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THE RESEARCH STATUS OF FORMATIVE ASSESSMENT IN SCIENCE EDUCATION

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Abstract. *Although the number of publications on formative assessment in science education has long been high, there is no bibliometric analysis or scientific mapping in the literature to understand research trends in formative assessment research. This research aimed to examine the bibliometric results of articles on formative assessment in science education. Based on the criteria for inclusion and exclusion, 94 articles were selected for analysis. The results show that between 2015-2016 and 2020-2022, the number of publications on formative assessment increased substantially. Among the top ten institutions that contributed to the research are three institutions from the United States. The results also show that the United States had the most publications. Analysis of the co-citations showed that the Journal of Research in Science Teaching, Science Education, and the International Journal of Science Education were cited more than 100 times. The three most cited studies were published in Assessment in Education: Principles, Policy, and Practice. The results show that the researcher used formative assessment, students, science education, teaching, education, engineering education, curricula, STEM, and e-learning in research on formative assessment. In light of the obtained results, practical suggestions for further studies are made in the conclusion.*

Keywords: *formative assessment, science education, SCOPUS, bibliometric analysis*

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Introduction

Over the years, formative assessment has become one of the research topics in science education. In particular, the increasing number of publications on formative assessment since the early 2000s has shown how important this topic is for science educators and teachers (Kariri et al., 2018). Formative assessment is essential for learning and teaching because it provides continuous feedback and information on student comprehension, progress, and needs (Furtak & Ruiz-Primo, 2008; Kariri et al., 2022; Wiliam, 2009). Unlike summative assessments, typically used to evaluate students at the end of a unit or course, formative assessments are designed to be embedded in classroom learning processes (Cisterna & Gotwals, 2018; Kariri et al., 2022; Menéndez et al., 2019). Hence, it is crucial to learning and teaching because it facilitates student development, guides instruction, and fosters a deeper understanding of content (Clark, 2011; Menéndez et al., 2019). It empowers students to take responsibility for their learning and fosters a collaborative and reflective learning environment (Jacoby et al., 2013; Taras, 2002). Formative assessments allow students to receive timely feedback on their learning that helps them understand their strengths and areas for improvement (Havnes et al., 2012; Kariri et al., 2022; McCarthy, 2017). This feedback allows students to adjust their responsibility during learning, leading to increased motivation and engagement (Cauley & McMillan, 2010; Leenknecht et al., 2020).

The research literature demonstrates that formative assessment significantly affects students' learning (Hidayat & Irdiyansyah, 2023; Ozan & Kincal, 2018). Evaluation is crucial to effective learning (Menéndez et al., 2019). Formative assessments are characterized primarily by their purpose and timing in identifying and discussing a student's performance and determining the required next steps. Studies have shown that it helps students achieve higher academic objectives and improves curriculum and teaching practices (Kariri et al., 2022). With its importance for learning and teaching, formative assessment in science education has been a topic of great research interest to improve teaching and learning experiences in the education field (Black, 2009; Park, 2019).

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Researchers have explored and used various formative assessment strategies and techniques that can be used in science classrooms (Decristan et al., 2015; Park, 2019; Quellmalz et al., 2012). These strategies and techniques include concept mapping, self-assessment, peer assessment, and feedback strategies. Studies have examined the effectiveness of these strategies in promoting student engagement, conceptual understanding, and scientific inquiry skills (Decristan et al., 2015; Park, 2019; Quellmalz et al., 2012).

Growing interest is in developing learning progressions and frameworks that outline students' science understanding of developmental stages (Alonzo, 2017; Furtak et al., 2018). Formative assessment is critical in creating these learning progressions by providing insights into student thinking and conceptual development over time (Alonzo, 2017; Furtak et al., 2018). With this aim, many studies have been conducted to assess the effects of formative assessment on students' learning in science education literature (Furtak et al., 2018; Hidayat & Irdiyansyah, 2023; Leenknecht et al., 2020; Ozan & Kincal, 2018). To keep up with the latest research on formative assessment in science education, it is important to monitor the development of the knowledge produced in science education by searching the most recent academic journals, conference proceedings, and databases specializing in science education research.

To assist students in learning and teaching, studies need to be reviewed that summarize the current state of research on formative assessment to inform researchers. However, no bibliometric analysis or scholarly mapping of formative assessment in the science education literature has been found. Only one research (Sudakova et al., 2022) conducted a bibliometric analysis of online formative assessment in higher education. They collected the Scopus database and analyzed 898 publications. Their results demonstrated that the rate of increase between 2019 and 2021 was greater than the collaboration index of 3.02 co-authors per document. The highest percentage of annual citations per document was 17.44%. The growth rate between 2019 and 2021 was greater. In addition, their results suggested that the publications frequently used online assessment, blended learning, e-learning, and COVID-19 keywords. To address these gaps, this study used a bibliometric analysis to thoroughly review formative assessment in science education to identify trends in formative assessment research covering a longer period from 2008 to 2022. Researchers use bibliometric evaluation techniques to determine a single author's influence and establish the relationship between two or more authors or works. Therefore, this study aimed to examine the research status of formative assessment in science education.

Research Significance

Researchers have agreed that bibliometric analysis enables researchers to identify and analyze trends and patterns in a specific research area and topic. By analyzing publication output, citation patterns, and collaboration networks, researchers can gain insight into the topics, methodologies, and theories that have garnered the most attention in a field. These insights assist researchers in comprehending the current state of knowledge and identifying possible research gaps. Thus, bibliometric analysis provides a quantitative evaluation of the impact and influence of research on formative assessment. Researchers can contribute to developing new research questions and priorities by identifying under-researched topics or aspects that require further examination. In addition, bibliometric analysis can reveal emerging fields or novel approaches in formative assessment research, allowing researchers to follow the most recent advancements.

Bibliometric research provides evidence-based information to guide education policy, curriculum development, and instructional practice decisions. Policymakers and educators can use bibliometric analysis to comprehend the efficacy and impact of formative assessment strategies and make informed implementation decisions. In brief, bibliometric research on formative assessment is important for researchers because it enables them to gain insights into the field, evaluate research impact, identify research gaps, and contribute to evidence-based educational decision-making. This study focuses on articles published between 2008 and 2022 on formative assessment in science education. These articles were analyzed using bibliometric mapping regarding the most frequently used keywords, most frequently cited authors, and most frequently cited journals.

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Research Methodology

Background

Bibliometric analysis allows researchers to analyze and evaluate themes, patterns, and connections between scientific papers in a discipline. This technique examines published data on authors, citations, institutions, journals, keywords, and subjects to create networked knowledge maps in a research area (van Eck et al., 2010). It allows researchers to use co-citation and keyword analysis to identify and examine research themes in publications about current research on formative assessment in science education. Therefore, this finding provides the opportunity to gain valuable insight into the current state of research on formative assessment.

Data Collection

In this study, bibliometric mapping analysis was used. To answer the research question, the researchers searched the database for publications on formative assessment in science education articles published between 2008 and 2022. The SCOPUS database was selected as the primary source of literature. It is a top-level research platform that facilitates discovering, analyzing, and disseminating knowledge in the sciences, social sciences, arts, and humanities (Elsevier, 2023). It is used to find relevant research papers by indexing the most relevant journals in the field of education and providing the necessary data for bibliometric analysis.

The time frame was restricted to the years 2008 to 2022. To ensure quality consistency, "English" was selected as the language, and all publication types were selected as the document type. The subject area keywords "formative assessment" and "science education" were selected to collect the data. The "education/educational research" category was used to perform an advanced search, and researchers found 122 articles related to formative assessment in science education. The full texts of all articles were downloaded. Two researchers assessed each article using specific criteria for inclusion and exclusion. For inclusion, articles pertained to formative assessment and one of the science education disciplines, including biology, chemistry, physics, science, and STEM education. The second was whether the articles were conducted in the education field. For example, some articles were found outside of education fields and unrelated to one of the disciplines in science education specifically. Consequently, 94 articles from numerous journals and proceedings were chosen for analysis in this study. Of the eligible articles for analysis, the number of articles was 63, while there were 26 conference papers, two book chapters, two reviews, and one book. Figure 1 is a summary of the article selection procedure for this study.

Bibliometric Analysis

SCOPUS was chosen as the literature source for the bibliometric mapping analysis using the same keywords. Since it was impossible to examine each article individually, keywords related to formative assessment and science education-related keywords were used. Using the advanced search function, "formative assessment" and "science education" or "biology education", "chemistry education," "physics education, "STEM", and "STEM education" were entered in the subject field in the database. The full records and references were then downloaded in Bibtext and CSV formats. These files were later converted to tab-delimited (Windows) file formats. The file was uploaded to the program VOSViewer. The bibliometric mapping analysis comprises articles published between 2008 and 2022.

The VOSViewer program was used for the bibliometric analysis to generate a network representation of the articles' most frequently used keywords, abstract words, citation analyses, and co-citation analyses. Two researchers analyzed the data together.

Research Results

Change in the Number of Publications

Figure 1 shows an annual change in the number of publications on formative assessment from 2008 to 2022. According to Figure 1, the number of publications on formative assessment increased importantly between 2015-2016 and 2020-2022. Namely, there was an increase in the number of formative assessment articles over the past three years.

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Figure 1
Change in the Number of Publications

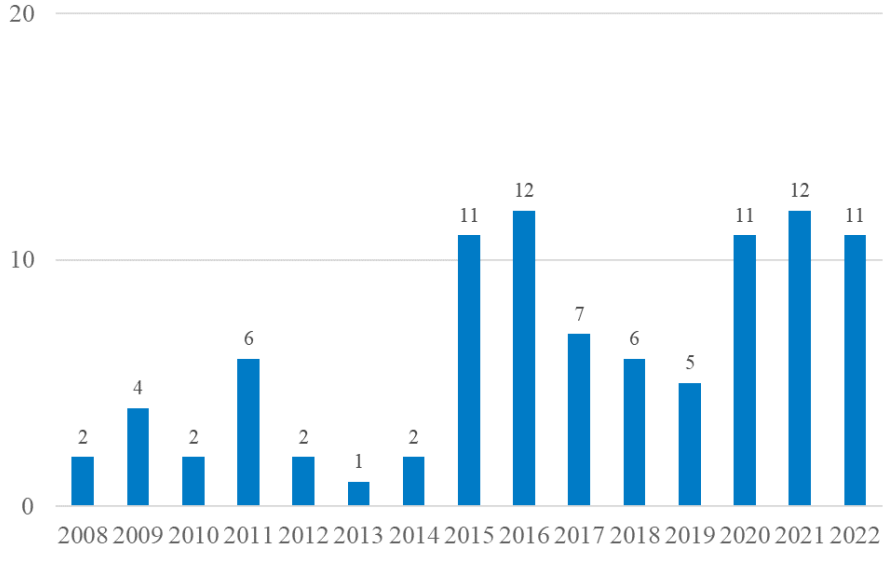

Table 1 shows the institutions that contributed to formative assessment research between 2008 and 2022. The top ten institutions that contributed to the research on formative assessment were first the University of Colorado Boulder, the University of Nebraska–Lincoln (n = 7), the University of California, Berkeley (n = 4), the University of Missouri (n = 3), the School of Natural Resources (n = 3), University of the Andes (n =3), North Carolina State University (n = 2), Educational Testing Service (n =2), and University of South Bohemia (n = 2). The results revealed that seven of the top ten institutions came from one country, the United States. According to this result, the institutions in the United States conducted much more research on formative assessment in science education during the last fifteen years. Four countries entered into the list among the top ten institutions. They are the United States, Colombia, the Czech Republic, and Switzerland. In particular, the University of Colorado Boulder and the University of Nebraska–Lincoln had contributed the most to research on formative assessment. These results indicated nine institutions, excluding Colombia, originate from developed nations. It is important to note that universities in developed nations, particularly the United States of America (USA), have been at the forefront of formative assessment research in the academic literature.

Table 1
Top 10 Institutions Contributed to Formative Assessment Research

Institutions	Country	Number of publications
University of Colorado Boulder	United States	7
University of Nebraska–Lincoln	United States	7
University of California, Berkeley	United States	4
University of Missouri	United States	3
University of the Andes	Colombia	3
North Carolina State University	United States	2
Educational Testing Service	United States	2
University of South Bohemia	Czech Republic	2
The University of Arizona	United States	2
FHNW University of Applied Sciences and Arts	Switzerland	2

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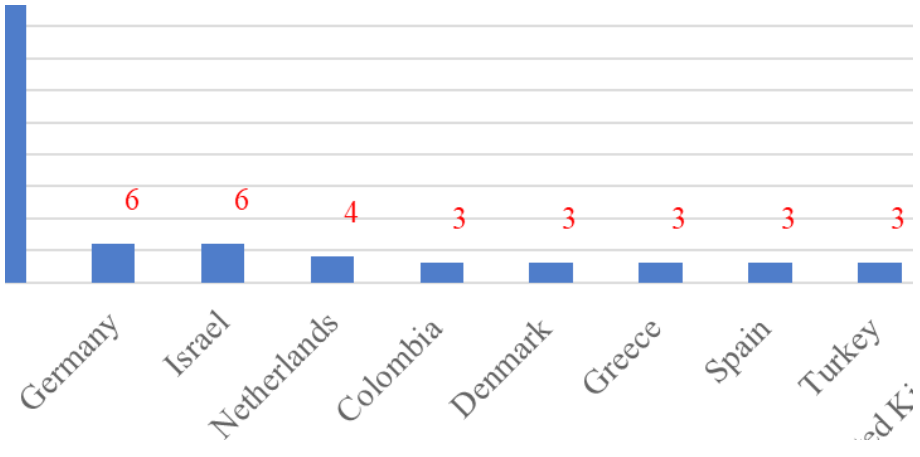
Figure 2 shows the top 10 countries that contributed to formative assessment research. The results in Figure 2 demonstrate that the United States had the most publications ($n = 45$, or 47.8%). Germany and Israel rank second in productivity ($n = 6$, 6.3%). The Netherlands came third with four publications ($n = 4$, or 4.2%). In terms of the number of publications on attitudes and STEM, the following nations are represented: Colombia (n = 3, 3.2%), Denmark (n = 3, 3.2%), Greece (n =3, 3.2%), Spain (n = 3, 3.2%), Turkey (n = 3, 3.2%), and the United Kingdom (n =3, 3.2%).

Figure 2
Top 10 Countries That Contributed to Formative Assessment Research



Analysis of Sources

Table 2 displays the top ten sources determined by co-citation analysis within the Vosviewer software. The journal with the most citations is the Journal of Research in Science Teaching (JRST), Science Education, and the International Journal of Science Education (IJSE) had more citations than 100 times. The scopes of these journals are closely related to formative assessment in science education. The impact factor for the JRST was 3.918%. In 2021, science education had a 6.0 impact factor. In 2021, the IJSE had a five-year impact factor of 2.77. According to the cluster analysis (see Figure 3), the journals that published articles on formative assessment were collected in two clusters. Accordingly, the first cluster included these journals: JRST, Science Education, Journal of Science Teacher Education, Educational Researcher, Assessment in Education: Principles, Policy & Practice, Applied Measurement in Education, and Teaching and Teacher Education. The second cluster incorporated the IJSE, Review of Educational Research, and Computers & Education journals. The main pattern of these journals is that prominent publishers have published them for more than 30 years.

Table 2
Top 10 Sources by Co-Citation Analysis

		Citations	Total link Strength	Cluster
1	Journal of Research in Science Teaching	158	2346	1
2	Science Education	105	1637	1
3	International Journal of Science Education	103	1389	2
4	Journal of Science Teacher Education	40	798	1
5	Educational Researcher	42	745	1
6	Assessment in Education: Principles, Policy & Practice	41	727	1
7	Review of Educational Research	51	647	2

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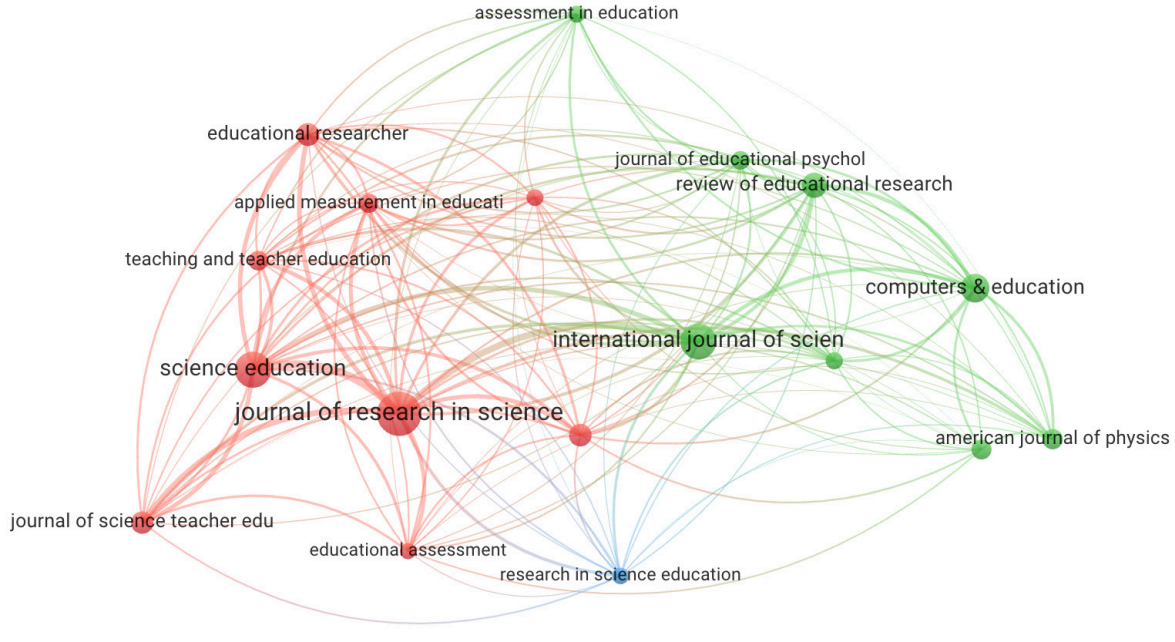
		Citations	Total link Strength	Cluster
8	Computers & Education	66	619	2
9	Applied Measurement in Education	30	595	1
10	Teaching and Teacher Education	31	535	1

Figure 3
Analysis of Sources by Co-Citation Analysis



Analysis of Authors

Table 3 lists the ten most co-cited authors by co-citation analysis. Only Dylan Wiliam, Erin Marie Furtak, Paul Black, Maria Araceli Ruiz-Primo, and Richard J. Shavelson were cited more than fifty times. The remaining five authors were co-cited over thirty times, including Bronwen Cowie, Christine Harrison, Marcia C. Linn, Yue Yin, and Beverley Bell. Figure 4 shows an analysis of the most cited authors by co-citation. Based on the most cited author analysis, Table 3 and Figure 4 reveal that six out of the top ten authors are from the United States. Meanwhile, three authors come from New Zealand, and one is from the United Kingdom.

Table 3
Top 10 Authors by Co-Citation Analysis

	Author	Organization	Country	Citations	Total link Strength	Cluster
1	Dylan Wiliam	Educational Testing Service	United States	93	1470	2
2	Erin Marie Furtak	University of Colorado Boulder	United States	82	1638	1
3	Paul Black	King's College London	United Kingdom	80	1269	2
4	Maria Araceli Ruiz-Primo	Stanford University	United States	58	1261	1

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	Author	Organization	Country	Citations	Total link Strength	Cluster
5	Richard J. Shavelson	Stanford University	United States	52	1172	1
6	Bronwen Cowie	The University of Waikato	New Zealand	42	857	1
7	Christine Harrison	The University of Waikato	New Zealand	38	827	2
8	Marcia C. Linn	University of California Berkeley	United States	36	82	2
9	Yue Yin	University of Illinois, Chicago & University of Hawaii, Manoa	United States	35	842	1
10	Beverley Bell	The University of Waikato	New Zealand	30	639	1

Figure 4
Analysis of Authors by Co-Citation Analysis

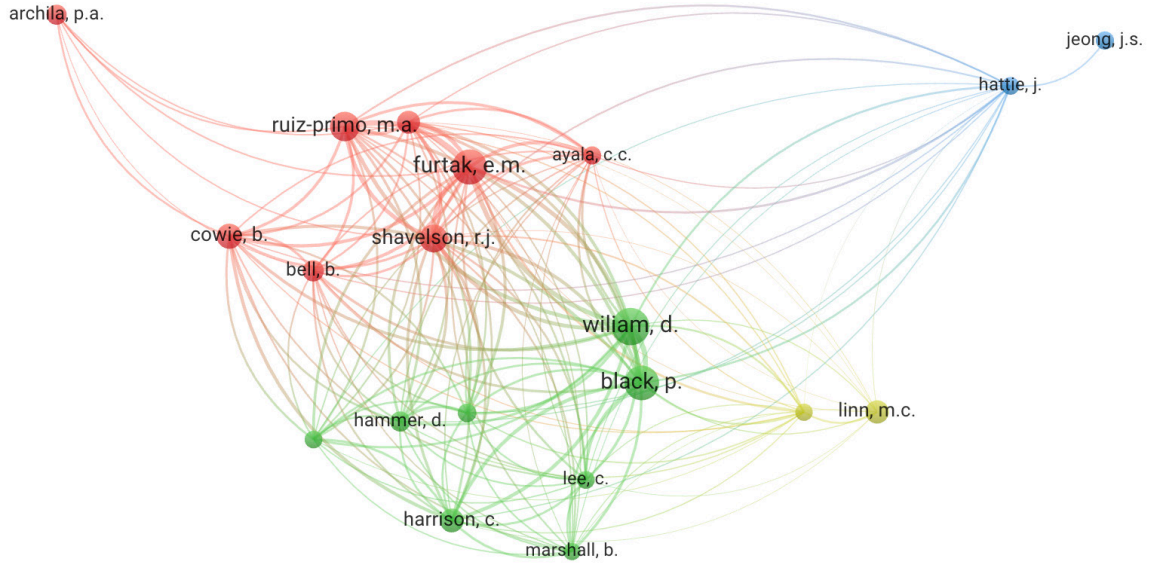

Table 4 displays the top ten references based on co-citation analysis. The first six references were cited by researchers more than five times. Three studies among the top ten references based on co-citation were from Assessment in Education: Principles, Policy & Practice journal. The other two studies were from the Journal of Research in Science Teaching.

Table 4
Top 10 References by Co-Citation Analysis

		Authors(s)	Source	Citations	Total link Strength	Cluster
1	Assessment and Classroom Learning (Black & Wiliam, 1998)	Paul Black & Dylan Wiliam	Assessment in Education: Principles, Policy & Practice	8	21	1
2	The Power of Feedback (Hattie & Timperley, 2007)	John Hattie and Helen Timperley	Review of Educational Research	7	27	2

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		Authors(s)	Source	Citations	Total link Strength	Cluster
3	From Evidence to Action: A Seamless Process in Formative Assessment? (Heritage et al., 2009)	Margaret Heritage, Jinok Kim, Terry Vendlinski, Joan Herman	Educational Measurement: Issues and Practice	5	23	1
4	Formative assessment: a critical review (Bennett, 2011)	Randy Elliot Bennett	Assessment in Education: Principles, Policy & Practice	5	20	1
5	The characteristics of formative assessment in science education (Bell & Cowie, 2001)	Beverley Bell, Bronwen Cowie	Science Education	5	14	1
6	Developing the theory of formative assessment (Black & Wiliam, 2009)	Paul Black & Dylan Wiliam	Educational Assessment, Evaluation and Accountability	5	12	1
7	The missing disciplinary substance of formative assessment (Coffey et al., 2011)	Janet E. Coffey, David Hammer, Daniel M. Levin, Terrance Grant	Journal of Research in Science Teaching	4	22	1
8	Strategies and Challenges to Changing the Focus of Assessment and Instruction in Science Classrooms (Duschl & Gitomer, 1997)	Richard A. Duschl & Drew H. Gitomer	Educational Assessment	4	21	1
9	Exploring teachers' informal formative assessment practices and students' understanding in the context of scientific inquiry (Ruiz-Primo & Furtak, 2007)	Maria Araceli Ruiz-Primo, Erin Marie Furtak	Journal of Research in Science Teaching	4	21	1
10	A Model of Formative Assessment in Science Education (Cowie & Bell, 1999)	Bronwen Cowie & Beverley Bell	Assessment in Education: Principles, Policy & Practice	4	20	1

Analysis of References

The cluster analysis results indicated that the top 10 references by co-citation were frequently cited together (see Figure 5). The findings for this result produced two clusters, including the top ten references. The studies of Bell and Coiwe (2002), Bennet (2011), Black and William (1998), Black and William (2009), Coffey et al. (2011), Cowie and Bell (1999), Duschl and Gitomer (1997), Furtak (2012), (Heritage et al., 2009), and (Ruiz-Primo & Furtak, 2007) comprised the first cluster. The second cluster consisted of Bell and Coiwe (2001), Black and William (1998), Black and William (2009), Coffey et al. (2011), Hattie and Timperlay (2007), Shepard (2000), White and Frederiksen (1998) studies.

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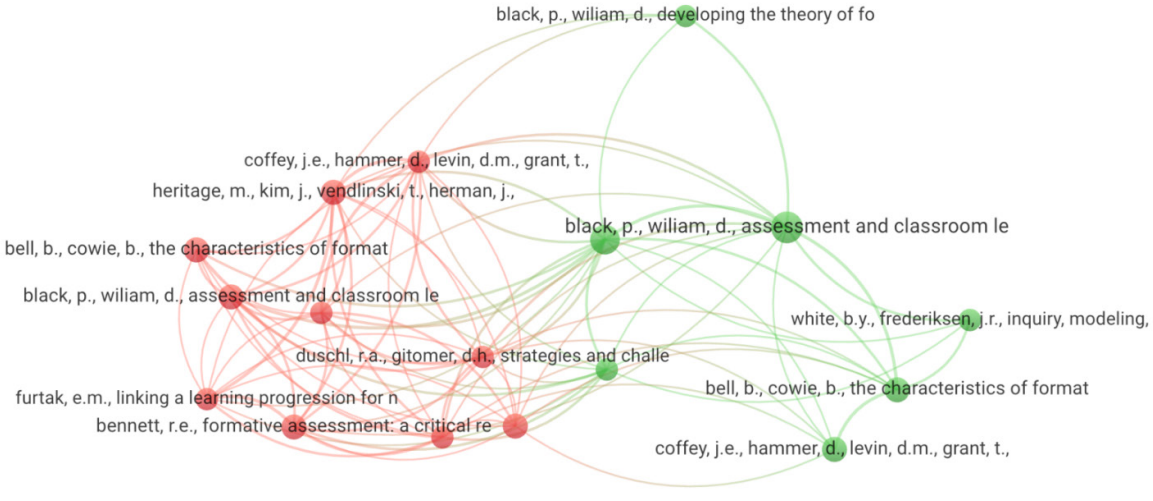
Figure 5
Network Analysis of References by Co-Citation Analysis



Research Fronts in Formative Assessment

Bibliographic coupling analysis is ideally suited for identifying research fronts because it offers two advantages (Boyack & Klavans, 2010). Firstly, it can pinpoint newly researched topics. Secondly, it can complement the findings of keyword co-occurrence analysis. The bibliometric coupling method is useful for identifying articles and researchers related to similar topics, but it does not evaluate the quality of the studies. In the analyses, the bibliographic coupling of documents was performed in a formative assessment to highlight the research front (themes). The results yielded four clusters. Accordingly, cluster 1 included Decristan et al. (2015), Genlott & Grönlund (2016), Grob et al. (2017), Hondrich et al. (2016), Maier et al. (2016), and Prince et al. (2020). The studies in this cluster focused on the effects of formative assessment on students' understanding and learning outcomes and analyzed teachers' challenges. For example, Decristan et al. (2015) examined the effects of formative assessment on students' science understanding. Genlott and Grönlund (2016) studied the effects of a "Write to Learn" (WTL) method using written real-time formative feedback on students' learning outcomes. Hondrich et al. (2016) evaluated primary school science teachers' implementation fidelity under two conditions. Grob et al. (2017) investigated teachers' challenges when implementing formative assessment methods in inquiry-based science classrooms and analyzed their recommendations. Maier et al. (2016) developed computer-assisted formative assessments for an evolutionary adaptations instruction unit and reported their effects on studied variables.

Cluster 2 consisted of Adams and Wieman (2011), Coffey et al. (2011), Cohen and Sasson (2016), Dong et al. (2009), and Shen and Linn (2011). In this cluster, the studies emphasized the importance of formative assessment in science teaching. For example, Adams and Wieman (2011) created an assessment test that measured the effectiveness of instruction in a specific area of science and used formative assessment techniques. Coffey et al. (2011) examined the state and development of formative assessment research.

Cluster 3 included Archila et al. (2018), Furtak (2012), Furtak and Heredia (2014), and Furtak et al. (2016). Archila et al. (2018) studied the effects of a formative assessment-based strategy on university students' argumentation. The studies of Furtak and her colleagues focused on teachers' understanding of formative assessment in teaching processes.

Cluster 4 included the studies of Buck et al. (2010), Offerdahl and Tomanek (2011), Tomanek et al. (2008), and Trauth-Nane and Buck (2011). These studies examined the processes of teachers and instructors regarding formative assessment. For example, an inquiry process with formative assessment was the focus of Buck et al.'s (2010) action research. A case study was conducted by Offerdahl and Tomanek (2011) to explore the assessment strategies of three science instructors at a research university in the United States. Tomanek et al. (2008) sought to identify factors that influenced the reasoning of prospective and experienced secondary science teachers' formative assessment tasks for their students. In 2011, Trauth-Nane and Buck researched the effectiveness of reflective

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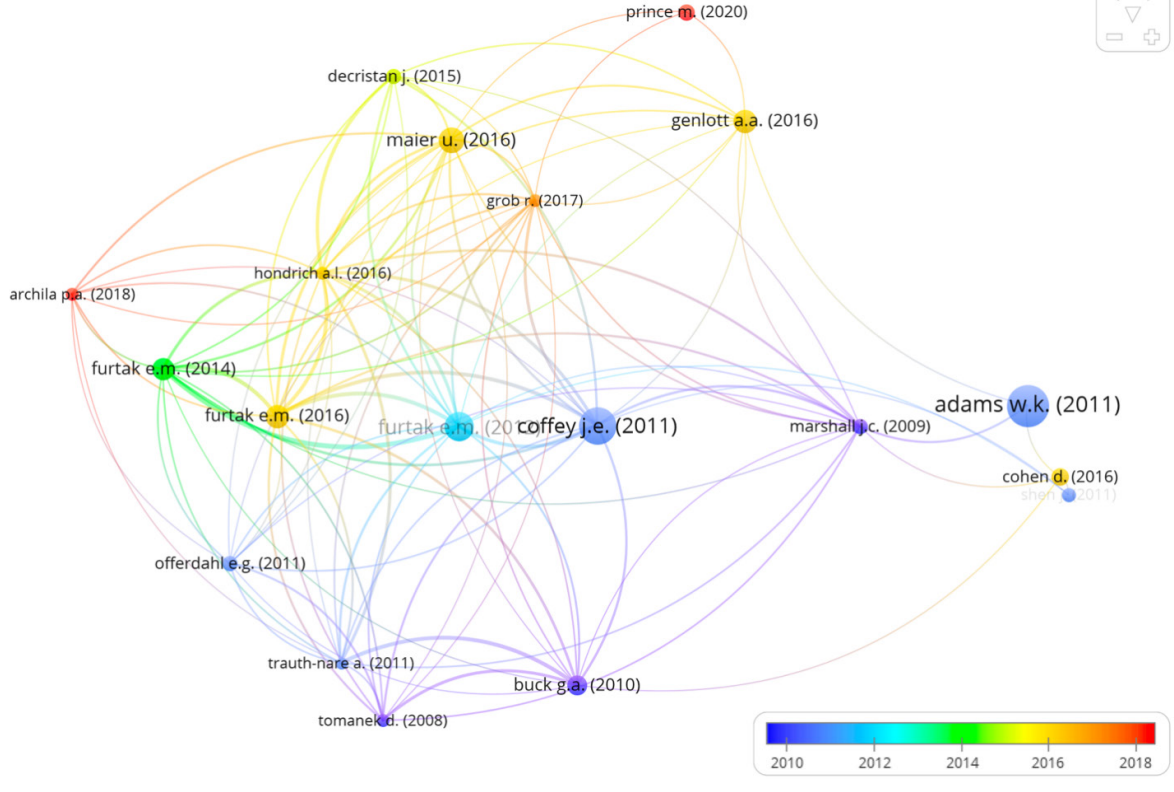
practice in an action research study. Their study focused on incorporating formative assessment into middle school science teaching and learning.

Figure 6
Research Fronts in Formative Assessment



Hotspot Themes in Formative Assessment

The frequency analysis revealed the ten most frequently occurring keywords associated with the formative assessment. These are formative assessment, students, science education, teaching, education, engineering education, curricula, stem, stem (science, technology, engineering, and mathematics), and e-learning (see Table 5).

Table 5
Ten Most Commonly Used Keywords

Keyword	Occurrences	Total link strength
Formative assessment	82	154
Students	29	109
Science education	21	46
Teaching	20	80
Education	19	73
Engineering education	11	43
Curricula	10	46

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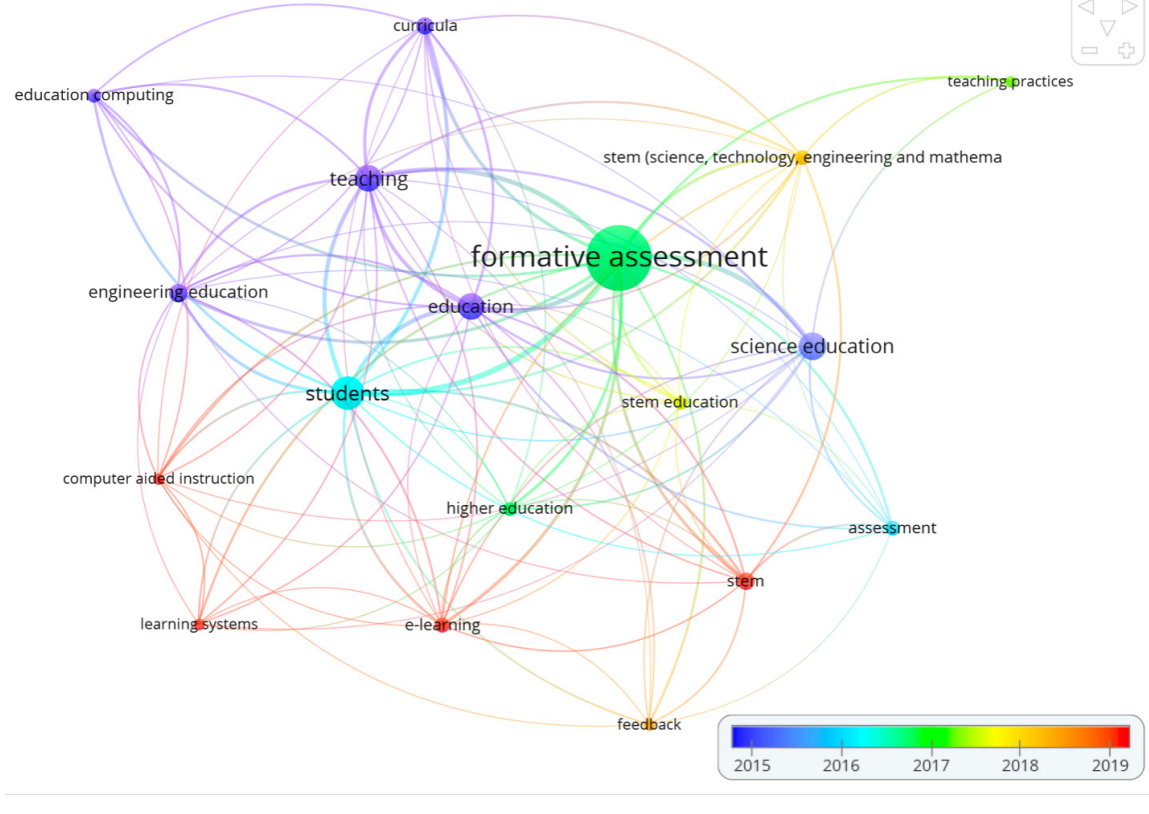
Keyword	Occurrences	Total link strength
Stem	10	31
Stem (science, technology, engineering and mathematics)"	8	33
E-learning	8	32
Assessment	8	21

In addition, themes associated with "hotspots" may emerge at various times and are distinct from research fronts. These themes that emerge from keyword co-occurrence analysis are displayed in four clusters and groups. The keywords are naturally clustered into four groups, as determined by cluster analysis (see Figure 7). Keywords belonging to the same cluster frequently appear within the same occurrence. Each cluster may reveal multiple research hotspots. Even though the keywords between clusters are distinct, different clusters may point to the same research objective in some of the research literature. Through an in-depth analysis of the keywords in each cluster, we can understand the nature of research hotspots on formative assessment. Publications containing Cluster 1 (purple) focused on students and assessment and contained curricula, education, education computing, engineering education, students, and teaching keywords. Cluster 2 (light blue color, orange, and red) focused on STEM and included assessment, feedback, STEM, and STEM education keywords. Cluster 3 (red) was named e-learning and involved Computer aided instruction, e-learning, higher education, and learning systems. Cluster 4 (green and orange) focused on formative assessment and comprised Formative assessment, science education, stem (science, technology, engineering, and mathematics), and teaching practices keywords.

Figure 7
Keywords in Co-Occurrence Analysis



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Research Trends in Formative Assessment

An analysis of the occurrence of keywords provides a diachronic overview of the evolution of research on formative assessment over the past fifteen years regarding major themes (see Figure 7). Figure 7 shows the most popular themes in formative assessment research over time. In 2015, topics such as curriculum, education, education computing, teaching, and engineering education appeared. Between 2015 and 106, the theme of science education appeared in the literature in formative assessment studies. Between 2016 and 2017, themes such as students appeared in the studies. In 2017, themes such as formative assessment, higher education, and teaching practices emerged in the studies. In 2018, the research included themes such as STEM and STEM education. In 2019, the topics found in the studies were STEM, e-learning, computer-aided instruction, learning systems, and feedback.

Discussion

This study aimed to examine the bibliometric results of articles on formative assessment in science education. For this aim, the SCOPUS-indexed publications on formative assessment in science education were analyzed to answer the research question in this study. Based on the criteria for inclusion and exclusion, 94 articles were examined. The results revealed an increasing publication trend on formative assessment in science education between 2015-2016 and 2020-2022. Accordingly, the number of publications on formative assessment has increased substantially. These results showed a research trend on formative assessment in science education literature. In particular, much of the research has been conducted in the last decade. It is unsurprising that much of the literature on formative assessment has been published in the last decade, given the strong connection between science and STEM education.

The results also revealed that seven of ten institutions that contributed to the research on formative assessment were from the United States. The first three institutions are the United States and the University of Colorado Boulder, the University of Nebraska–Lincoln, and the University of California, Berkeley. In addition, nine of the top ten institutions are from developed countries except Colombia. After analyzing the data, it is clear that institutions in developed countries focused more on formative assessment in their research compared to those in developing countries. The top ten institutions show less diversity since seven are from the same country. This result also suggests that American universities have conducted more research on formative assessment.

Another finding was revealed from the results regarding the number of research by countries. The results demonstrated that The United States had the most publications (see Figure 2). Germany and Israel tied for second place. The Netherlands ranked third among the nations. Later, Colombia, Denmark, the United Kingdom, Greece, Spain, Turkey, and the United Kingdom contributed to the research regarding the number of publications on formative assessment. In particular, the United States had the most publications. This result can explain researchers' interest in formative assessment in American universities. This result is similar to that of Sudakova et al. (2022). They found articles from 20 countries on online formative assessment in a bibliometric study. In particular, their findings suggest that the United States is a leader in research on online formative assessment. They indicated that the top countries in online formative assessment are the U.S., the U.K., Australia, Spain, and Germany. Their results are partly similar to those of the findings in this research.

The results regarding publication sources of formative assessment research showed that the most cited journals, the Journal of Research in Science Teaching (JRST), Science Education, and the International Journal of Science Education (IJSE) journals, had received more citations on formative assessment research than one hundred times. As scholars know, citations are a reliable way to evaluate the importance and quality of research. The articles with the most citations in a particular field significantly influence other researchers. Articles with over 100 citations can indicate that other scholars are building on the research of these authors to conduct more impactful studies. Results regarding the cluster analysis showed two clusters. The journals in the first cluster are JRST, Science Education, Journal of Science Teacher Education, Educational Researcher, Assessment in Education: Principles, Policy & Practice, Applied Measurement in Education, and Teaching and Teacher Education. The second cluster comprised the IJSE, Educational Research Review, and Computers & Education journals. One common feature among these journals is that well-known publishers have published them for over 30 years. In addition,

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it can be thought that these most cited journals are the most prominent in science education literature. Another issue is that journals with high impact factors are typically regarded as more influential, of higher quality, and frequently cited. Therefore, scholars researching formative assessment could prefer to publish their findings in these prestigious journals to increase the impact of their research.

Another finding is that results regarding most co-cited authors showed that Dylan Wiliam, Erin Marie Furtak, Paul Black, Maria Araceli Ruiz-Primo, and Richard J. Shavelson were cited more than fifty times. This finding is not surprising as these authors are probably the leading authors of formative assessment. The remaining five authors, Bronwen Cowie, Christine Harrison, Marcia C. Linn, Yue Yin, and Beverley Bell, were co-cited over thirty times. The results also show that six top ten authors are from the United States. Meanwhile, three authors come from New Zealand, and one is from the United Kingdom. This result also demonstrates that the most cited authors come from developed countries. Based on the results, it is likely that developed countries are heavily involved in advancing scientific education through scholarly research. This result is partially similar to the findings of Sudakova et al. (2022).

Lastly, the results regarding the network analysis of keywords revealed that the ten most frequently occurring keywords were formative assessment, students, science education, teaching, education, engineering education, curricula, stem, stem (science, technology, engineering, and mathematics), and e-learning. As Chen et al. (2020) suggested, keyword analysis can help researchers identify relevant research trends, with the most frequently used keywords indicating the most researched topics. Much of the research has been conducted in the context of STEM education; the keywords STEM and STEM education have emerged as the central keywords in cluster analysis. This result also shows that formative assessment has received attention from science and STEM education researchers. This result is different from those of Sudakova et al. (2022). They found that between 2010 and 2020, the keyword "blended learning" rose to the top of the most popular topics in their bibliometric analysis regarding online formative assessment. In addition, their analysis revealed that between 2011 and 2019, "formative assessment" and "assessment" were extremely common. After 2015, they found that authors frequently added "Moodle" to the keywords regarding formative assessment.

Conclusion and Educational Implications

Although the number of publications on formative assessment in science education has long been high, there is no bibliometric analysis or scientific mapping in the literature to understand research trends in formative assessment research. This research aimed to examine the bibliometric results of articles on formative assessment in science education. The results showed that the development of studies on formative assessment had reinforced an increasing publication trend in science education between 2015-2016 and 2020-2022. The five most influential authors are Dylan Wiliam, Erin Marie Furtak, Paul Black, Maria Araceli Ruiz-Primo, and Richard J. Shavelson. The five most influential journals are the JRST, Science Education, the IJSE, the Journal of Science Teacher Education, and Educational Researcher. The most influential countries from which research papers originate are the University of Colorado Boulder, the University of Nebraska–Lincoln, the University of California, Berkeley, the University of Missouri, the School of Natural Resources, and the University of the Andes. The result shows that academics from the United States have made considerable contributions to this field, and American universities employ the best researchers working on formative assessment. The findings have suggested that most publications and top authors in this field are from developed countries. This research emphasizes that the majority of studies on formative assessment are conducted in developed nations' contexts. This finding was further supported by the top ten references, which showed that the most cited documents were also from developed nations. According to the study, formative assessment has been the subject of extensive research in numerous fields. It is now one of the most popular research topics in science education. As developed nations (e.g., the United States and Germany) receive more attention, many scholarly publications have been focused on the Western context.

According to the keyword co-occurrence analysis, the 'hotspot' themes and potential research trends pointed out formative assessment, students, science education, teaching, engineering education, curricula, stem, stem (science, technology, engineering, and mathematics), and e-learning. Theoretically, this study confirms a research trend for formative assessment based on the bibliometric characteristics of the retrieved records. It reveals information about research on formative assessment. More specifically, more research on formative

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assessment is essential to determine its impact on student and teacher outcomes and uncover existing challenges and difficulties that can provide solutions for effectively teaching science and STEM subjects in schools.

While the articles offer valuable insights for researchers in less developed countries, examining the state of research in developing countries is essential. It is recommended that future studies should focus on formative assessment research in other countries. It is worth noting that many scholars from developed nations contribute to establishing a knowledge base on formative assessment. We also encourage researchers and practitioners from developed and developing nations to collaborate on formative assessment, as our study has identified a research gap in this area.

Although there has been an increasing interest in formative assessment within science education literature, there has been limited knowledge of the current status of research using bibliometric analysis. To our knowledge, no research has examined the current state of formative assessment bibliometrically, except for one study. Therefore, the authors needed to conduct this present research to contribute to the existing knowledge by providing an overview of the current research in this field.

Bibliometric research is useful for policymakers and educators to make informed decisions regarding education policy, curriculum development, and instructional practices. This research provides a piece of evidence-based information on the research status of formative assessment in science education. Researchers can use bibliometric analysis to gain insights into the field, evaluate research impact, identify research gaps, and contribute to evidence-based educational decision-making. This study analyzed studies from the SCOPUS database. However, future research should consider including data from other databases like ERIC, EBSCOhost, and Web of Science. Further research can focus on tracking the development of this field, research directions, and international cooperation networks between nations and organizations. Scholars can also study changes in research results on formative assessment in science education separately for students and teachers. To explore different aspects of research on formative assessment, future studies should conduct more bibliometric research to identify research trends.

Limitations

Although this study provides a comprehensive knowledge map of research on formative assessment in science education literature, some limitations should be noted. This study uncovered collaboration potential through bibliometric analysis and provided valuable results for formative assessment research. Although this study provides valuable insights into formative assessment studies, it is important to note that the search period may have limited the scope and depth of the included studies. One significant limitation of the study is that it only included research studies indexed by the Scopus database. It is possible that other valuable studies on formative assessment were not indexed by Scopus, making them inaccessible for this study. In addition, we were unable to review studies conducted in local languages. On the other hand, the analyses were performed using the keywords selected by the authors. Our search parameters, which include only SCOPUS-provided and English-language documents, may exclude relevant studies unavailable through SCOPUS or written in other languages. Future bibliometric studies should expand the search parameters to include additional studies.

Researchers using other databases for this type of research using bibliometric analysis may reach different conclusions. Researchers can create a more thorough analysis by combining studies from multiple databases when conducting bibliometric studies. Depending on their interests, researchers interested in formative assessment may also conduct studies on "alternative assessment," "self-assessment," and "authentic assessment" in the educational context. Finally, additional research is required to conduct a more in-depth analysis.

Declaration of Interest

The authors declare no competing interest.

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