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Bibliometric Analysis of 21st Century Skills in Practical Laboratory Learning Research Trends from 1986 to 2023 Using RStudio Bibliometrix and VOSViewer Software Tools

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Abstract.
The acceleration of technological advancements and globalization underscores the importance of 21st-century skills in practical learning contexts. This manuscript presents a comprehensive bibliometric analysis of scholarly publications from 1986 to 2023, delineating the evolution and trends of research in 21st-century skills within practical learning environments. Utilizing the robust capabilities of RStudio's Bibliometrix and VOSviewer tools, we systematically quantify and visualize the data, providing a meta-analysis of the existing literature. Our analysis encompasses publication output, citation patterns, keyword frequency, thematic concentrations, and collaborative networks. We reveal significant growth in research interest, particularly in areas such as critical thinking, collaboration, communication, and creativity, often referred to as the "4 Cs" of 21st-century skills. The study identifies key authors, influential institutions, and pivotal publications that have shaped the discourse. Moreover, it highlights interdisciplinary collaborations and the geographical distribution of contributions, offering insights into the global research landscape. Our findings suggest that practical learning pedagogies are increasingly integrating 21st-century competencies, reflecting a paradigm shift towards skills that prepare students for the demands of the modern workforce and society. This work not only serves as a barometer for past and present research trajectories but also provides a scaffold for future inquiries in the domain of practical and experiential education.

Keywords: bibliometric analysis, 21st century skills, practical laboratory learning, vosviewer, rstudio

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1. INTRODUCTION

The 4C skills (critical thinking, creativity, collaboration, and communication) are key markers of 21st-century talents that participants must possess in the context of 21st-century learning [1–3]. The 4C skills are formally included in an international survey conducted by the Organization for Economic Co-operation and Development (OECD) that assesses country performance [4]. 4C skills, which refer to a set of talents that are increasingly in demand in the modern workforce [5], have the potential to enhance the quality of workers by fostering collaboration between higher education and clinical settings [6, 7]. Skills such as critical thinking, creativity, and communication play a significant role in the realm of employment. Critical thinking facilitates the resolution of intricate difficulties, the formulation of astute decisions, and the creation of efficient solutions. Effective communication skills are crucial for cooperating with coworkers, coordinating meetings, delivering presentations, and negotiating agreements. Creativity enables firms to foster innovation, tackle issues in novel ways, and swiftly adjust to market fluctuations. Contemporary learners must acquire and proficiently employ these talents to surmount obstacles and achieve success as future members of society. Hence, this study centres on 21st-century abilities, which are seen as the key to achieving success in an increasingly rigorous, intricate, and demanding era.

The phenomenon of 21st-century skills is regarded as enjoyable, capable of fostering growth, and persistently expanding, as demonstrated by a search on Scopus using the keyword “21st Century Skills,” which yielded 6,325 items (including journals and conferences) spanning 2003 to 2023. Hence, it is imperative to examine and comprehend the current research patterns pertaining to cultivating 21st-century talents [8]. A bibliometric study [9] is a valuable approach to comprehending research trends, uniqueness, and influential papers. This study can also quantify the extent to which research contributes to advancing 21st-century skills and knowledge using a statistical methodology. Utilizing this method can enhance comprehension of a particular field with less expenditure [10].

[11] did a prior study on visualising curriculum developments in the 21st century. Furthermore, [12] conducted another research that focused on analysing collaboration abilities in education, one of the talents relevant to the 21st century. [13] studied the difficulties of learning mathematics in the 21st century and analyzed the concept of 21st-century learning. [14] reviewed 21st century learning using the Scopus database. [15] conducted a study that examined the current research trends in critical thinking within the field of scientific education. According to [16], there is a visualization of the developments in 21st-century abilities during the past two decades. Researchers have

recognized the significance of mapping trends in 21st-century skills to aid in developing these skills. However, there needs to be more bibliometric analysis specifically focused on the research trends of 21st-century skills in laboratory practice learning. This laboratory practice believes that it can effectively enhance 21st-century skills through learning.

Hence, a bibliometric study was conducted to investigate acquiring 21st-century abilities in laboratory practice learning. The study spanned from 1986 to 2023 and utilized Scopus metadata and two software tools, VOSviewer and RStudio Bibliometrix. This study aimed to identify research patterns, innovative approaches, and potential future directions in laboratory-based learning within 21st-century education. The precise aims of this study are to: 1) Analyze the top document types, sources, and country contributions in 21st-century skills research in laboratory practice learning; 2) Analyze the most popular keywords used in 21st-century skills research in laboratory practical learning; 3) Analyze the cooperative relationships between countries in 21st-century skills research in laboratory practical learning; 5) Review some of the most cited publications, including research findings and recommendations on 21st-century skills research.

2. METHOD

2.1. Method of Research

The bibliometric technique has been utilized in diverse study disciplines. VOSviewer, an open-source software, enables users to generate and analyze bibliometric maps. [17] highlighted that VOSviewer is a software that places a higher importance on visually representing bibliometric maps compared to other regularly used tools in the field of bibliometric mapping. VOSviewer provides a range of capabilities, including a text-mining functionality. By employing this unique feature, correlations can be generated and presented within the context of the cited work [18]. In addition to VOSviewer, Bibliometrix R is another software package offering various tools for doing quantitative research.

2.2. Data Collection

The accessibility of extensive bibliometric data has been facilitated by the advent of scholarly databases like Scopus. They have utilized practical data analysis techniques by employing bibliometric software tools like VOSviewer and Bibliometrix. Researchers

are granted access to a diverse selection of top-notch publications [19] using this platform, which is regarded as the most broad and complete data source [20, 21]. The research methodology section is bifurcated into two distinct segments. A search strategy is formulated during the project's initial phase, and crucial research data is gathered. This study incorporates bibliometric analysis utilizing the Scopus database (www.scopus.com). The search process comprises the elements "21st century skills" and "laboratory" (Title-Abs-Key). A total of 220 papers were discovered, encompassing all types of publications scrutinized in the investigation. Following modifications to the publishing type and stage, 197 documents were collected and deemed suitable for study. This study analyzed a total of 197 distinct papers published up until 2023. The survey was done on January 1, 2024, to avoid disrupting routine database updates.

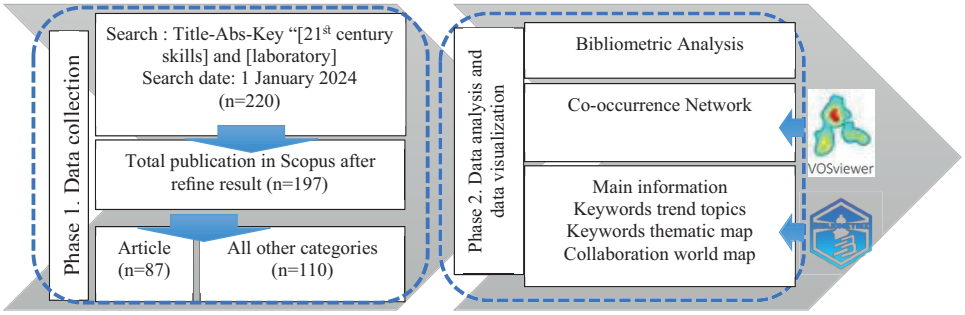

Figure 1: Flowchart of data collection, data analysis, and data visualization.

3. RESULTS AND DISCUSSIONS

3.1. Publication, Document Type, Source and Country

Figure 2 clearly shows fluctuations in the range between 1986 and 2023, with both increases and decreases observed. Looking again at the figure, it is clear that there was a significant increase in publications in 2019, with a count of 20 articles. However, from 2022 onwards, there was a significant decrease in the number of articles discovered. Considering the correlation between this situation and the Covid-19 outbreak in 2019, it is imperative to conduct research on 21st century skills through laboratory practice activities. Several studies in 2019 include those by [22–27], with some focus on developing 21st century skills such as critical thinking, creativity, communication, and collaboration through laboratory practical learning. With the shift to online learning, it is crucial to find a suitable approach to ensure the continuation of practical training and the development of essential cognitive skills. In 2022, as conditions improve, the

learning process returns to the previous year, resulting in a decline in the trend of research focused on 21st century skills through laboratory-based learning.

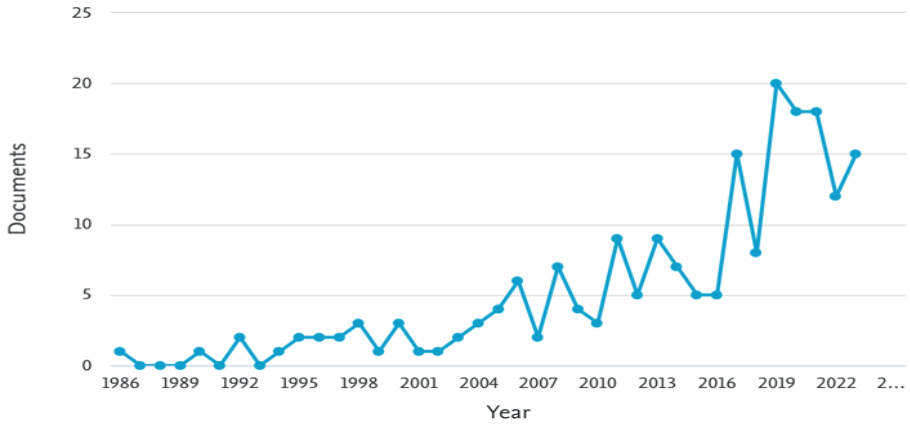

Figure 2: 21st Century skills in laboratory practice learning publication years.

Of the 197 documents processed, conference papers are the most common with 90 items, closely followed by journals with 87 documents. The results show that proceedings articles were the most frequently accessed document source with a total of 90 documents. This was followed by journal articles with 87 documents, notes with 1 document, reviews with 16 documents and short surveys with 3 documents.

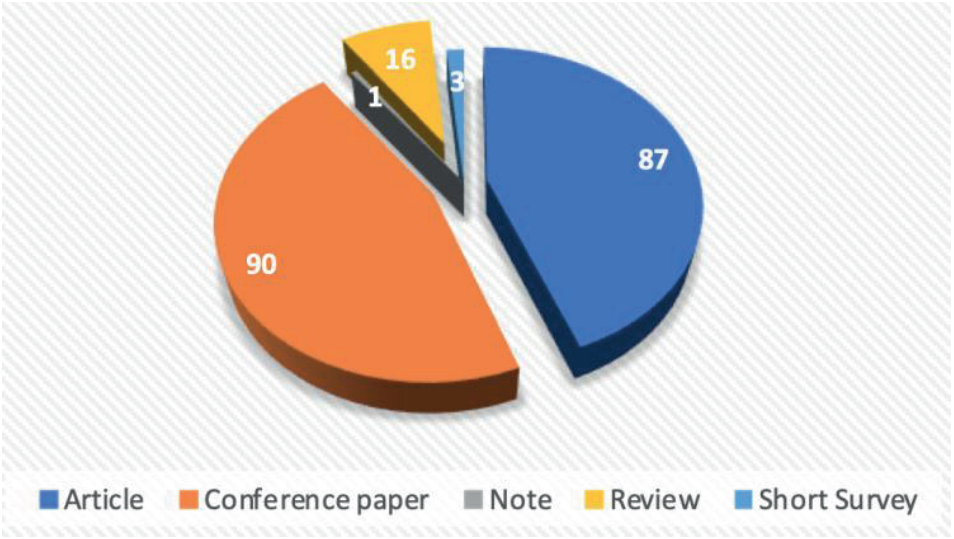

Figure 3: Flowchart of data collection, data analysis, and data visualization.

The United States (US) has published 82 documents on laboratory-based learning, making it the leading country in research on 21st century skills up to 2023. Indonesia secures second place with a total of 29 documents, followed by Australia with 8 documents, and so on. As shown in Figure 4, this research has emerged as a compelling research trend in the United States. In addition, Indonesia provided 29 documents,

demonstrating the productivity of Indonesian researchers in promoting 21st century skills through the use of learning laboratories. However, the number of publications related to 21st century skills in laboratory-based learning is rather low compared to other areas where there are hundreds or thousands of publications. In terms of quantity, Indonesia is far behind the United States and the following country, which contributed less than 8 papers. Therefore, more research is needed to explore 21st century skills, especially through the use of laboratory learning methods.

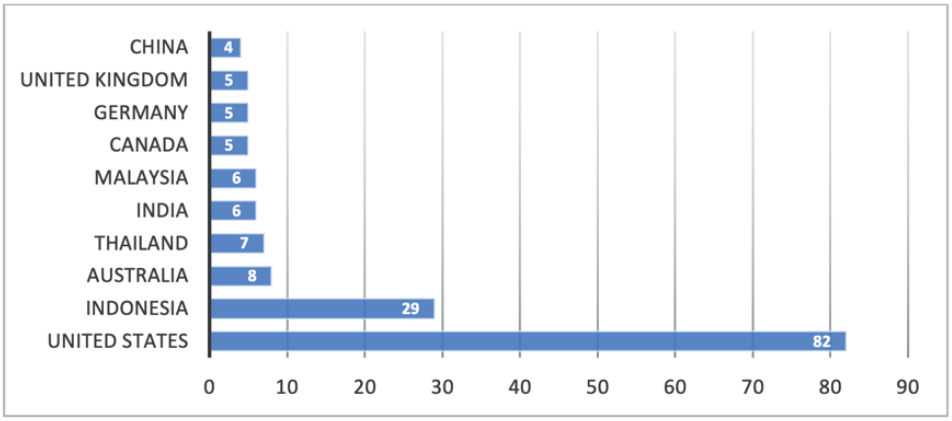

Figure 4: Ten countries contributing to research on 21st century skills in laboratory practical Learning, published until 2023.

Regarding collaboration between countries, the United States stands out as the country with the most extensive number of collaborations. Specifically, the USA has engaged in 11 collaborations with 10 distinct countries. Malaysia and South Africa are the second largest countries, each collaborating with two distinct countries. Indonesia has only one bilateral collaboration with another country, specifically with Malaysia. Figure 5 displays a map illustrating the global links mentioned in the article regarding the development of practical laboratory abilities in the 21st century.

3.2. Most Relevant and Trending Keywords

The word “student” had the highest connection strength of 274, making it the most influential phrase. “Education” ranked fourth with a link strength of 218, followed by “21st century skills” at eighth place with a link strength of 158, and “laboratory” at eleventh place with a link strength of 129. The phrase “students” had the most robust network of interconnected terms. The study findings indicate that the terms “student,” “education,” “21st-century skills,” and “laboratory” are commonly employed in conversations pertaining to 21st-century learning. The network visualization map represents each label using nodes differentiated by a distinct colour, as seen in Figure 6. Keyword

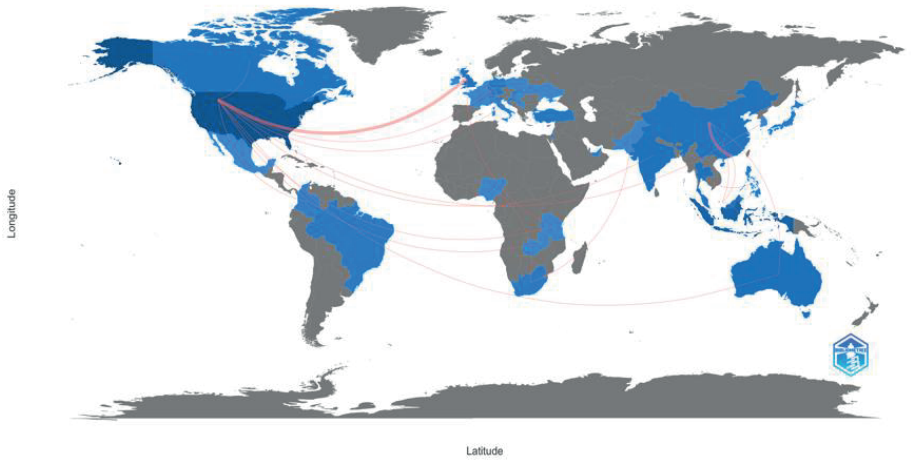

Figure 5: Country collaboration map.

co-occurrence analysis seeks to systematically identify and classify the underlying concepts suggested by keywords [28]. Subsequently, analysts can utilize this information to outline a conceptual framework or bibliographic summary. The scope of keyword subjects addressed in South African literature has significantly expanded. The VOSviewer software produced a report encompassing 1,736 distinct phrases derived from the analysis of co-occurrence networks. The keyword “students” held the highest significance in the third cluster and was positioned at the central node of the group. Within this cluster, the keyword “laboratories” was also connected to other keywords such as “critical thinking,” “problem solving,” and “experimental group.”. In another cluster, keywords such as “curricula,” “e-learning,” “engineering,” “education,” and “twenty-first century” were interconnected.

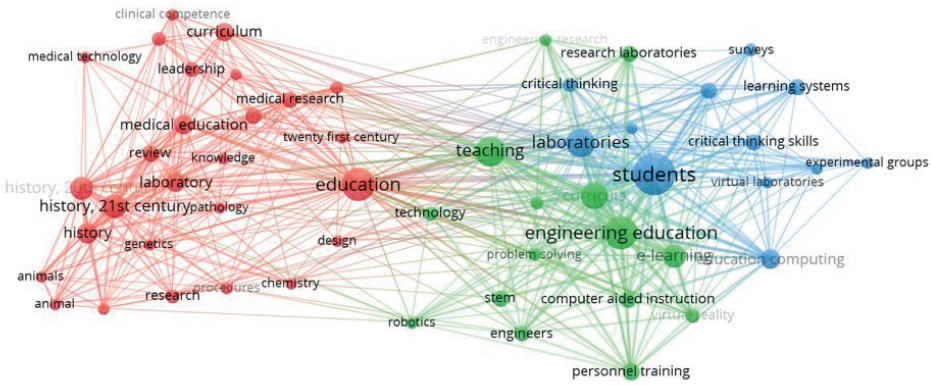

Figure 6: A network map showing the co-occurrence of keywords.

Figure 7 illustrates the chronological progression of research articles on 21st century abilities in laboratory practical learning, explicitly highlighting the keywords employed in each article. The articles written between 1995 and 2005 on laboratory practical

learning primarily concentrated on health-related topics such as career choices, laboratory exercises, outstanding performance, and epidemiology. However, the focus has shifted towards more comprehensive themes, particularly in education and technology. These include digitalization, project-based learning, STEM (science, technology, engineering, and mathematics), engineering education, 21st century skills, assessment, and competencies, as highlighted in the latest publication.

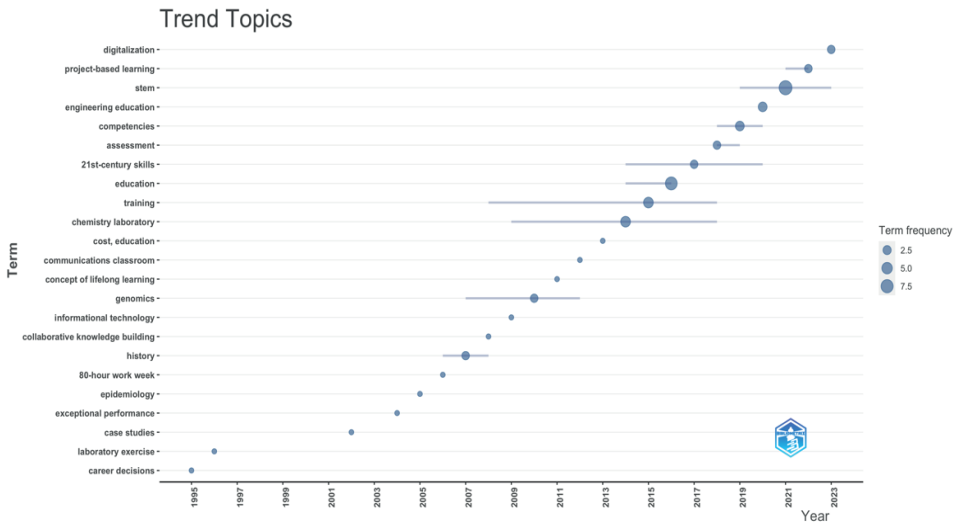

Figure 7: Keyword trend topic.

3.3. The three most cited articles

Of the 197 articles obtained, the top 3 most cited are from 2007, 2013, and 2017. The first article is by [29] with a total of 235 citations, which reports that issues regarding learning in and from science laboratories and laboratories in the context of chemistry learning are still relevant for research and development and implementation problems. The article with the second most citations is by [30] with 119 citations, which reports that using computer-based assessment for learning improves learning and other outcomes in various content areas such as biology, mathematics and programming. This computer-based assessment can also be an option for assessing 21st-century skills. The article with the third most citations is by [31], with 103 citations, reporting that the synthetic implementation of a simulation curriculum in neurosurgery training programs is feasible, considered good, and positively impacts trainees at all levels.

4. CONCLUSION

Since 1986, there has been a steady increase in scientific interest in 21st century skills in laboratory practical learning, and this trend has continued and increased since 2015. The most common types of documents are proceedings, with 90 papers, and journals, with 87 documents. The country that contributed the most to this research was the United States (US), with 82 papers, followed by Indonesia, which was in second place with 29 papers. Some relevant/trending words that are often used in this research are "student" (link strength 274), then "education" in fourth place (link strength 218), "21st-century skills" in eighth place (link strength 158), and "21st-century skills" in eighth place (link strength 158), and " laboratories" eleventh (link strength 129). The current topics related to research on 21st century skills in laboratory practical learning are digitalization, project-based learning, stem, and competency improvement orientation. If we look at this pattern, it can be seen that the pattern of 21st-century skills research in laboratory practical learning is student-focused learning; its application is more in the field of technical education, as well as teaching, education and curriculum oriented towards 21st-century skills such as critical thinking, problem-solving, collaboration, creativity, and communication. Practical laboratory learning, as included in the current topic highlights, recommends the development of practical learning that integrates technology, is project-based, and links various aspects such as social, economic, and environmental in a series of practical learning oriented towards solving projects/problems around students.

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