and keywords [64]. In the Publish or Perish (PoP) software, some initial statistical data such as document title, document type, citation, author, publication year, publisher, and source could be observed. Moreover, the software was able to provide a summary of descriptive analysis such as total citation (TC), the total publication (TP), number of authors per publication (NAP), number of citations per publication (NCP), number of citations per year (NCY), g-index, m-index, and h-index [58].

E. Data Analysis

The performance analysis presented the publication and citation trend related to technological literacy studies [27]. PoP software was utilized to support the performance analysis [28]. Meanwhile, some science mapping analyses, such as citation, co-word, and co-authorship, were employed to examine the relationships among research constituents [27]. In detail, citation analysis was used to present the most productive and influential document, author, country, affiliation, and source related to technological literacy studies. In contrast, co-word analysis was used to show the most frequently emerging keywords regarding the technological literacy studies and present the distribution of the most appearing keywords in 2021–2022. On the other hand, co-authorship analysis was used to show the social interactions among authors and countries related to technological literacy studies. In addition, to enrich the science mapping analysis, network analysis consisting of network & overlay visualization and hierarchical clustering was performed [27, 65–67]. VOSviewer software supported science mapping and network analysis [68].

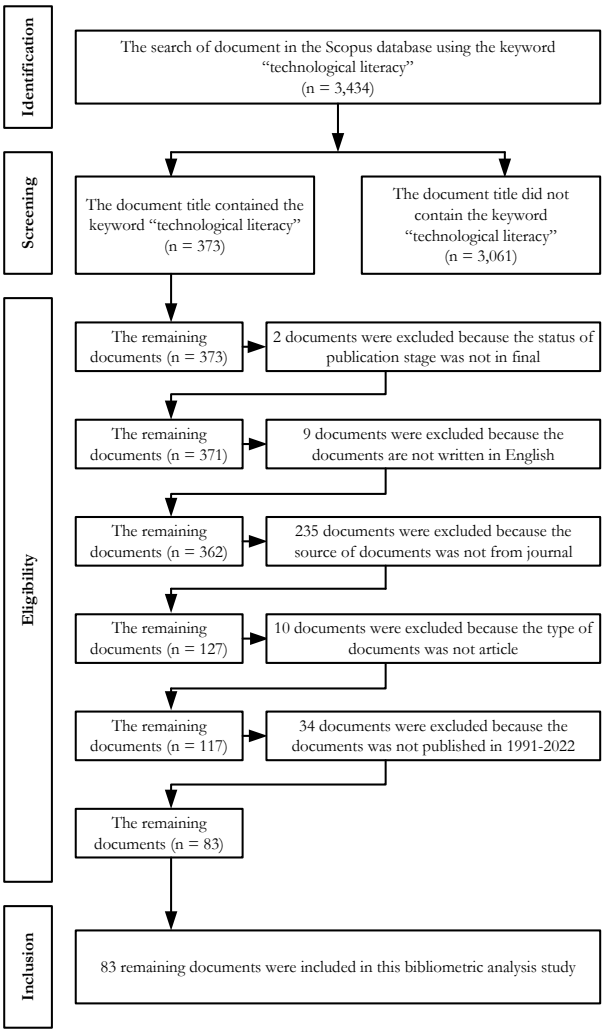

Fig. 2. The stages of document selection.

III. Results

A. Performance Analysis

Performance analysis was used to present the development of publications and citations related to the technological literacy studies from 1991–2022 (See Fig. 3).

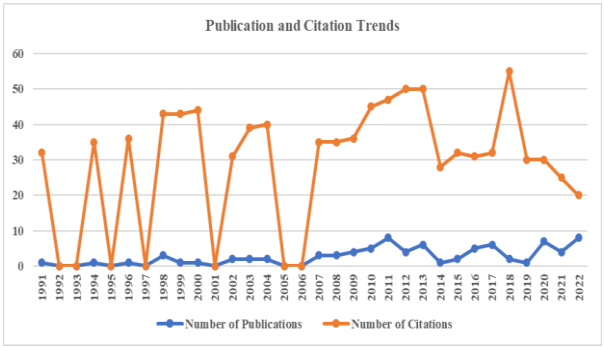

Fig. 3. The development of publication and citation regarding technological literacy studies.

Fig. 3 presents that the development of publications related to technological literacy studies relatively increased from 1991 to 2022. In detail, of 83 documents published in the period, there was one document published in 1991, 1994, 1996, 1999, 2000, 2014, and 2019, followed by two documents in 2002, 2003, 2004, 2015, and 2018, three documents in 1998, 2007 and 2008, four documents in 2009, 2012 and 2021, five documents in 2010 and 2016, six documents in 2013 and 2017, seven documents in 2020, and eight documents in 2011 and 2022. Meanwhile, of 930 citations recorded in Scopus database, there were 20 citations in 2022, followed by 25 citations in 2021, 28 citations in 2014, 30 citations in 2019 and 2020, 31 citations in 2002 and 2016, 32 citations in 1991, 2015 and 2017, 35 citations in 1994, 2007 and 2008, 36 citations in 1996 and 2009, 39 citations in 2003, 40 citations in 2004, 43 citations in 1998 and 1999, 44 citations in 2000, 45 citations in 2010, 47 citations in 2011, 50 citations in 2012 and 2013, and 55 citations in 2018. These show that the development of citations on technological literacy studies relatively soared from 1991 to 2018 but sharply fell between 2018 and 2022. Generally, the development of citations on documents related to technological literacy studies fluctuated between 1991 and 2022.

B. Science Mapping and Network Analysis

1) Citation analysis

Citation analysis presented the most productive and influential documents, authors, countries, institutions, and sources related to technological literacy studies. Total publication (TP) was used to establish the most productive authors, countries, institutions, and sources. In contrast, total citation (TC) was employed to determine the most influential documents, authors, countries, institutions, and sources [58]. Analysis of every unit was partially explained in the subsection. Firstly, the most influential documents related to technological literacy studies were presented in the top five documents with the highest citation (See Table I).

Table I shows that the document titled "the effect of principles' technological leadership on teachers' technological literacy and teaching effectiveness in Taiwanese elementary schools" was the most influential document regarding technological literacy. The document written by Chang was published by Educational Technology

and Society in 2012. From 2012 until 2022, the document had been cited as many as 38 times by other relevant documents.

TABLE I: TOP FIVE DOCUMENTS WITH THE HIGHEST CITATION

Document Title	Authors	Source	TC	Year
The effect of principles' technological leadership on teachers' technological literacy and teaching effectiveness in Taiwanese elementary schools	Chang, I. H	Educational Technology and Society	38	2012
Technological literacy classes: The state of the art	Byars, N. A	Journal of Engineering Education	28	1998
Technological literacy: A multiliteracies approach to democracy	Williams, P. J	International Journal of Technology and Design Education	25	2009
Emergent technological literacy: What do children bring to school?	Mawson, W. B	International Journal of Technology and Design Education	24	2013
Technological literacy reconsidered: A model for enactment	Ingerman, A. & Collier-Reed, B	International Journal of Technology and Design Education	22	2011

Secondly, the top five authors with the highest publication were the most productive authors, while the top five presented the most influential authors with the highest citation (See Table II).

TABLE II: TOP FIVE AUTHORS WITH THE HIGHEST PUBLICATION AND CITATION

The Five Productive Authors			The Five Influential Authors		
Author	Institution	TP	Author	Institution	TC
Avsec, S.	Ljubljana University	5	Isaacs, M. I.	Florida Gulf Coast University	135
Compton, V.	Waikato University	3	Poynton, T. A.	Suffolk University	120
Hallstrom, J.	Linkoping University	3	Sabella, R. A.	Florida Gulf Coast University	120
de Vries, M. J.	Delf University of Technology	2	Martinovic, D.	Windsor University	62
Ingerman, A.	Gothenburg University	2	Zhang, Z.	Windsor University	62

Table II shows that Avsec was the most productive author affiliated with Ljubljana University. He published five documents related to technological literacy studies. Meanwhile, Isaacs was the most influential author affiliated with Florida Gulf Coast University. Other relevant documents cited his document related to technological literacy studies as many as 135 times.

TABLE III: TOP FIVE COUNTRIES WITH THE HIGHEST PUBLICATION AND CITATION

The Five Productive Countries		The Five Influential Countries	
Country	TP	Country	TC
United States	23	United States	340
New Zealand	10	New Zealand	129
Sweden	9	Canada	96
South Africa	6	Spain	65
Slovenia	6	Netherland	56

Thirdly, the top five countries with the highest publication were the most productive countries, while the top five presented the most influential countries with the highest citations (See Table III).

Table III shows that the United States was the most productive country, which published 23 documents regarding technological literacy studies. The United States was also the most influential country. The documents related to technological literacy studies authorized by it had been cited as many as 340 times by other relevant documents.

Fourthly, the most productive institutions were presented by the top five institutions with the highest publication, while the top five institutions presented the most influential institutions with the highest citation (See Table IV).

TABLE IV: TOP FIVE INSTITUTIONS WITH THE HIGHEST PUBLICATION AND CITATION

The Five Productive Institutions			Top Five Influential Institutions		
Institution	Country	TP	Institution	Country	TC
Ljubljana University	Slovenia	3	Florida Gulf Coast University	United States	135
Waikato University	New Zealand	2	Suffolk University	United States	120
Florida Gulf Coast University	United States	1	Windsor University	Canada	62
Suffolk University	United States	1	Granada University	Spain	60
Windsor University	Canada	1	Salamanca University	Spain	60

Table IV shows that Ljubljana University was the most productive institution in Slovenia, publishing three documents related to technological literacy studies. Meanwhile, Florida Gulf Coast University was the most influential institution in the United States. The documents regarding the technological literacy studies reported by the institution had been cited as many as 135 times by other relevant documents.

Fifthly, the most productive sources were presented by the top five sources with the highest publication, while the top five sources presented the most significant sources with the highest citation (See Table V).

TABLE V: TOP FIVE SOURCES WITH THE HIGHEST PUBLICATION AND CITATION

The Five Productive Sources			The Five Influential Sources		
Source	Publisher	TP	Source	Publisher	TC
International Journal of Technology and Design Education	Springer	36	International Journal of Technology and Design Education	Springer	373
IEEE Transaction on Education	Institute of Electrical and Electronics Engineers Inc.	3	Computers in Human Behavior	Elsevier Ltd	120
Journal of Engineering Education	Willey-Blackwell Publishing Ltd	3	Journal of Engineering Education	Willey -Blackwell Publishing Ltd	90
World Transactions on Engineering and Technology	World Institute for Engineering and Technology Education	2	Teaching and Teacher Education	Elsevier Ltd	62

Education Computers and Composition	Elsevier Ltd	2	Journal of Librarianship and Information Science	SAGE Publications Ltd	60

Table V shows that the International Journal of Technology and Design Education was the most productive source, which published 36 documents related to technological literacy studies. It was also the most influential source. The documents associated with the technological literacy studies published by Springer Publishing Inc. had been cited as many as 373 times by other relevant documents.

2) Co-word analysis

Co-word analysis consisted of network visualization and overlay visualization enriched by the hierarchical clustering analysis [58]. Firstly, network visualization supported by hierarchical clustering analysis was performed to present the most emerging keywords related to technological literacy studies. The smallest number of occurrences of a keyword was selected, as many as two occurrences in which it appeared 21 inter-connected keywords (See Fig. 4).

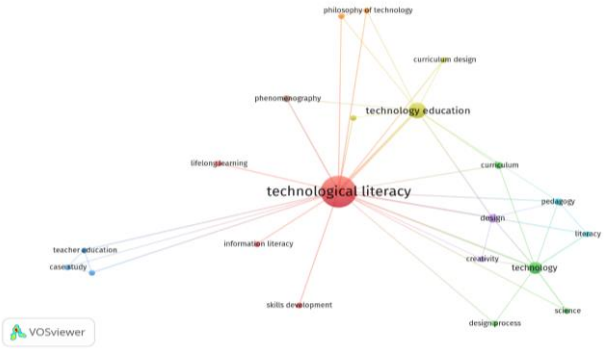

Fig. 4. The emerging keywords related to technological literacy.

TABLE VI: THE RESULTS OF HIERARCHICAL CLUSTERING ANALYSIS OF THE EMERGING KEYWORDS

Cluster	Keywords	Occurrence	Total Link Strength
Red	Technological Literacy	63	48
	Skills Development	2	2
	Lifelong Learning	2	2
	Information Literacy	2	2
Green	Technology	9	14
	Curriculum	3	3
	Science	2	3
	Design Process	2	2
Blue	TPACK	2	4
	Teacher Education	2	4
	Case Study	2	3
Yellow	Technology Education	15	22
	Curriculum Design	2	3
	Democracy	2	3
Purple	Design	5	9
	Creativity	2	3
Blue Sky	Pedagogy	3	6
	Literacy	2	5
Orange	Philosophy of Technology	2	4
	Technological Knowledge	2	4
Brown	Phenomenography	3	4

Fig. 4 presents that 21 inter-connected keywords were distributed to eight clusters by which there were four keywords in the red and green clusters, followed by three keywords in the blue and yellow clusters, two keywords in the purple, blue sky, and orange clusters, and one keyword in the brown cluster. Hierarchical clustering analysis supported the group the themes of the emerging keywords (See Table VI).

Table VI shows that the most emerging keyword in the red cluster was "technological literacy," followed by "technology" in the green cluster, "technology education" in the yellow cluster, "design" in the purple cluster, "pedagogy" in the blue-sky cluster, "phenomenography" in the brown cluster, "philosophy of technology" and "technological knowledge" in the orange cluster, and "TPACK," "teacher education," and "case study" in the blue cluster.

Secondly, overlay visualization supported by the hierarchical clustering analysis was performed to present the distribution of the most emerging keywords regarding technological literacy between 2021 and 2022. The smallest number of occurrences of a keyword was selected, as many as one occurrence by which appeared 258 inter-connected keywords (See Fig. 5).

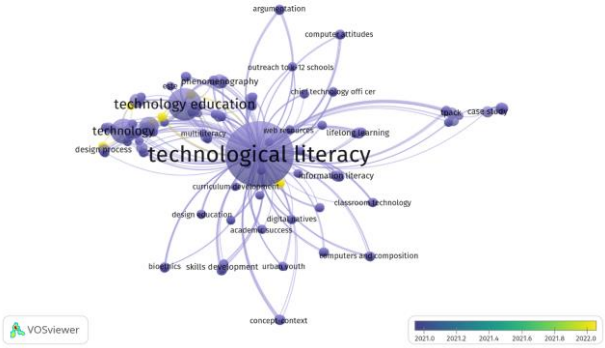

Fig. 5. The distribution of emerging keywords regarding technological literacy in the recent period

Fig. 5 presents that there were some emerging keywords in the period 2021–2022, such as "information security", "autonomous technology", "assessment", "design activity", and "curriculum". These findings show that the emerging keywords have become the trending research on technological literacy.

3) Co-author analysis

This study's co-authorship analysis consisted of the author unit and country unit. Firstly, co-authorship analysis in the author unit was used to present authors' social relationships related to technological literacy. The smallest number of documents of an author was selected, as many as one document in which it appeared eleven commonly inter-connected authors (See Fig. 6).

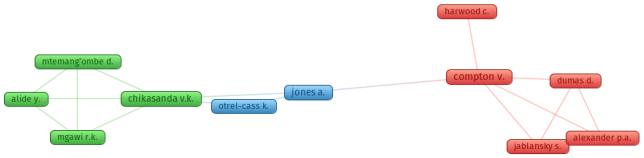

Fig. 6. The social interactions among authors related to technological literacy studies.

Fig. 6 shows that there were three clusters such as green, blue, and red, in which each author was commonly connected

among each other. There were five authors in the red cluster: Alexander, Compton, Dumas, Harwood, and Jablansky. Meanwhile, there were four authors in the green cluster: Alide, Chikansanda, Mgawi, and Mtemang-Ombe. In addition, there were two authors in the blue cluster such as Jones and Otrel-Cass.

Secondly, co-authorship analysis in the country unit was used to present the social interactions among countries regarding technological literacy studies. The smallest number of documents of an author was selected as many as one document in which it appeared four commonly inter-connected authors (See Fig. 7).

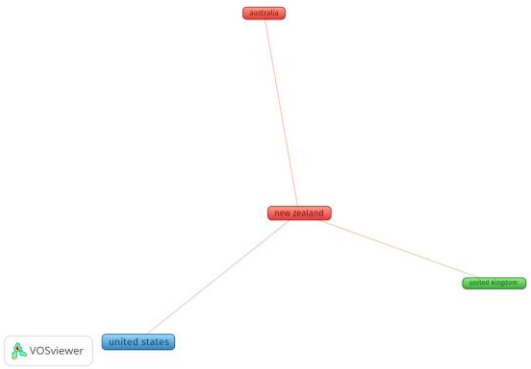

Fig. 7. The social interactions among countries regarding the technological literacy studies.

Fig. 7 shows that New Zealand was one country that had social relationships with the United States, United Kingdom, and Australia in conducting the studies related to technological literacy. It shows that New Zealand has wide networking in technological literacy studies.

IV. Discussion

A. Publication and Citation Trend of Technological Literacy Studies

The development of publications regarding technological literacy studies relatively soared from 1991 to 2022. It shows that every year the number of studies about technological literacy increases gradually. A lot of bibliometric analysis studies also revealed that the development of publications related to information literacy relatively increased every year between 2000 and 2022 [39, 40, 42–44, 46]. These reports show that the development of studies related to information literacy soars gradually. The fast progress of technology in the 21st century affects the much information which the information abundance can provide a positive effect and also a negative impact on each individual [69]. This indicates that information literacy is required for individuals to select beneficial information from the phenomena of much information. It can be interpreted that the abundant information caused by the rapid progress of technology affects the development of publications related to technological literacy from 1991–2022, which is relatively increasing.

In addition, the development of citations on documents related to technological literacy studies relatively fluctuated between 1991 and 2022. It indicates that the progress of citations on the studies about technological literacy is not consistent every year, which is not equal to the development of publications of studies related to technological literacy. A few bibliometric analysis studies also reported that the growth of citations towards information literacy studies fluctuated relatively from 2000 to 2015 [42, 43]. These reports show that the number of citations on documents related to information literacy does not soar consistently every year. It interprets that the citation progress of studies about technological literacy, which does not increase consistently, is related to the citation development of documents regarding information literacy which relatively fluctuates. It is due to the abundant information being highly affected by the fast growth of technologies.

B. The Most Productive and Influential Documents, Authors, Countries, Institutions, and Sources Regarding Technological Literacy Studies

Most of the top five documents with the highest citation focus on the principles of technological leadership and its impact on the technological literacy of Taiwanese elementary teachers. In addition, these documents also study technological literacy classes, emergent technological literacy, and a model for enhancing technological literacy. Some interventions, such as learning models and strategies, become the focus of research related to technological literacy in the educational field. These interventions are used to enhance the technological literacy of students and teachers. A few of the pieces of literature argued that several interventions, such as learning models and learning strategies, are highly needed to enhance students' or teachers' technological literacy through the learning process [3, 13, 70]. It is in line with Avsec and Jamsek [4], stating that rapid technological progress in the 21st century requires technological literacy. Thus, technological literacy is the ability that has to be enhanced to support fast technology development.

Furthermore, Avsec, affiliated with Ljubljana University, was the most productive author who had published five documents related to technological literacy studies. He conducted some studies related to technological literacy for students aged 6–18 in Avsec and Jamsek [4], factors affecting secondary school students' technological literacy in Avsec and Jamsek [71], academic success and technological literacy in secondary education in Avsec and Szewczyk-Zakrewska [72], profiling an inquiry-based teacher in the technology-intensive open learning environment in Avsec [73], and a transdisciplinary educational approach on students' technological literacy in Rupnik and Avsec [10]. This shows that to carry out the studies about technological literacy, Avsec involves some authors such as Jamsek, Szewczyk-Zakrewska, and Rupnik. It indicates that Avsec has social interactions with other authors concerned about technological literacy studies. On the other hand, Isaacs, affiliated with Florida Gulf Coast University, was the most influential author by which his study with the title "school counselor perceived importance of counseling technology competencies" published in Computers in Human Behavior in 2010 has been cited by

many as 135 times to date. He carried out the study by involving other authors such as Sabella and Poynton. It shows that the study conducted by Isaacs *et al.* [74] has been cited by an average of nearly ten citations every year between 2010–2022.

From then on, the United States was the most productive country, which published 23 documents related to technological literacy studies. Many meta-analysis studies also revealed that the United States was the most productive country in reporting the study results related to information literacy [39, 41–43]. In addition, Alagu and Thanuskodi [49] stated that the United States was the most productive country and had published many documents related to digital literacy. It shows that the United States is the most productive country in reporting the study results regarding technological literacy and the most productive country in reporting the study results related to information literacy and digital literacy. Furthermore, the United States was also the most influential country. The documents related to technological literacy studies reported by it had been cited as many as 340 times by other relevant documents. A few bibliometric analysis pieces of literature also revealed that the United States was the most influential country in which the documents related to information literacy and digital literacy [39, 41, 50]. It shows that the United States is not only the most influential country related to technological literacy studies but also the most influential country related to information literacy and digital literacy.

In addition, Ljubljana University was the most productive institution in Slovenia, which published three documents related to technological literacy studies. Meanwhile, Florida Gulf Coast University was the most influential institution in the United States. The documents regarding the technological literacy studies reported by the institution had been cited as many as 135 times by other relevant documents. It shows that most institutions reporting technological literacy studies are affiliated with the United States, such as Florida Gulf Coast University and Suffolk University. In addition, most of the institutions that influence the studies related to technological literacy also affiliate in the United States, such as Florida Gulf Coast University and Suffolk University, and Spain, such as Granada University and Salamanca University. Some bibliometric analysis studies also revealed that many institutions located in the United States contribute to the studies related to information literacy [39, 41–43, 46], and digital literacy [49, 50]. This shows that the United States contributes to technological literacy studies and information and digital literacy.

Furthermore, the International Journal of Technology and Design Education was the most productive source, which published 36 documents related to technological literacy studies. The source was also the most influential source. The documents regarding the technological literacy studies published by Springer Publishing Inc. had been cited as many as 373 times by other relevant documents. Many bibliometric analysis literatures also reported that Springer Publishing Inc was the most contributed publisher in reporting the studies related to information literacy [38, 39, 41–44, 46, 47], digital literacy [49–51, 54], and media literacy [53, 55]. It shows that Springer Publishing Inc not only contributes to publishing studies about technological literacy but also publishes studies related to information literacy, digital literacy, and media literacy.

C. The Most Emerging Keywords Regarding Technological Literacy Studies and Its Distribution in the Recent Period

The red cluster consists of four keywords such as "technological literacy," "skill development," "lifelong learning," and "information literacy." Technological literacy and information literacy become the focus of this cluster. The keyword of technological literacy emerges as many as 63 times which shows that the keyword of technological literacy appears in 63 documents. In 2022, there is one study containing the keyword of "technological literacy" by which the study with the title "optimizing technological literacy acquirement to protect privacy and security" was conducted by Hirschprung *et al.* [75]. Technological and information literacy are commonly related in that the fast progress of technologies in the 21st century affects abundant information. The information abundance provides both positive and negative effects [69, 76]. Consequently, information literacy requires individuals to sort every piece of information obtained to get beneficial information.

The green cluster contains four keywords such as "technology", "curriculum", "science", and "design process". "Technology" and "science" become the focus of this cluster. Technology and science are two components that are commonly related to each other. The development of science is affected by the progress of technology, while the appearance of new technologies is due to the advancement of science [77]. It shows that there is a positive relationship between technology and science. Furthermore, the orange cluster consists of keywords such as "philosophy of technology" and "technological knowledge". Rupnik and Avsec [10] stated that technological knowledge is one of the components of technological literacy, which refers to teacher or lecturer knowledge regarding traditional and new technologies that can be integrated into the curriculum [15, 17, 18]. From now on, the blue cluster contains three keywords such as "TPACK," "teacher education," and "case study," in which technological knowledge is one of the units of the technological, pedagogical, and content knowledge (TPACK) framework [22–24]. In addition, one keyword in the brown cluster was "phenomenography." Case studies and phenomenography are research types of the qualitative approach [78, 79]. This shows that the qualitative approach is often used to conduct studies related to technological literacy.

The yellow cluster contains three keywords such as "technology education", "curriculum design", and "democracy". The keyword of "technology education" occurs 15 times which shows that the keyword of "technology education" appears in 15 documents. There are four documents containing the keyword "technology education" in 2022. Firstly, the study by Hallstrom [80] with the title "embodying the past, designing the future: technological determinism reconsidered in technology education". Secondly, the study by Lind *et al.* [81] with the title "students' knowledge of emerging technology and

sustainability through a design activity in technology education". Thirdly, the Nordlof *et al*. [77] study with the title "Towards a three-part heuristic framework for technology education". Fourthly, the study by Fang and Lee [82] with the title "research front and evolution of technology education in Taiwan and abroad: bibliometric co-citation analysis and maps". These studies show that technology education has a vital role in enhancing the technological literacy of students or teachers. Furthermore, the blue-sky cluster includes keywords such as "pedagogy" and "literacy". Pedagogy and literacy are two keywords with a typical relationship in which pedagogy is a conceptual tool to enhance literacy. Technology education covers pedagogy and literacy in the learning process involving the component of technology.

Furthermore, there were some emerging keywords in the period 2021–2022, such as "information security", "autonomous technology", "assessment", "design activity", and "curriculum". The "autonomous technology" keyword becomes an interesting keyword to be researched for further educational studies. Some literature argues that autonomous technology is utilized with a more intelligent self-management capability than standard automation [83, 84]. Today, artificial intelligence has an essential role in developing autonomous technology. For example, the robot is one of the implementation forms of autonomous technology utilizing artificial intelligence [85–87]. Artificial intelligence can be developed through technology education, which can facilitate students or teachers to have high technological literacy. Vrontis *et al*. [87] stated that high technological literacy would construct and create artificial intelligence. It shows that technological literacy is required to develop autonomous technology through technology education.

D. The Social Interaction Among Authors and Countries Regarding Technological Literacy Studies

Four authors in the green cluster Alide, Chikasanda, Mgawi, and Mtemang-Ombe, collaboratively conducted a study related to the introduction of technology research in Malawi primary schools, which the survey conducted by Chikasanda *et al*. [88] was published in 2015 by International Journal of Technology and Design Education, and it has two citations. In addition, Chikasanda and two other authors such as Otrel-Cass and Jones, also carried out a study regarding Malawi teachers' view on technology education which the study carried out by Chikasanda *et al*. [89] was published in 2011 by the International Journal of Technology and Design Education and it has three citations. Meanwhile, four authors in the red cluster Jablansky, Alexander, Dumas, and Compton, collaboratively conducted the study related to a longitudinal investigation in technology education. The study by Jablansky *et al*. [90] was published in the International Journal of Technology and Design Education in 2020. It has been cited as many as seven times. Collaboratively, Compton and Harwood also carried out the study regarding an assessment of technology education in New Zealand. The study conducted by Compton and Harwood [91] was published by the International Journal of Technology and Design Education in 2003 and has been cited as many as 26 times. On the other hand, Compton and Jones also collaboratively conducted a study reflecting on teacher development in technology education. The study carried out by Compton and Jones [92] was published by the International Journal of Technology and Design Education in 1998, and it has been cited as many as 14 times. It shows that authors distributed in the red, green, and blue clusters are commonly connected because of the social interactions between Chikasanda, Otrel-Cass, and Jones and the social relationships between Jones and Compton.

Furthermore, New Zealand was one country that had social relationships with the United States, United Kingdom, and Australia in conducting studies related to technological literacy. It shows that New Zealand has wide networking in technological literacy studies. Baber *et al*. [50] stated that the United States, United Kingdom, Australia, and New Zealand collaboratively carry out studies related to digital literacy. They are commonly inter-connected, represented by their researchers and institutions in those countries. In addition, Effendi *et al*. [57] argued that some authors from the United States, Australia, and United Kingdom collaboratively conduct studies regarding scientific literacy. The authors from the countries are commonly inter-connected with each other in performing several pieces of research related to scientific literacy. It shows that those countries carry out research on technological literacy collaboratively and conduct scientific and digital literacy studies. The collaboration among countries in performing research related explicitly to technological literacy is highly required to expand the research development related to autonomous technology as the direction of further educational study focusing on technology education.

E. The Limitation of Study

There are some limitations of this bibliometric analysis study. Firstly, this study only employs Scopus database to search the documents related to technological literacy while there are other scientific databases such as Web of Science, PubMed, and MDPI that can also be used to search the documents in which these databases can provide more information regarding the trends of technological literacy studies. Secondly, to present the frequently emerging keywords related to technological literacy studies, this study only uses the co-word analysis even though bibliographic coupling and co-citation analysis can support it in providing sharp analysis results of the emerging keywords of technological literacy studies. Thirdly, this study only utilizes the VOSviewer as a tool to visualize the networking among keywords, authors, and countries in which the visualization results are not so clear, meanwhile, there is another software such as Gephi and Bibliometrix R that can also be utilized to visualize the interactions among keywords, authors, countries, affiliations, sources, and documents.

V. Conclusion and Implication for Further Educational Research

This bibliometric analysis provides some information related to the research development of technological literacy between 1991 and 2022. The number of studies regarding

technological literacy increases gradually every year. In contrast, the progress citations on the technological literacy studies are inconsistent every year, which is not equal to the development of publications of studies related to technological literacy. Furthermore, the most productive and influential documents, authors, countries, institutions, and sources contribute to developing technological literacy research. It can be shown that from 1991 to 2022, there are 83 documents regarding technological literacy have been published in a lot of well-qualified sources. In addition, these documents have been cited as many as 930 times to date. From now on, autonomous technology referring to the use of a more intelligent self-management capability than standard automation is expected to be newly trending research in the technology field. The studies related to autonomous technology can be directed to further educational studies focusing on technology education. The development of autonomous technology in the future, like a robot for teaching, remarkably contributes to the educational advancement by which it can be explored and examined by many researchers to observe the role of autonomous technology in the education field. Technology education is urgently required to facilitate the implementation of autonomous technology in the learning process. So, innovative technology education, such as learning models and strategy, has to accommodate the involvement of autonomous technology in the learning process.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Edi Suyanto carried out the initial search of documents in Scopus database. Muhammad Fuad established the inclusion criteria and selected the initial documents using the inclusion criteria. Bayu Antrakusuma provided some figures and diagrams. Ari Syahidul Shidiq conducted the performance analysis using the PoP software. Suparman carried out science mapping and network analysis using the VOSviewer software. All authors were involved in finishing the final manuscript.

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