Contemporary Educational Technology, 2025, **17**(1), ep554
ISSN: 1309-517X (Online)

OPEN ACCESS

Review Article

Computer-based assessment research trends and future directions: A bibliometric analysis

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Citation: Syahbrudin, J., Istiyono, E., Khairudin, M., Anggraini, A., Wusqo, I. U., Mariam, M., & Muflihan, Y. (2025). Computer-based assessment research trends and future directions: A bibliometric analysis. *Contemporary Educational Technology, 17*(1), ep554. https://doi.org/10.30935/cedtech/15743

ARTICLE INFO

Received: 13 Jun 2024
Accepted: 7 Nov 2024

ABSTRACT

Computer-based assessment (CBA) is a top-rated tool for conducting assessments, mapping learning outcomes, and selecting new candidates. Research that examines the development and use of CBA is also increasing from year to year, so without bibliometric analysis, it would be quite challenging to keep up with all of these studies. This study aims to clarify the status and world trends in CBA research around the world. Bibliometric analysis was performed using bibliometrix based on 2,020 articles published in Scopus from 1982 to 2023 (data update time on 5 January 2024). This bibliometric analysis identified the state of research publications, scientific productivity, the network state of research publications, and CBA research priorities and directions going forward. Results show that research on CBA has grown rapidly, with the highest number of publications in 2022, with the USA being the most productive country. Greiff is the most prolific and Wise is the most impactful author. The journal with the highest impact is "Computers and Education". These findings also indicate that research themes that show research potential due to their high relevance to CBA but are still little studied are those related to "regression analysis", "automation", "information technology", "assessment", "motivation", "quality control", "problem solving", "online systems", "decision making", and "teaching".

Keywords: bibliometric, bibliometrix, computer-based assessment, assessment

INTRODUCTION

The use of technology in education continues to increase, especially since the COVID-19 pandemic, where learning is "forced" to be carried out online (Boyko et al., 2021; Cuaton, 2020; Villegas-Ch et al., 2021), which presents challenges for students and educators. This online learning certainly has implications for assessments that also need to be carried out online, or what is now often called e-assessment, electronic assessment, online assessment, digital assessment, or computer-based assessment (CBA) (Kundu & Bej, 2021). CBA is an e-learning system that utilizes information communication technology for assessment activities, exams, and recording the responses of examinees (Bello & Abdullah, 2021).

Research on CBA in an educational context was first published in a Scopus-indexed journal in 1982 by Brooks et al. (1982) who developed a computer-based multiple-choice test item bank and implemented it on junior medical clerkships, followed by CBA research on students with special needs (Hasselbring, 1984), then on various subjects, student characteristics, and the needs of CBA itself. Although CBA has advantages (Alsadoon, 2017; Antón-Sancho et al., 2021; Ilgaz & Adanır, 2020; Jawaid et al., 2014; López-Zambrano et al., 2020; Shakeel et al., 2021) and disadvantages (Farooq et al., 2020; Mellar et al., 2018; Qazi et al., 2020; Xie et al., 2020), CBA-related research has continued to develop rapidly over the past two decade (Huerta et al., 2022).

However, with the rapid increase in academic publications related to CBA from year to year, it will also becoming increasingly difficult to follow the direction of all these studies, while the current research landscape still needs to be assessed to propose appropriate research paths in the future (Kushairi & Ahmi, 2021). In addition, the existence of diverse and fragmented research streams can also make it challenging to gather knowledge and empirical evidence from previous studies. To review literature, a researcher must spend much time and effort. Even then, they may still not get a complete picture of the research area they are looking for.

Bibliometric analysis is necessary to facilitate numerous, fragmented, and perhaps even controversial research. One of the unique open-source tools that can be used for bibliometric analysis is the R-based bibliometrix program with the biblioshiny function developed by Aria and Cuccurullo (2017) and available in wide network file R, or Comprehensive RArchive Network (CRAN). This analysis is relatively easy because it does not require steps to re-check or correct the collected data code (keywords); everything is done automatically by the program. This bibliometric only requires four easy steps: determining the objectives and scope of the research, collecting metadata, conducting bibliometric analysis, and interpreting the results.

This bibliometric analysis helps evaluate the corpus literature of a particular field or research subject (Ellegaard & Wallin, 2015), which allows for a summary of the scientific productivity of a scientific discipline (Tran & Aytac, 2021), which in this case is related to CBA. By conducting a bibliometric analysis, publication trends and patterns of collaboration between research can be determined (Ellegaard & Wallin, 2015) and can also be selected as the core source of related research (Desai et al., 2018; Venable et al., 2014), as well as to learn about the focus and description of a study through the analysis of co-occurrence keywords (Chen et al., 2016). These results are undoubtedly valuable and profitable for researchers by narrowing the scope of the literature search.

Bibliometric research related to CBA was conducted by Huan and Meng (2021), but they only focused on "electronic feedback in an educational context", not CBA as a whole. Another bibliometric analysis was conducted by Sudakova et al. (2022), which only focused on online assessment formats in colleges. Therefore, this paper explores the evolutionary path and trends of educational research related to CBA since its initial publication in Scopus indexed journals. This research uses scientific articles in the Scopus database from 1982 to 2023, intending to help researchers save time and effort looking at the "big picture" in the field for this study as well as assisting in determining research topics that are needed in the future, to fill in and improve the quality of related research, through answers to the following questions.

1. What is the state of research publications related to CBA?
2. How is the productivity of scientific research related to CBA?
3. What is the network state of research publications related to CBA?
4. What are the priorities and directions of CBA research in the future?

METHOD

Bibliometric Design

The scientific methodology used in this study is a type of bibliometric analysis known as scientific mapping workflow, which seeks to demonstrate scientific research's structural and dynamic aspects. This methodology requires statistical tools to assist data analysis. This study uses the bibliometrix package proposed by Aria and Cuccurullo (2017) to implement the scientometric methods, with four easy steps adapted from Donthu et al. (2021), namely.

Step 1: Determine the scope and objectives of the bibliometric study
Step 2: Collect metadata for bibliometric analysis
Step 3: Perform a bibliometric analysis using bibliometrix
Step 4: Interpreting the results

These stages will be explained in detail in the following section.

Bibliometric Stages

In the following steps, we outline a comprehensive approach to conducting a bibliometric study, focusing specifically on research related to CBA in social science studies.

Step 1. Determine the scope and objectives of the bibliometric study

The scope of this research is limited to research related to the development and use of CBA in social science studies. The aim is to assist researchers in seeing the "big picture" of this field of study and determining what research topics are needed to fill and improve the quality of related studies in the future.

Step 2. Collect metadata for bibliometric analysis

The data for this bibliometric analysis are only scientific articles published in journals and collected through the Scopus database from 1982 to 2023. The search format is TITLE-ABS-KEY ("computer based assessment" OR "computer based test" OR "e-assessment" OR "electronic assessment" OR "digital assessment" OR "online assessment") AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (SUBJAREA, "SOCI")) AND (LIMIT-TO (SRCTYPE, "j")) AND (EXCLUDE (PUBYEAR, 1969)) retrieved 5 January 2024; where double quotation marks ("") indicate that the displayed article contains basic words with the same wording, and the word "OR" is used to search for other keywords but with equivalent meanings, so that the articles obtained are only related to CBA. In this search format, the field of study is limited to the social sciences, so the results obtained only focus on CBA in an educational context. At the same time, the article published in 1969 was excluded because, after being traced, the article had nothing to do with CBA. The last search query found 2020 related articles exported directly to "CSV format".

Step 3. Perform a bibliometrix analysis

The data files that have been collected are then processed using a special package for bibliometric analysis developed by Aria and Cuccurullo (2017) called bibliometrix and equipped with the biblioshiny function. The custom package is a unique open-source tool available on wide network file R or CRAN.

The steps are, as follows:

(1) install the bibliometrix package with the syntax: install.packages ("bibliometrix"), this step can be omitted if the bibliometrix package is already installed on our computer,
(2) call the bibliometrix library with the command: library(bibliometrix),
(3) plug-in biblioshiny with the syntax: biblioshiny(), and
(4) import data, then select what analysis will be carried out according to the purpose of this research and click "run".

Step 4. Interpreting the results

According to the research question, the results are interpreted in terms of "state of the CBA publication", "scientific productivity", "network state", and "research topic and future research directions".

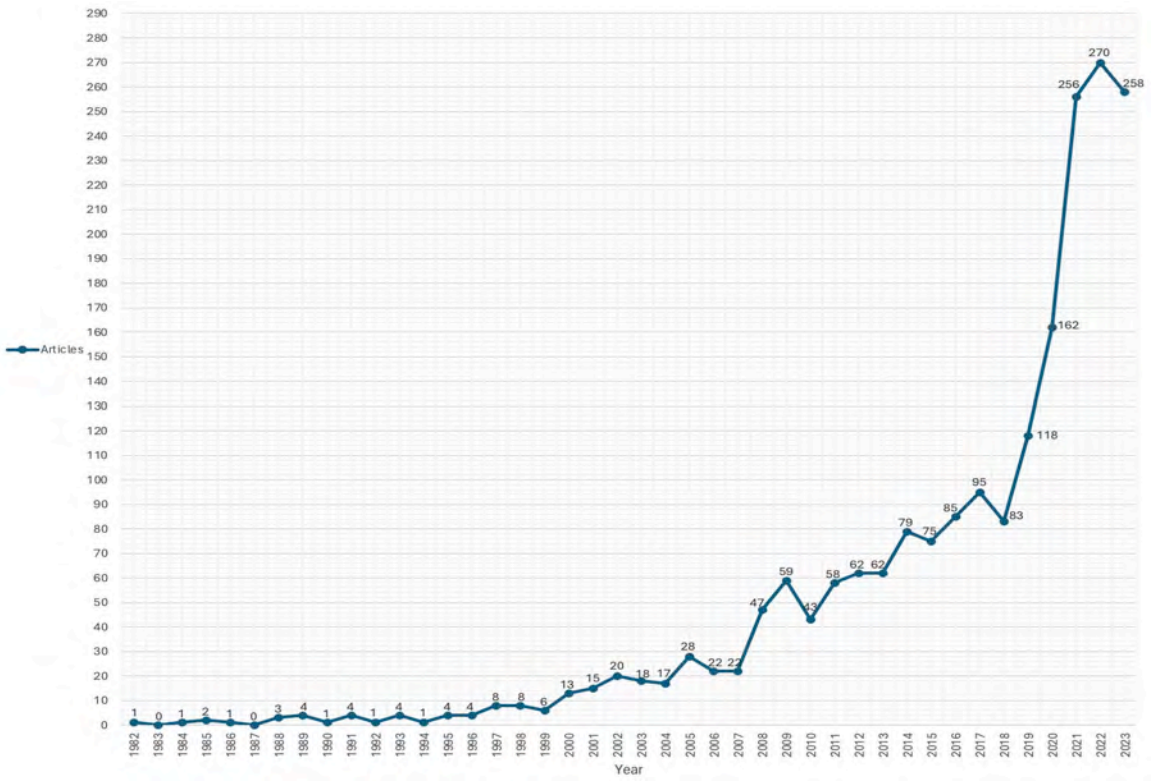

Figure 1. The annual publication on CBA in educational context from the year of 1982 to 2023 (Source: Author-generated visualization using Biblioshiny)

RESULTS AND DISCUSSION

State of the CBA Publication

Publication trend

Annual publications related to CBA in the educational context from 1982 to 2023 are represented using bar graphs, as shown in **Figure 1**.

The number of publications reached 10 for the first time in 2000 and fluctuated in the range of 15 and 28, then there was a steady increase in publications from 2007 to 2023 with slight dips in 2010, 2015, 2018, and 2023, with the highest number of publications in 2022 at 270 articles.

Citation trend

CBA publication citation analysis from 1982 to 2023 is shown in **Figure 2**. The trendline of average citations over the years provides a visual representation of how the influence and recognition of CBA-related publications has grown. The increasing trend suggests increased recognition or interest in CBA studies over time or perhaps due to advances in the field, and vice versa. The flat trendline indicates stable citation levels without significant changes over the years.

Based on **Figure 2**, there is a fluctuating number of citations from year to year. Even so, in 1988, the increase was quite significant. The mostly cited publications during this period likely focused on foundational studies in the field of CBA, which laid the foundation for future research as it was an early period of research on CBA. There is a quite unique incident here, where during the period 2019 to 2021 (during the COVID-19 pandemic) there was a significant increase in the citation trend, but in 2022 and 2023 there was a quite significant decline.

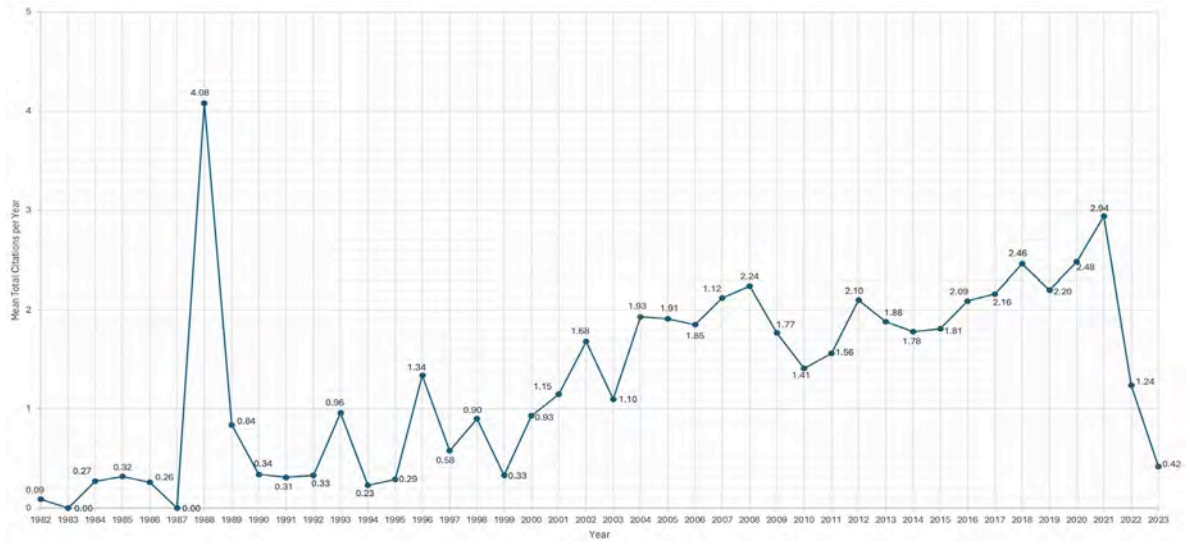

Figure 2. Trendline of average citations over years (Source: Author-generated visualization using Biblioshiny)

Table 1. Top-10 countries contributed to the publications

No	Region	Frequency
1	USA	1,442
2	UK	603
3	Australia	428
4	Germany	389
5	Spain	328
6	China	287
7	Canada	183
8	Malaysia	158
9	Netherlands	154
10	Indonesia	143

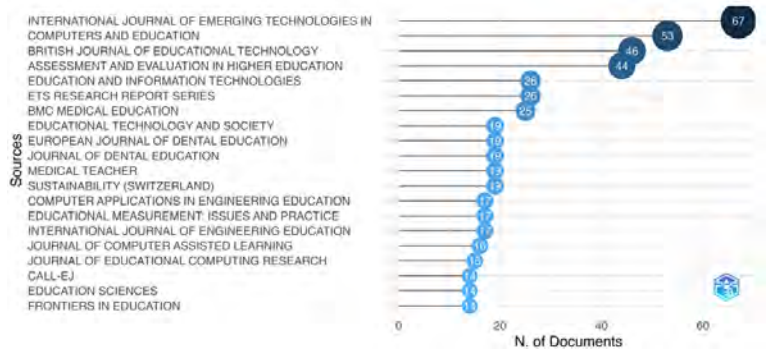

Figure 3. Top 20 most relevant sources (Source: Author-generated visualization using Biblioshiny)

Geographical distribution of the publication

Based on author affiliation, the USA has the highest publication distribution with 1,442 articles. The top-10 countries that make the most enormous contribution are shown in **Table 1**.

Most relevant sources

The top-20 most relevant journals are shown in **Figure 3**, with "International Journal of Emerging Technologies in Learning" ranking first, although the impact factor based on the H index ranks fourth. In comparison, the journal with the highest impact is occupied by "Computer and Education" (**Figure 4**). In addition, there are also "British Journal of Educational Technology", and "Assessment and Evaluation in Higher Education" which occupy the top-4 most relevant and impactful journals.

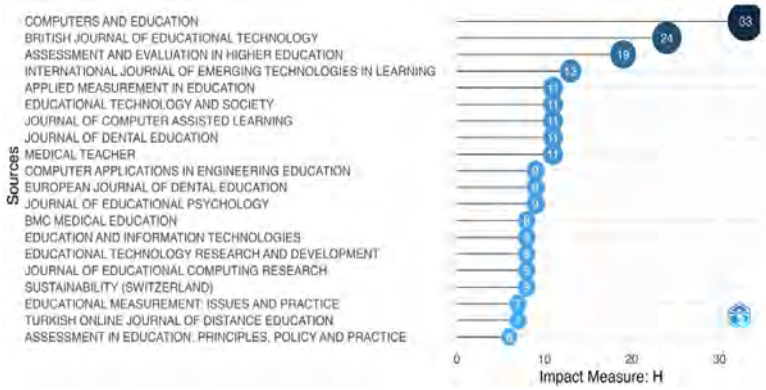

Figure 4. Top 20 sources local impact by h-index (Source: Author-generated visualization using Biblioshiny)

Figure 5. Top 20 author's production over time (Source: Author-generated visualization using Biblioshiny)

The h-index is used in this analysis of the most impactful journals because it is a metric used to measure the productivity and impact of a person's scientific publications, journals, or academic institutions (Fassin, 2023; Poirrier et al., 2021). A journal with a high h-index means that it not only publishes many articles, but is also frequently cited by other researchers, indicating that the research published is of high quality and relevance in its field (Hirsch & Buela-Casal, 2014). The h-index also shows the long-term impact of a journal by providing a cumulative assessment of a journal's contributions over a certain period of time (Bihari et al., 2023). In other words, journals that have a high h-index are usually considered to have a significant impact and play an important role in the development of science in their field.

Author's production over time

Figure 5 shows the 20 most productive authors in the CBA field in an educational context over time, with Greiff as the most productive author. He published his first CBA article in 2013, where he immediately published three articles in different journals, all discussing the assessment of complex problem-solving skills using CBA. Greiff et al. (2015) wrote about utilizing CBA in the program for international student assessment (PISA) as the most cited article with a total of 118 citations.

Author impact

Frequently cited articles are more likely to attract attention (Wang et al., 2022), as they contribute to 'author impact'. The top-20 authors with the highest total citations are shown in **Figure 6**, with Wise ranking first. So far, all of Wise's articles on CBA have a total of 686 citations, with the most cited article entitled "Response time effort: A new measure of examinee motivation in computer-based tests" (Wise & Kong, 2005) with a total of 358 citations.

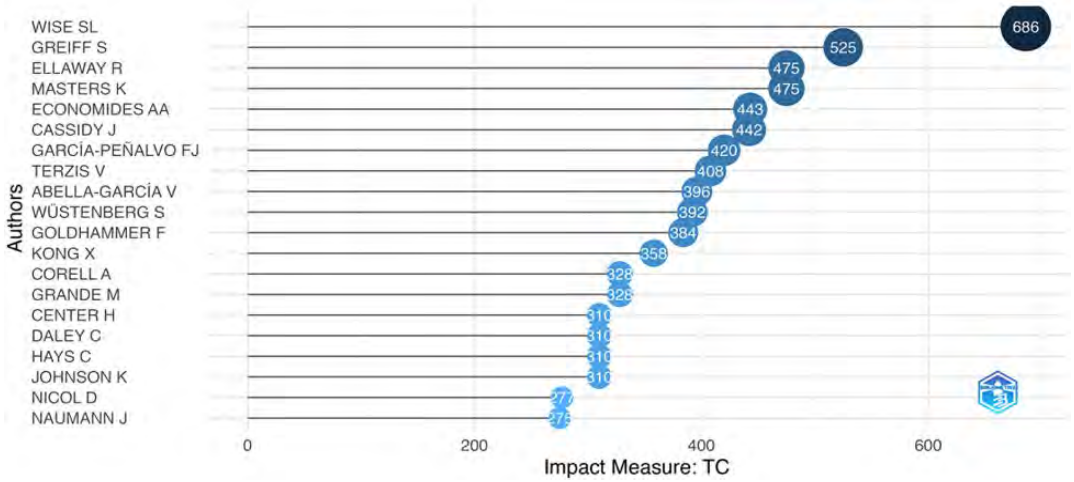

Figure 6. Top 20 author impact by total citation index (Source: Author-generated visualization using Biblioshiny)

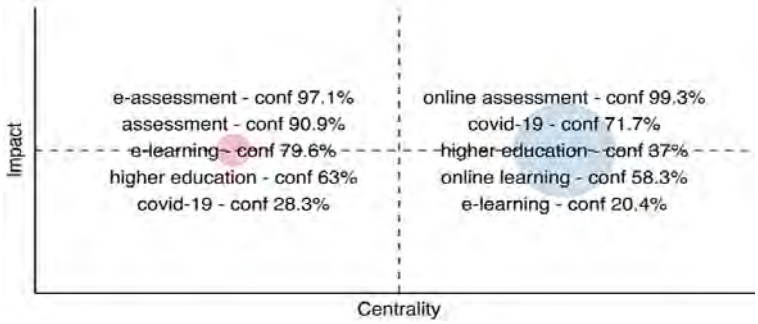

Figure 7. Clusters by documents coupling on author's keywords (Source: Author-generated visualization using Biblioshiny)

Network State

Bibliographic coupling

Bibliographic coupling, or two articles bibliographically matched, occurs when at least one source or keyword cited appears in the reference lists of the two articles (Habib & Afzal, 2019; Phan Tan, 2022). The analysis results are, as shown in **Figure 7**; two clusters have occurred. First, the red cluster with low centrality contains the top-5 keywords "e-assessment", "assessment", "e-learning", "higher education", and "covid-19". Second, the blue cluster with high low centrality contains the top-5 keywords "online assessment", "covid-19", "higher education", "online learning", and "e-learning".

Co-occurrence analyses

The co-occurrence network of terms used in CBA research is depicted in **Figure 8**.

In **Figure 8**, the size of each circle represents the number of papers that mention a particular term, with larger circles indicating terms that appear more frequently in the literature. The three main groups:

(1) the largest, concentrating on online assessment,

(2) the second largest, focusing on e-assessment, and

(3) about assessment, followed by those concerning CBA, COVID-19, higher education, e-learning, formative assessment, and so forth–are closely tied to one another.

The word count for each of the previously stated keywords is shown in **Figure 9**.

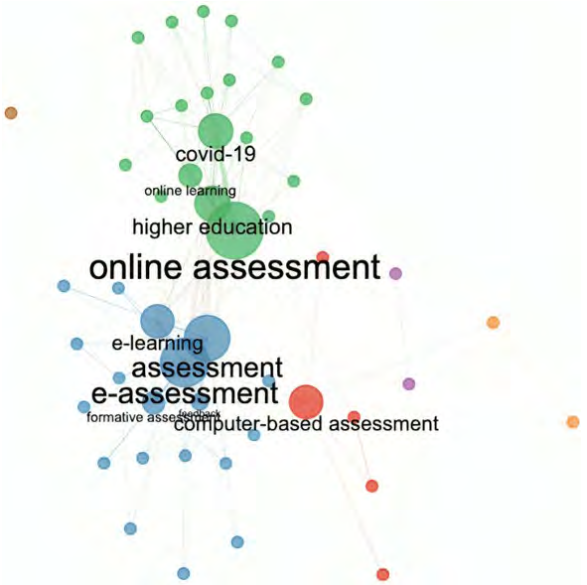

Figure 8. Co-occurrence term map of CBA studies (Source: Author-generated visualization using Biblioshiny)

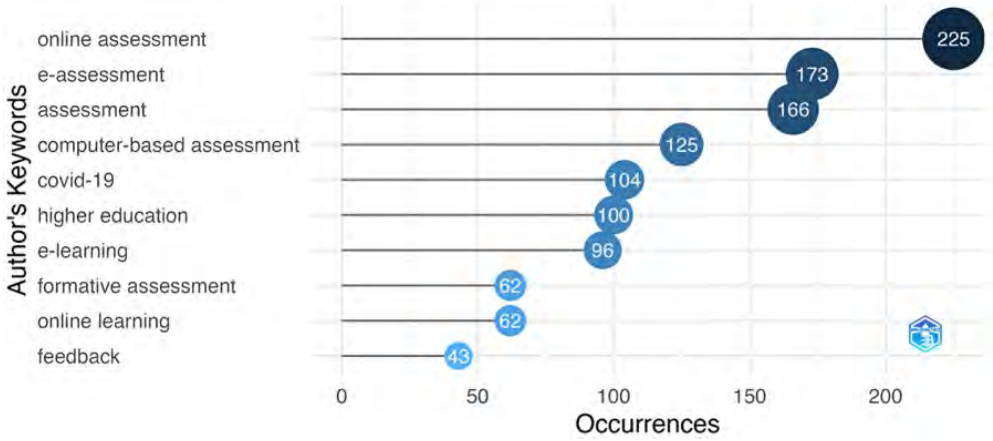

Figure 9. Most relevant words (Source: Author-generated visualization using Biblioshiny)

Co-citations network and collaboration network

The co-citations network in this research field is shown in **Figure 10**. The collaboration network is shown in **Figure 11**.

The relationships between various publications are represented by the co-citations network in **Figure 10**, which is based on how frequently they are cited together in other works (Tang et al., 2023). The dots in this network stand in for individual papers or authors, and the connections between them indicate that these authors are frequently cited together by other researchers (Tang et al., 2016). A dense cluster of dots suggests a strong thematic link or a shared research field. This network assists in identifying the most important authors and foundational works that have shaped research trends in the subject of CBA (Tang, 2021).

Figure 10 here

The collaboration network among CBA researchers is depicted in **Figure 11**. The connections between the dots in this network signify co-authorship or cooperative effort on published papers, and the dots themselves represent specific scholars or research organizations (Zinilli et al., 2024). Stronger community collaboration is indicated by a more densely connected network, whereas isolated dots might represent researchers working independently. **Figure 11** is valuable for identifying the most active research relationships that support the advancement of CBA studies and for recognizing top-collaborators.

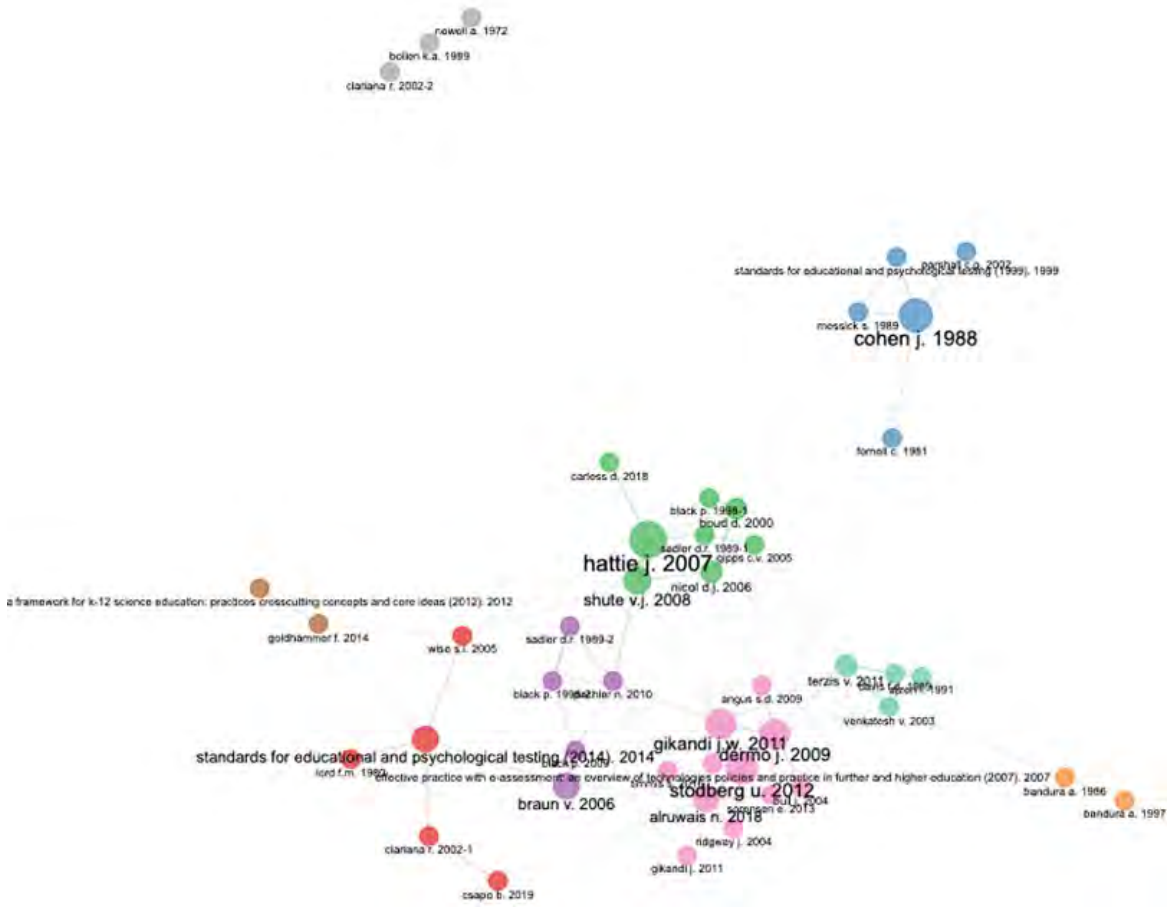

Figure 10. Co-citations network (Source: Author-generated visualization using Biblioshiny)

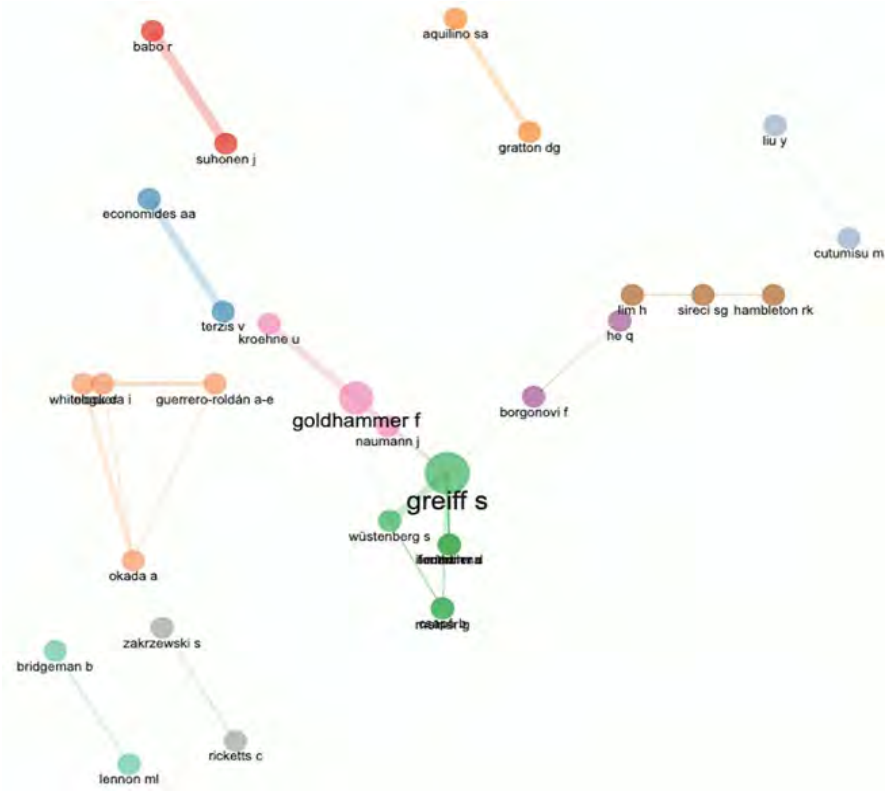

Figure 11. Collaboration network (Source: Author-generated visualization using Biblioshiny)

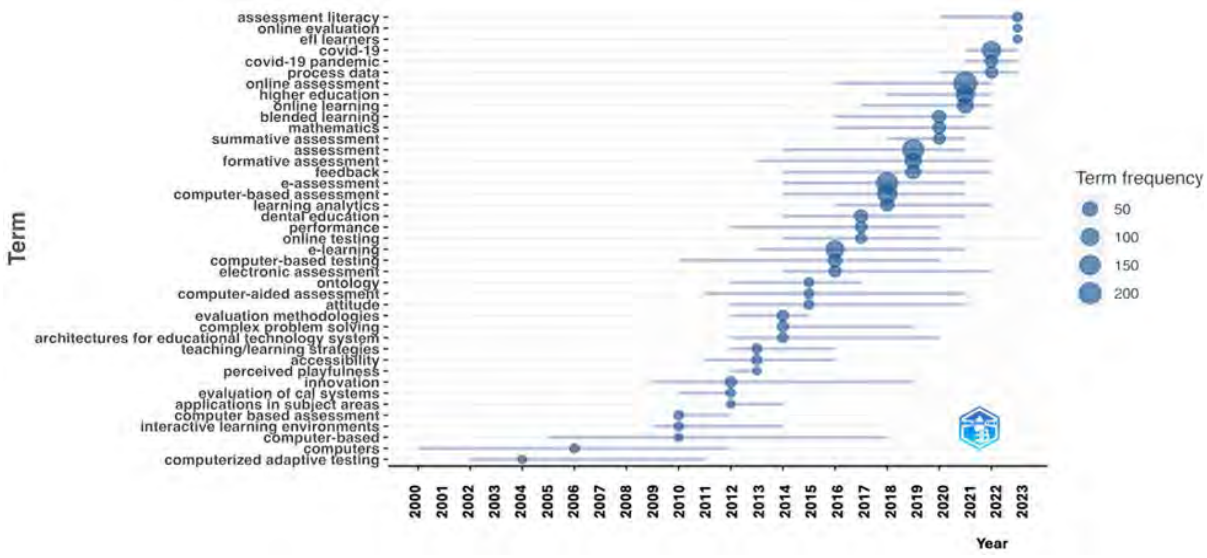

Figure 12. Trend topics (Source: Author-generated visualization using Biblioshiny)

Table 2. Top-10 trending topics or themes in CBA

No	Online assessment	Frequency
1	E-assessment	173
2	Assessment	166
3	Computer-based assessment	125
4	COVID-19	103
5	Higher education	100
6	E-learning	96
7	Formative assessment	62
8	Online learning	62
9	Feedback	43
10	Online assessment	225

Research Topics and Future Research Directions

Trending topics

Trending topics or themes in this research area are shown in **Figure 12**, where online assessment, e-assessment, assessment, CBA, COVID-19, higher education, e-learning, formative assessment, online learning, and feedback are the most popular recently (2018 to 2023). The top-10 trending topics or themes in this research area are shown in **Table 2**, with the distribution of topics from year to year shown in **Figure 12**. The evolution of the development theme of this research field from time to time is shown in **Figure 13**.

CBA research opportunities

To identify research trends and future research opportunities for CBA, we used a thematic-map analysis based on the co-use of keywords applied by the authors, using the "word co-occurrence network" to classify and map terms extracted from titles, abstracts, or keywords that are in bibliographic collections (Aria & Cuccurullo, 2017). The theoretical foundation of this analysis is because the co-occurrence of keywords simultaneously describes the contents of documents in these files (Callon et al., 1991).

The thematic networks are represented on two axes, with the horizontal axis representing the centrality of the thematic network (relevance of the theme–the farther to the right, the more connections, and the stronger they are, the more this group represents a critical research challenge set by the scientific or technical community) and the vertical axis density representation (a measure of thematic development–the higher it is, the more related research is in that cluster) (Zammarchi & Conversano, 2021).

According to the centrality and density of the study subjects, they are separated into four segments (**Figure 14**).

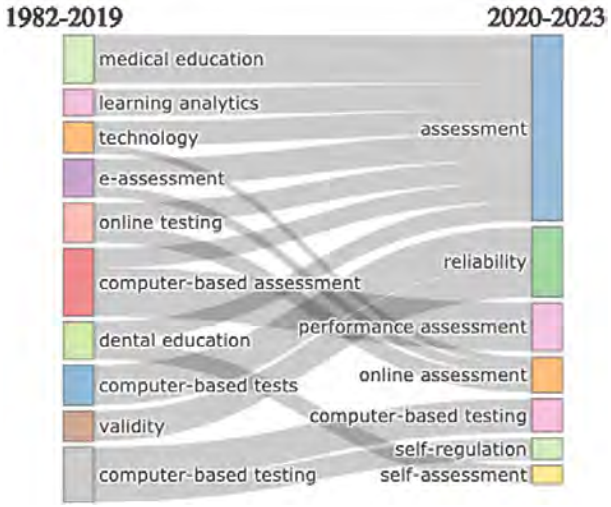

Figure 13. Thematic evolution (Source: Author-generated visualization using Biblioshiny)

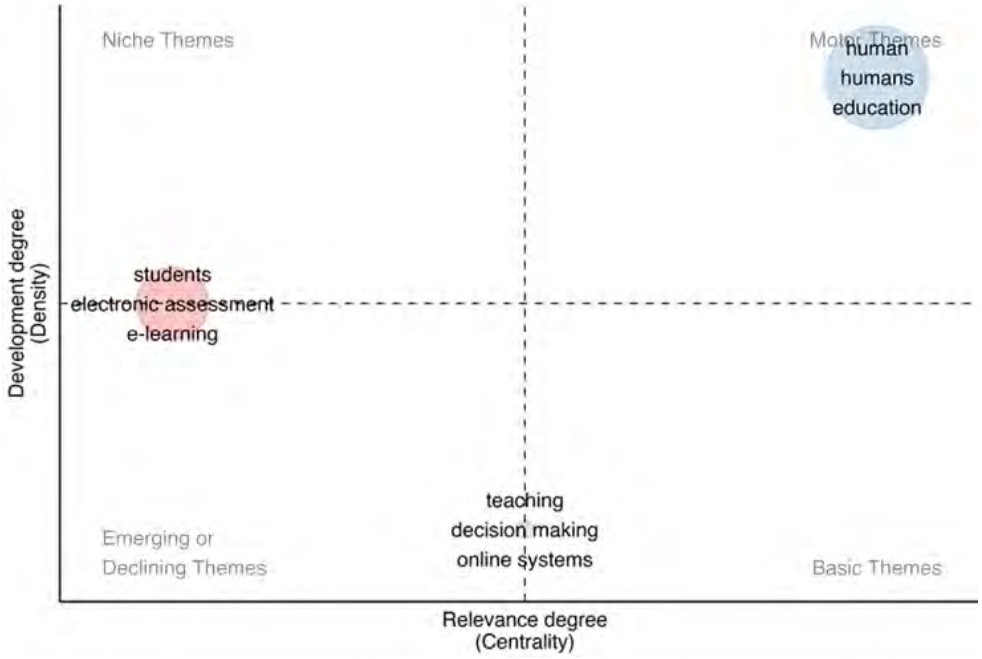

Figure 14. Clusters by studies themes (Source: Author-generated visualization using Biblioshiny)

In the first segment, subjects in the lower left part are subjects with low centrality and decreased density, which are referred to as “emerging or declining themes”. In the second segment, “niche themes” or subjects with high density but low centrality (indicating highly advanced but isolated themes). In the first and second segments, keywords do not appear, but instead appear between the first and second segments, namely “student”, “electronic assessment”, and “e-learning”. In the segment with high density and centrality, known as the “motor themes”, are dominated by the keywords “human”, “humans”, and “education”. The last segment, the “basic theme”, stands out for having a high centrality but a low density. In this fourth segment, no keywords appear, but instead appear between the first and fourth segments, namely “teaching”, “decision making”, and “online systems”.

Meanwhile, future research opportunities in CBA are centered on the keywords of the low-density segment, namely “emerging or declining themes” and “basic themes” or those in between. When these areas are examined more closely, the specific keywords and how often they occur become clear, as shown in **Figure 15**.

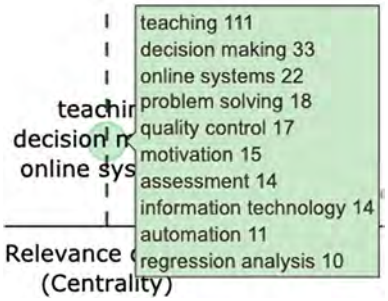

Figure 15. Distribution of keywords that are relevant to CBA and still little researched (Source: Author-generated visualization using Biblioshiny)

Recommendations for Future Computer-Based Assessment Research

Figure 15 also shows that the research that are recommended to be developed on the basis of the low number of studies and the high relevance of CBA based on the results of bibliometric analysis from bottom to top are those that prioritizes "regression analysis", "automation", "information technology", "assessment", "motivation", "quality control", "problem solving", "online system", "decision making", and "teaching". Therefore, rather than examining emerging or declining patterns, this approach focuses on investigating subjects that are truly relevant to CBA but that have not received enough attention or have not been thoroughly researched. Below are some more detailed descriptions of recommendations for future CBA research.

Regression analysis–CBA

Regression analysis is useful for identifying and analyzing factors that influence assessment results, which in turn are useful for predicting future student performance or providing valuable information to improve the learning process. Regression analysis is a useful tool for analyzing the relationship between the variables in an assessment (Cohen, 1968; Thwe & Kálmán, 2023), including to determine the factors that most influence the assessment results and identify patterns that can influence participants' performance in the assessment (Aggarwal & Ranganathan, 2017; Schmidt, 1971). Apart from that, automatic regression analysis can also help in making predictions about future assessment results (Christensen, 2020; Maryati et al., 2021). Thus, the addition to automatic regression analysis features to CBA creates a powerful framework for exploring and understanding the factors that influence student learning outcomes in more detail, thereby enriching educational decision making.

Automation–CBA

Automation in CBA was created to increase efficiency, consistency and objectivity throughout the assessment process (Palmer, 2020; Viloria, 2016; Zawacki-Richter et al., 2019), from administering tests to providing grades and feedback (Savulescu et al., 2015; Schoen-Phelan & Keegan, 2016). Data analysis or scoring assessment results, announcing results, and providing feedback automatically or semi-automatically can also avoid increasing teacher workload (Adesina et al., 2014). More specifically, automated assessment software assists teachers in making decisions using a combination of technology and humans (Colonna, 2024).

Overall, these automated systems in CBA have been very helpful, but the important role of teachers in providing useful feedback to students must continue to be maintained. Future research may concentrate on developing CBA automation systems that are more integrated with the teacher's role, so that teachers can help provide contextual and useful feedback to their students.

Information technology–CBA

Information technology (IT) has changed the educational landscape towards the digital era, playing an important role in various aspects of life (Sokku & Anwar, 2019), including improving learning experiences and assessing learning outcomes. IT can be utilized to improve academic performance, helping students and teachers collaborate in an interactive and challenging environment for critical thinking, sharing knowledge, and learning (Asamoah et al., 2017; Nadeem et al., 2018). IT also enables the development and

implementation of CBA tools, which offer several advantages over traditional paper-based assessments (Hunsu, 2015; Schoen-Phelan & Keegan, 2016).

Specifically in the assessment of learning outcomes, IT provides a crucial foundation for the implementation of CBA, which enables the efficient administration of exams, assignments and other assessments via online platforms, as well as connecting students and educators from various locations, thereby increasing administrative efficiency. Future research can explore the impact and further implications of the use of IT in the implementation of CBAs on learning experiences, academic performance, interactions between students and teachers, and the development of a learning ecosystem that is dynamic and responsive to the demands of the digital era.

Assessment–CBA

Assessment has the potential to improve self-regulation skills and student learning outcomes, as it provides evidence-based guidance for improving teaching based on learning objectives. The assessment process itself has evolved into CBAs that provide a more dynamic and engaging way to demonstrate student knowledge and skills, while allowing for an efficient and automated assessment process (Efendi et al., 2021; Schoen-Phelan & Keegan, 2016; Tomasik et al., 2018). It is efficient here because it not only provides direct feedback to students, but also allows teachers to collect and analyze data more quickly, identify areas of improvement and adapt teaching to meet each student's needs, leading to improved learning outcomes (Baharun et al., 2019; Nangawe, 2015; Vásquez et al., 2016; Zamahsari et al., 2020). Thus, future research could explore the important role of teachers in using CBA data to provide appropriate support and guidance to students, with a focus on personalizing learning to meet each individual's needs.

Motivation–CBA

The emergence of computers in educational assessment has led to a shift from paper-pencil-based assessments to CBAs. Computer-web and mobile device-based assessments are more motivating for students and more promising than paper-pencil-based assessment procedures (Nikou & Economides, 2016). This motivation is because in CBAs, there is instant feedback which can provide a motivational boost to students because they can see the results of their performance quickly. Kuklick and Lindner's (2023) study shows that providing feedback to confirm correct answers tends to improve students' affective-motivational state, and feedback that contains knowledge descriptions for both correct and incorrect answers is more useful than just a simple notification. These results are in accordance with the findings of Wang et al. (2023) revealed that elaborated feedback had more beneficial effects on dominant learning-oriented learners, although it had no effect on dominant performance-oriented learners.

However, designing motivating feedback is a challenging task, especially feedback for wrong answers. Even though feedback for wrong answers may not be more motivating than not giving feedback, at least research (Kuklick et al., 2023) shows that feedback that contains descriptions of knowledge has the potential to reduce the impact of negative motivation. Even feedback that includes completion steps seems to have the potential to increase student motivation (Wang et al., 2019). Thus, in developing CBA it is necessary to pay attention to appropriate feedback to respond to correct and incorrect answers, so that it can help increase test takers' motivation, as well as help understand their strengths and weaknesses, so that the improvement process can be more focused according to needs.

Quality control–CBA

Quality control is crucial to the accuracy, reliability, and fairness of CBAs (Gulikers et al., 2009; Nguyen et al., 2017). CBA must be able to provide assurance that the assessment results are an accurate and reliable picture of student knowledge and achievement (Adhikari et al., 2024). This quality control involves a variety of processes and measures implemented to avoid any errors related to the content or quality assurance of instruments, administration, assessment processes, CBA performance and maintenance, and assessment reporting. However, it seems that no current research has comprehensively examined all of these actions in one article. The next research recommendation is to dig deeper into the implementation of quality control measures, both at the instrument and administrative process levels, performance and maintenance of CBA, as well as reporting of assessment results, in order to provide more insight into the accuracy, reliability and

fairness of assessments using CBA in a comprehensive manner. Accuracy and reliability are primarily determined by the quality of the instrument (Bello & Abdullah, 2021). Therefore, CBA research should also examine the quality of the instrument.

Problem-solving–CBA

Different types of problem-solving have unique characteristics and require different assessment approaches, including through the help of CBA. For example, complex problem-solving requires deep analytical skills, can be assessed using computer assistance, as in research conducted by Greiff et al. (2016). Creative problem-solving that focuses on innovation and can also be assessed through computer-assisted methods, as in Nurrijal et al. (2023). Collaborative problem-solving requires teamwork and effective communication, has also been effectively assessed with CBA, as in research conducted by Andrews-Todd et al. (2023). In support of this assertion, Adesina et al. (2014) proposed that it is best to provide feedback on all steps and actions during the problem-solving process. Thus, in developing CBA it is necessary to provide constructive feedback in the form of insight and guidance needed in each problem-solving process in order to help test takers understand and improve their skills.

Online systems–CBA

Online systems in CBA are very important for modern education, because they offer several benefits for students and educators. For students, the online system allows them to access exams remotely, thereby reducing the need for physical presence at the exam center and eliminating geographic barriers, eliminating the need to travel to a specific location (Dhawan, 2020; Gernsbacher, 2015; Schoen-Phelan & Keegan, 2016; Topuz et al., 2022). Online systems also provide flexibility in terms of exam scheduling, allowing students to choose the time that best suits them (McLaughlin & Yan, 2017), and can provide students with immediate feedback that allows them to identify areas of achievement as well as those that need improvement (Bulut et al., 2019).

For educators, the online system in CBA also simplifies the assessment process, because test scores are given automatically (Bulut et al., 2019; Gernsbacher, 2015). This not only saves time for educators but also ensures more consistent and objective assessment (Langenfeld, 2020; Pei & Wu, 2019). Overall, online systems of CBA offer many advantages for students and educators. In addition, online systems also create an interactive learning ecosystem, enable faster distributed exam administration, and provide a more dynamic evaluation experience (Jiang et al., 2020; Navaneedhan & Kamalanabhan, 2015).

Future research can explore more deeply the long-term impact of implementing online systems in CBA on student learning outcomes and teaching efficiency. Studies can deepen understanding of how exam scheduling flexibility and remote access affect student engagement, their level of satisfaction, and ability to achieve academic goals. In addition, researchers can also explore technical aspects of automatic scoring to ensure consistency, accuracy, and objectivity of scoring.

Decision making–CBA

CBA provides information about students' grades and even progress quickly and automatically, where the results of the assessment can be an important basis for making decisions. This decision can cover several aspects, including setting scores and providing feedback that can be done automatically, as well as evaluating student performance and determining further action steps that require the role of teachers or administrators in understanding the context and needs of students, such as adjusting curriculum and teaching strategies.

Apart from that, CBA can also be used to develop students' decision-making skills if it is equipped with appropriate feedback, as stated by Goosen and Steenkamp (2023), providing feedback on adaptive strategy guidelines per learning style helps students strengthen their decision-making skills. decisions because they can identify deficiencies and plan corrective actions. Recommendations for future research are that the CBA application developed really pays attention to feedback on each response to help students strengthen their decision-making skills. Research on CBA should also further strengthen studies related to decision-making methods based on assessment results obtained through CBA, so as to create a more adaptive, responsive and effective learning environment, in order to improve the quality of education.

Teaching–CBA

Computer-based teaching and assessment complement each other in creating an innovative and effective educational environment. The use of online learning tools can support the implementation of online formative assessments, build an environment of mutual participation between teachers and students, and have a positive impact on student learning outcomes and continuous teaching program renewal (Ma et al., 2023). This continuous teaching program update is based on assessment results, which are then used as evaluation material to improve teaching strategies. So, it is important to conduct more research on how online learning tools can facilitate teachers and students collaborating better and how to use CBAs to optimize teaching.

CONCLUSION AND FUTURE WORK

These findings indicate that studies on CBA have experienced growth in quantity and theme from year to year, with the highest number of publications in 2022, where the USA is the most productive country. The most relevant journal about CBA is occupied by "International Journal of Emerging Technologies in Learning". In contrast, the journal with the highest impact is occupied by "Computers and Education", besides that there are also "British Journal of Educational Technology", and "Assessment and Evaluation in Higher Education", which are among the top-4 most relevant and impactful journals. The number of citations related to this research also fluctuated from year to year, but in 1988 there was a significant increase. Greiff is the most prolific author from 1982 to 2023, and Wise is the most impactful author (with the highest number of citations) from 1982 to 2023.

Research themes that show research potential because of their low density are those related to "regression analysis", "automation", "information technology", "assessment", "motivation", "quality control", "problem solving", "online systems", "decision making", and "teaching". Based on these various keywords, CBA development needs to pay attention to appropriate feedback features to help increase motivation, as well as understanding test takers' strengths and weaknesses, so that the improvement process can be more focused according to needs. The addition of an automatic regression analysis feature is also needed to explore and understand the factors that influence student learning outcomes in more detail, in order to support the development of more focused and adaptive learning approaches according to the unique needs of each student, as well as assist teachers in providing support and appropriate guidance to students, with a focus on personalizing learning to meet each individual's needs. The automation system in CBA should be more integrated with the teacher's role, so that the teacher's role in providing feedback can be more contextual and useful for their students. In addition, it is important to conduct research on the impact and further implications of the implementation of CBA on learning experiences, academic performance, interactions between students and teachers, quality control measures and the long-term impact of CBA, as well as further strengthening studies related to results-based decision-making methods assessment obtained through CBA.

Author contributions: The authors contributed to complement each other in this research, some as data collectors, analyzing data, interpreting data, or serving as supervisors. All authors approved the final version of the article.

Funding: This article was supported by Beasiswa Pendidikan Indonesia Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi (BPI Kemendikbudristek), an Indonesian Government scholarship program managed by Kemendikbudristek through funding from Lembaga Pengelola Dana Pendidikan (LPDP), and implemented by Balai Pembiayaan Pendidikan Tinggi (BPPT) Kemendikbudristek.

Ethics declaration: This research data has received legal permission on the Scopus database.

Declaration of interest: The authors declare no competing interest.

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

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