Visualizing and Bibliometrically Analyzing Information and Communication Technology-Based Blended Learning

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ABSTRACT

With the rapid development of information and communication technologies, blended learning has gained popularity after the COVID-19 pandemic. This study aims to visualize and bibliometrically analyze information and communication technology-based blended learning. Through bibliometric analyses and visualization via both VOSviewer and CitNetExplorer, this study identified the top ten cited authors, organizations, countries, sources, and keywords in the field of information and communication technologies used for blended learning, providing meaningful references for future research. Most studies reported that information and communication technology-based blended learning could improve learning effectiveness and environments despite numerous challenges revealed by several previous studies. In addition, this study suggested the main research methods to explore ICT-assisted blended learning given the present meta-analytical methods in the longest path where a citation network was established. Future research directions were suggested.

KEYWORDS

Bibliometric Analysis, Blended Learning, Environment, Information and Communication Technology, Visualization

INTRODUCTION

Motivation

The new century has been witnessing a dramatic change in educational modes, where blended learning has gained momentum and popularity after the COVID-19 pandemic. This dramatic change poses unexpected challenges to educators across the world. The extensive use of information and communication technologies (ICTs) has changed the educational model from teacher-centered to student-centered or mixed methods. Due to the advancement of ICTs, educational modes have shifted from traditional in-class methods to online or blended pedagogical approaches. The integration of ICTs into education has stimulated the emergence of the blended learning approach (Perez et al.,

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2013). Researchers and practitioners have been fully aware of this innovative educational mode and paid much attention to its investigation.

Blended learning has become a popular approach in higher education due to its flexibility and adaptability to different learning situations. The study conducted by Bezliudna et al. (2021) confirms Master students' positive perceptions of blended learning techniques in studying English during the COVID-19 pandemic. The authors provide recommendations for the improvement of the "Foreign Language for Specific Purposes (English)" course based on the study's findings on the benefits and challenges of blended learning. Segbenya and Mensahminadzi (2022) found in their study that challenges with both face-to-face sessions and online learning must be addressed to ensure successful blended learning for postgraduate distance learners. Moreover, the study highlighted a significant relationship between students' challenges with face-to-face and online learning and the usefulness of face-to-face and online intention in decision-making to continue or discontinue with online learning as compared to the traditional face-to-face mode.

Comparisons

Several studies have been devoted to the use of ICTs in blended learning via visualization methods. After visualizing scientific literature of blended learning, Wang et al. (2021) argued that ICTs played an important role in improving blended learning and addressing challenges. Various ICTs were explored, as well as the design of ICT-assisted blended learning models, providing foundations for the integration of ICTs into blended learning via visualization (Baek & Chung, 2007). A content analysis and case study concluded that blended learning was easy for students to participate in despite some visualized problems with software and solutions (Roda-Segarra & Mengual-Andrés, 2022). However, few studies have visualized and bibliometrically analyzed ICT-assisted blended learning through both VOSviewer and CitNetExplorer (See Table 1 for a comparative analysis).

Organization

The overall structure of the study takes the form of six sections. The first section, i.e. introduction, will reveal the importance of ICT-assisted blended learning research and present the outline of this study. The second section, i.e. literature review, will propose research questions after theorizing the research framework and reviewing previous studies. The third section, research methods, will explicate the specific research methods. The fourth section, results, will answer the proposed research questions via VOSviewer and CitNetExplorer. The fifth section, i.e. discussion, will investigate how to address the problems in ICT-assisted blended learning. The final section, the conclusion part, will summarize the major findings, limitations, and implications for future research into ICT-assisted blended learning.

Table 1. A comparative analysis between previous and current studies

Studies	Approach	Highlight
Wang et al. (2021)	Systematic Literature Review	ICTs could improve blended learning and address challenges.
Baek & Chung (2007)	Visualization	Various ICTs
Roda-Segarra & Mengual-Andrés (2022)	A content analysis and case study	Blended learning was easy for students to use.
The current study	Visualization and bibliometric analysis	Top ten cited authors, organizations, countries, sources, and keywords. ICT-based blended learning could improve learning effectiveness and environments.

THEORETICAL FRAMEWORK

Blended learning was defined as a pedagogical approach integrating online interactive activities into in-person learning, involving a combination of different educational technologies and ICT devices (McKenzie et al., 2022). Blended learning could neither be considered a simple use of ICTs between online and in-person learning, nor a simple teacher- or student-centered approach. Blended learning required a mixed pedagogical methodology to enhance learning engagement and learners' self-determination (De George-Walker & Keeffe, 2010). Blended learning could provide systematic learning methods and create digital learning environments assisted with ICTs. Additionally, it is necessary to formulate a solid theory to establish a theoretical foundation for the development of ICT-assisted blended learning.

The social cognitive theory could establish the theoretical framework of blended learning (Wu et al., 2010). The theory proposed that learner satisfaction was significantly influenced by cognitive beliefs, computer environments, and social contexts. Specifically, learners' self-efficacy, learning performance expectations, technological functions, content features, peer interactions, and learning climates could exert a great influence on learner satisfaction levels in blended learning environments, where ICT-assisted blended learning effectiveness could be greatly influenced. This study will, therefore, investigate ICT-assisted blended learning environments and effectiveness, as well as bibliometric analytical results, to improve the coherent development of the theory (Graham, 2013: 340). ICTs could provide learning management systems where learners' self-efficacy, learning performance expectations, technological functions, and content features might be enhanced. The online platform assisted with ICTs could also increase students' engagement, improve learners' satisfaction, facilitate peer interactions, and cultivate learning climates in blended learning (Dwivedi et al., 2019).

LITERATURE REVIEW

ICT-Assisted Blended Learning Effectiveness

Blended learning combines synchronous with asynchronous learning formats assisted with ICTs, which can be as effective as in-person learning in terms of health profession knowledge acquisition. Online learning could hardly satisfy the requirements of educational interactions, perceptions, practice, and training for health professionals, while blended learning, combining online learning with in-person learning, might be able to facilitate specialized training and practice for health professionals (Lawn et al., 2017). Despite the popularity of ICTs used in the healthcare field, workers had no enough skills to apply them to healthcare in Malawi, Africa. Blended training courses posed challenges for workers to comprehensively follow. Furthermore, no significant differences in learning effectiveness were revealed between traditional and blended learning methods in developing countries although the blended learning method might provide a satisfactory alternative in remote and rural areas in Africa (Mastellos et al., 2018).

Blended learning could greatly improve learning effectiveness by enhancing learners' satisfaction, meeting individual needs, and facilitating task completion. By integrating ICTs into traditional in-person learning, blended learning could meet various requirements of coursework and facilitate the completion of learning tasks (Zhang, 2021). Thus, learners were satisfied with blended learning and its operating procedures. Blended learning could improve presentations of individual learners and enhance learning collaboration, knowledge distribution, and critical conception in the education of English for special purposes (Zhang, 2021). ICT courses could improve knowledge acquisition, communicative abilities, interpersonal interactions, and self-directed learning. They could also enhance learning engagement, task completion, self-evaluation, and peer discussion (Stal & Paliwoda-Pekosz, 2019). The effective use of ICTs could reduce barriers to educational resources and combine international cultures with standardized educational dimensions. For instance, An Improved Neighbor Propagation

Algorithm, an online platform, could predict students' academic achievements and satisfaction, improve information distribution, and enhance problem solution (Liang & Jia, 2022).

ICT-assisted blended learning could improve learning effectiveness by providing resources and enhancing learning experiences and interactions. Innovations of ICTs and their wide use in education greatly facilitated the ease of access to learning resources of music knowledge and ICT-assisted blended learning improved the quality of music education among remote schools in Australia (Crawford, 2017). The rapid development of ICTs greatly changed the format of knowledge delivery, where blended learning was evidenced to improve learning achievements and enhance students' learning experiences (Carbonaro et al., 2008). The ICT-assisted blended instruction could significantly improve students' acquisition of English alphabetic letters in Greece (Tzagkourni et al., 2021). ICT-assisted blended learning could improve students' learning confidence, facilitate their communication, and enhance their mutual trust. Students could have enough opportunities to interact with peers and teachers through both in-person and online channels. It was necessary to clarify roles of learners and adopt an agreed method to communicate and purposefully use ICT tools in teamwork especially when they were confronted with barriers (McKenzie et al., 2022).

ICT-Assisted Blended Learning Environments

ICTs could cultivate beneficial blended learning environments through online platforms. A limited number of studies found that interpreter training was implemented mostly in virtual blended environments via online platforms such as Moodle and Blackboard. The online ICTs could create immersive blended learning environments to improve interpreter training by enhancing their autonomy and providing technological support despite the challenges such as physiological discomfort, authenticity levels, and equipment maintenance (Eser et al., 2020). ICTs could virtualize the blended learning environments and move courses easily between European countries with blended learning modes. Blended learning could improve students' learning achievements and support learning through digital platforms. Teachers should receive adequate training to master ICT-assisted blended teaching skills, use ICT platforms, and distribute learning resources (Munoz et al., 2011).

Inconsistent Findings

Numerous studies reported that teachers might feel resistant to blended learning based on the use of ICTs. Senior teachers might prefer traditional teaching methods to the blended mode in need of improvement in digital literacy. Students might easily drop out of the online learning since they were not supervised as closely as the in-person method. The popularity of ICTs was driving teachers to acquire adequate ICT skills since teachers in newly established educational institutes had no rich ICT-assisted teaching experiences. This fact might negatively influence the effect of ICTs on educational outcomes and perceptions of ICT-assisted blended pedagogical approaches in China (Wu et al., 2016). In general, although most educational institutes tended to use ICTs to carry out blended teaching and learning methods, there were still challenges such as lower motivation and poor academic performance (Liang & Jia, 2022).

ICT-assisted blended learning may not achieve success in learning due to various factors. While learning management systems assisted with ICTs could realize both online and blended learning, they failed to achieve most learning goals due to improper marketing strategies, lower-quality blended learning services, and inadequate blended learning support in developing countries such as Russia (Vershitskaya et al., 2020). Blended learning could be limited to a lack of plentiful opportunities for each learner, disconnection of networks, technical failures, and network jam. Designers could strike a balance between in-person and online education to overcome the difficulties and improve the quality of healthcare services through mixed methods (Khurshid et al., 2020). The final blended learning achievements depended on learners' age, educational backgrounds, and attendance rates (VictoriaLópez-Pérez et al., 2011).

RESEARCH QUESTIONS

Both bibliometric analyses and identification of main research methods could provide meaningful references for future research into ICT-assisted blended learning. Bibliometric analyses through both CitNetExplorer (Van Eck & Waltman, 2014a, b) and VOSviewer (Van Eck & Waltman, 2010, 2014b) could cluster academic publications to analyze the clustering solutions. Through counting methods, researchers could rank authors, sources, countries, organizations, and keywords based on citations or occurrences. They could visualize the findings by showing the connections, relatedness, and clusters. Considering the challenges, inconsistent findings, the importance of bibliometric analyses, and main research methods, researchers propose the following research questions:

RQ1: What are the top cited authors, organizations, countries, sources, and keywords in ICT-assisted blended learning?
RQ2: Can ICT-assisted blended learning improve educational effectiveness?
RQ3: Can ICTs improve blended learning environments?
RQ4: What are the challenges in ICT-assisted blended learning?
RQ5: What are the main research methods to explore ICT-assisted blended learning?

METHODS

VOSviewer and CitNetExplorer will be combined to conduct the bibliometric analysis. VOSviewer is a digital tool designed to construct and visualize the bibliometric analysis (Van Eck & Waltman, 2010). The analysis includes publications from journals, authors, and research institutes. The type of analysis in this software includes co-authorship, co-occurrence, citation, bibliographic coupling, and co-citation. The units of analysis include keywords, sources, organizations, countries, documents, cited references, cited sources, and cited authors. The counting methods include full and fractional counting. Through proper counting, it can calculate the occurrences, total link strengths, documents, and citations. VOSviewer highlights citation networks and bibliometrically analyzes the publications on a collective level, while CitNetExplorer focuses on an individual level.

CitNetExplorer is a digital tool designed to visualize, cluster, and investigate citation networks of academic publications. This tool can directly cluster and analyze publications output from the online database of Web of Science by positioning and establishing citation networks. This tool can visualize the citation links, time periods, and the number of publications and it focuses on individual publications by identifying their citation scores, authors, sources, titles, and publication years. Researchers can explore the intensely cited networks by obtaining the longest path through the function of "drill down" and analyzing the individual publications by shifting to the interface to "publications" (Van Eck & Waltman, 2014ab).

Researchers conducted a bibliometric analysis of the publications retrieved from online databases. They retrieved a total of 1841 publications from the Core Collection of Web of Science and keying in ICT* OR "information and communication technolog*" OR technolog* (topic) and "blended learn*" OR "blended educat*" OR "blended teach*" (topic) on November 25, 2022, ranging from 2008 to 2022. They then reduced the results to 1769 by excluding the early-access documents (n = 72) to avoid the technical errors (null pointer exception) in CitNetExplorer. The former dataset (n = 1841) was used to visualize the bibliometric analysis through VOSviewer, while the latter one (n = 1769) was adopted to analyze the citation network through the longest path in CitNetExplorer. To summarize, the specific process of this bibliometric analysis includes data collection, data preparation, data input, visualization, analysis, and interpretation (Figure 1).

While bibliometric analysis is a useful method for analyzing scholarly literature, there are some limitations to this approach. Bibliometric analysis is primarily focused on the number of publications, citations, and other quantitative measures. This can result in an overemphasis on quantity rather than

Figure 1. A flowchart to clarify the bibliometric analysis
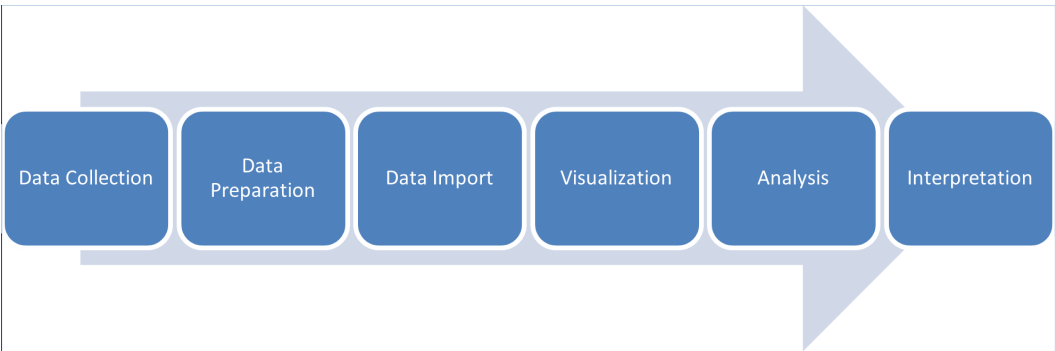
the quality and relevance of the research. Bibliometric analysis is limited by the availability and accessibility of bibliographic data. Some publications, particularly those in non-English languages or in less accessible formats, may be excluded from analysis. Bibliometric analysis provides quantitative data but does not offer much context or qualitative insights into the research. For example, the analysis may not consider the actual content or impact of the research. Bibliometric analysis is subject to citation biases, where more well-known or prestigious authors or journals receive more citations. This can skew the results and limit the visibility of less well-known researchers or journals, even if their research is equally significant. Bibliometric analysis relies on accurate and complete bibliographic data, which may not always be available. Errors in data entry, missing or incomplete records, and inconsistent citation practices can all affect the accuracy and reliability of the analysis.

RESULTS

What Are the Top Cited Authors, Organizations, Countries, Sources, and Keywords in ICT-Assisted Blended Learning?

By selecting "co-authorship" as the type of analysis and "author" as the unit of analysis, researchers identified the top ten authors, organizations, and countries in ICT-assisted blended learning. The top ten authors based on citations were Graham Charles R. (Citations = 1029), Halverson Lisa R. (Citations = 572), Henrie Curtis R. (Citations = 460), Zhu Chang (Citations = 416), Gasevic Dragan (Citations = 395), Pardo Abelardo (Citations = 264), Tamim Rana M. (Citations = 264), Rowe Michael (Citations = 204), Han Feifei (Citations = 194), and Ellis Robert A (Citations = 189). The top ten countries based on citations were the USA (Citations = 4895), Australia (Citations = 3305), Spain (Citations = 2041), England (Citations = 1711), Turkey (Citations = 1130), China (Citations = 1092), Canada (Citations = 987), Belgium (Citations = 872), Malaysia (Citations = 714), and New Zealand (Citations = 702).

To identify the top ten organizations, researchers visualized the results (Figure 2). The minimum number of documents of an organization was set at 4. Of the 1949 organizations, 140 of them met the threshold. The top ten organizations based on citations were Brigham Young University (Citations = 1100), Universidad de Granada (Citations = 535), University of Sydney (Citations = 514), Deakin University (Citations = 482), Vrije Universiteit Brussel (Citations = 453), University of Edinburgh (Citations = 441), Griffith University (Citations = 348), Ghent University (Citations = 325), Universiti Malaya (Citations = 291), and George Washington University (Citations = 282).

To identify the highly frequent keywords, researchers selected "co-occurrence" as the type of analysis, and "all keywords" as the unit of analysis. The "full counting" method produced a total of 407 keywords. The top ten keywords based on occurrences were blended learning (Occurrences =

Figure 2. Visualization of the top cited organizations in ICT-assisted blended learning
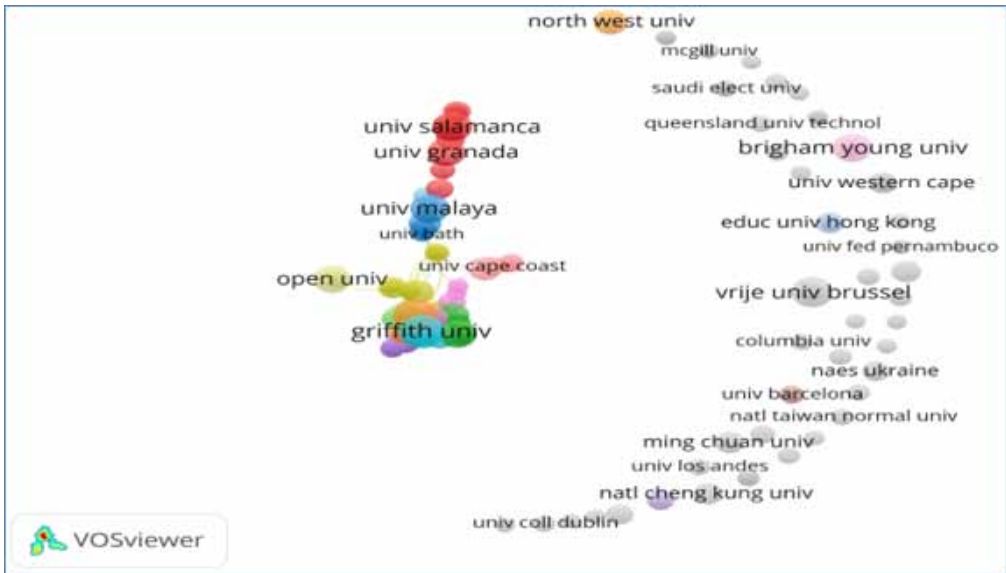
962), education (Occurrences = 288), technology (Occurrences = 279), students (Occurrences = 245), online (Occurrences = 196), higher education (Occurrences = 178), e-learning (Occurrences = 175), performance (Occurrences = 138), online learning (Occurrences = 134), and perceptions (Occurrences = 129). Researchers visualized the citation networks of keywords (Figure 3).

To explore the highly cited sources, researchers selected "co-citation" as the type of analysis and "cited sources" as the unit of analysis. The "full counting" method led to a total of 479 results. The

Figure 3. Visualization of the keywords in ICT-assisted blended learning
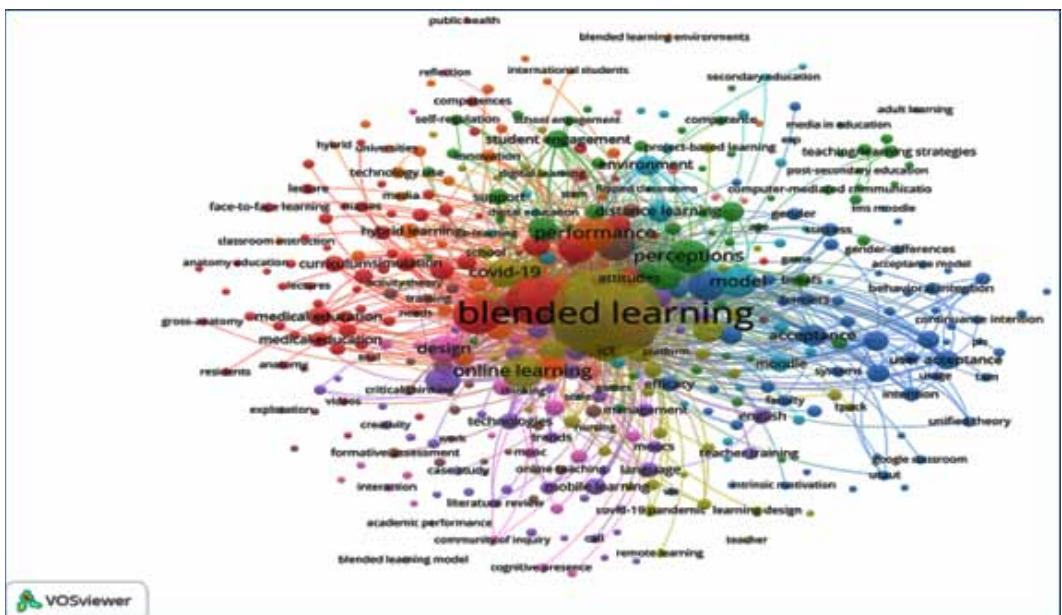
top ten cited sources based on citations were Computers & Education (Citations = 2858), Internet and Higher Education (Citations = 1049), British Journal of Educational Technology (Citations = 849), Computers in Human Behavior (Citations = 825), Educational Technology & Society (Citations = 593), International Review of Research in Open and Distance Learning (Citations = 528), Procedia Social and Behavioral Sciences (Citations = 525), Australasian Journal of Educational Technology (Citations = 492), Nurse Education Today (Citations = 459), and Educational Technology Research and Development (Citations = 439). Figure 4 shows the citation networks of the cited sources.

Researchers entered the data of publications (n = 1769) into CitNetExplorer to analyze the citation networks through clustering and visualization techniques. As shown in Figure 5, the most frequently cited scientific literature (n = 100) is displayed according to a timeline. It classifies each cluster into the same color through the functionality of the CitNetExplorer. Eight clusters were identified. Due to the limitation of size requirement, 361 publications do not belong to any cluster. The total number of the predecessors and successors is 2074 with 8039 citation links, ranging from 1975 to 2022. The first three clusters account for the majority of the publications. Cluster 1 includes the largest number of publications (n = 1050, Citation links = 5447). Cluster 2 includes 188 publications (Citation links = 489) and Cluster 3 includes 154 publications (Citation links = 219). Clusters 4-8 include 87, 83, 78, 57, and 16 publications, as well as 128, 104, 98, 64, and 21 citation links respectively.

Researchers attempted to analyze the citation network through the longest path. Researchers could explore research themes from citation networks based on the longest path out of the academic publications. To obtain the longest path, researchers firstly marked two publications after drilling down the first cluster of publications. One was the publication with higher citations in the network, while the other was located at the bottom of the longest path. The highest one, indicating the research theme, tends to be the literature with higher citations, followed by other publications in the citation network. The citation network in the first longest path was established via nine publications (De George-Walker & Keeffe, 2010; Spanjers et al., 2015; Halverson et al., 2014; Wanner & Palmer, 2015; Drysdale et al., 2013; Rasheed et al., 2020; Boelens et al., 2017; VictoriaLópez-Pérez et al., 2011; Garrison & Kanuka, 2004), led by Garrison & Kanuka (2004) (Figure 6).

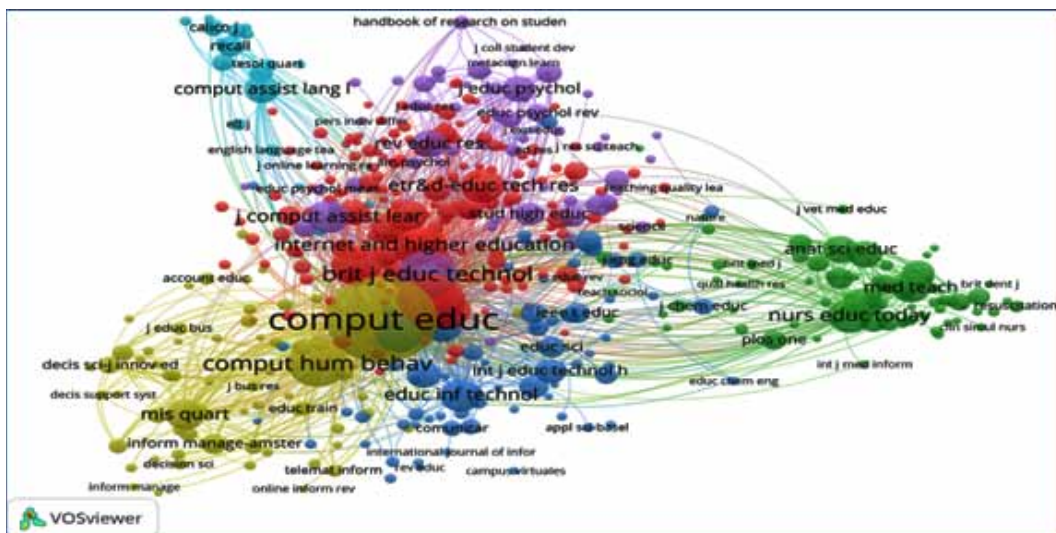Figure 4. Visualization of cited sources in ICT-assisted blended learning
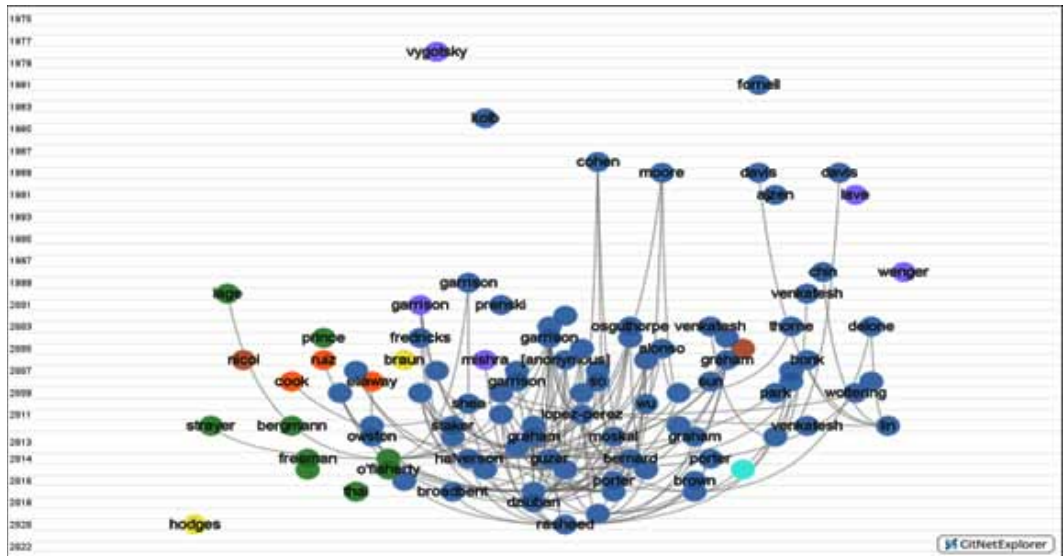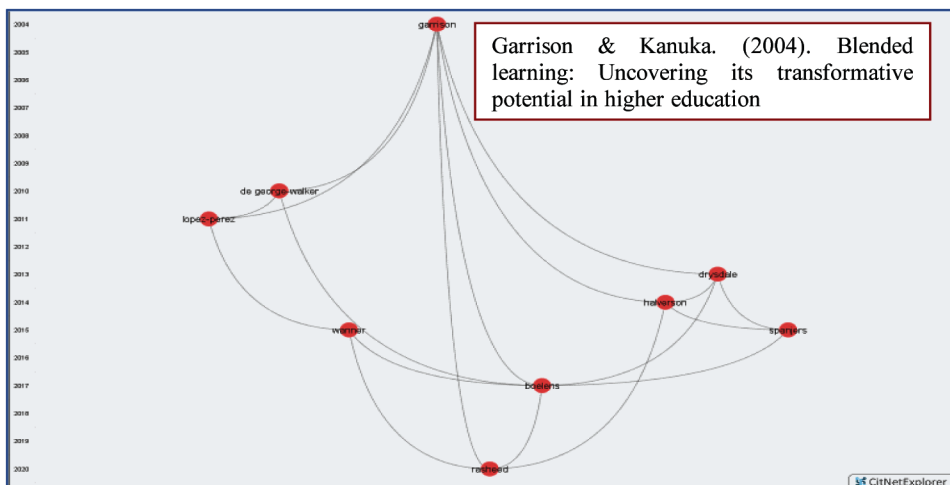
Figure 5. Visualizing the citation networks

Figure 6. The first longest path forming citation networks

Garrison & Kanuka. (2004). Blended learning: Uncovering its transformative potential in higher education

Can ICT-Assisted Blended Learning Improve Educational Effectiveness?

ICT-assisted blended learning has been catching an increasing number of scholars' attention because several lines of evidence suggested that it was beneficial to education (Drysdale et al., 2013) due to its effectiveness and environments. Blended learning could maintain the values of traditional learning in higher education and enhance learning effectiveness and experiences (Garrison & Kanuka, 2004). ICTs could enhance learning and teaching effectiveness by providing beneficial learning environments, where blended learning could improve learning effectiveness and reduce dropout rates (VictoriaLópez-Pérez et al., 2011). Blended learning could improve learning effectiveness and receive learners' positive comments, but this method was demanding. Quizzes could enhance blended learning effectiveness and improve blended learning evaluation (Spanjers et al., 2015).

Data from several other sources have identified the positive ICT-assisted blended learning effectiveness. Blended learning could reduce dropout rates and improve learning effectiveness of academic courses such as business administration, economics, business administration, and law among undergraduate students in the University of Granada. They also positively evaluated the blended learning method and felt satisfied with blended learning (Perez et al., 2013). MobileEdu, a mobile learning platform easing access to academic resources, could improve computer science learning through mobile devices among universities in Nigeria. This platform could improve learning effectiveness and students held positive attitudes toward the use of it in education (Oyelere et al., 2018). Blended learning assisted with ICT could improve disciplinary knowledge acquisition and had gained popularity among various kinds of learners. Properly designed blended courses could improve students' enjoyment, knowledge sharing, teamwork effectiveness, and learning effectiveness (Lin et al., 2020). A growing number of higher education institutes are adopting ICTs which may provide more effective educational outcomes than traditional methods. Streaming services with blended learning could improve teaching and learning effectiveness (Hasan et al., 2019).

Can ICTs Improve Blended Learning Environments?

To improve blended learning effectiveness, teachers could improve flexibility of educational modes, enhance interactions, facilitate learning process, and cultivate blended learning environments. Interactions could be enhanced in in-person learning, while online learning could facilitate learning process. However, little is known about how to cultivate affective learning environments (Boelens et al., 2017). ICTs could foster beneficial blended learning environments to better educational design and practice (Pearson & Trinidad, 2005). ICTs could fortify the beneficial blended learning environments which could encourage students to participate in learning activities, promote the completion of coursework, and enhance students' motivation to learn by increasing joyfulness and learning interest (Gecer & Dag, 2012). The joyfulness and interest could enhance positive affective learning environments in blended contexts where teachers could attempt to include interesting and joyful components.

What Are the Challenges in ICT-Assisted Blended Learning?

Despite the benefits of ICT-assisted blended learning, it also brought about many challenges. ICT-assisted blended learning has been confronted with numerous challenges such as self-regulation, technology skills, selection of proper technologies, and effective training (Rasheed et al., 2020). Learners preferred blended learning to fully online education, and they preferred the pedagogical approaches which were clearly structured and guided, as well as those flexibly assessed. The challenge was the flexible assessment which was in need of individualized assessments conducted by strongly responsible instructors (Wanner & Palmer, 2015). With the rapid development of research into ICT-assisted blended learning, results were becoming increasingly diverse (Halverson et al., 2014). ICT-assisted blended learning could meet the needs of learners and educational institutes. Instead of a simple combination of technology and learning, ICT-assisted blended learning needed a proper design (De George-Walker & Keeffe, 2010). Educators who did not experience enough training tended to improperly apply blended learning to education, leading to negative educational outcomes.

What are the Main Research Methods to Explore ICT-Assisted Blended Learning?

To find out the second longest path, researchers drilled down the first cluster, and then marked Cohen (1988) and Vo et al. (2017). The second longest path was constructed out of five publications (Cohen, 1988; Vo et al., 2017; Halverson et al., 2014; Spanjers et al., 2015; Ozkan & Koseler, 2009), led by the monograph authored by Cohen (1988). The monograph introduces the conceptions and debates of power analyses, effect size measurement, confidence intervals, correlation analyses, t test, and measurements of means and standard deviations. This provides a solid foundation for meta-analyses, where Cohen's d is usually used to measure effect sizes.

The second longest path (Figure 7) indicates that meta-analyses through Cohen's d are frequently used to measure blended learning effectiveness. Statistical Power Analysis, especially a meta-analysis through Cohen's d (Cohen, 1988), has been frequently used to explore the effects of ICT-assisted blended learning on educational outcomes. For instance, a meta-analysis, taking Cohen's d as the measurement of effect sizes, concluded that ICT-assisted blended learning was significantly more effective than the traditional learning (Vo et al., 2017). Another meta-analysis found that ICT-assisted blended learning improved learning effectiveness compared with traditional learning approaches (Spanjers et al., 2015). In blended learning, learning management systems could well support blended models and should be assessed by multiple dimensions, e.g. supportive factors, learner perspective, instructor attitudes, system quality, information (content) quality, and service quality (Ozkan & Koseler, 2009). A thematic review study (Halverson et al., 2014) cited and supported this conclusion.

DISCUSSION

How to Improve ICT-Assisted Blended Learning?

It is necessary to strike a balance between ICT technology development and educational levels. While ICT-advanced countries have started the co-development between ICTs and higher education, the ICT-growing countries have not been able to reach such a level due to slower development. The success of Finland in the balance between ICT and education could be attributed to co-development of both. The lower educational development was caused due to the improper balance between ICT and education. ICT-advanced countries could maintain the balance between ICT and education and transform traditional learning settings into digitally enhanced educational environments (Watanabe et al., 2017). It is thus essential to develop ICTs, design proper blended learning strategies, and improve educational quality synchronously.

Healthcare training and specialized knowledge acquisition could improve ICT-assisted blended learning effectiveness, especially during the pandemic time when healthcare systems were disrupted. Through ICTs, healthcare workers could receive proper training and education regarding how to improve healthcare service quality, which could then ensure the blended methods merging both in-person and online educational modes. The blended modes could in turn help them achieve success in

Figure 7. The second longest path forming citation networks
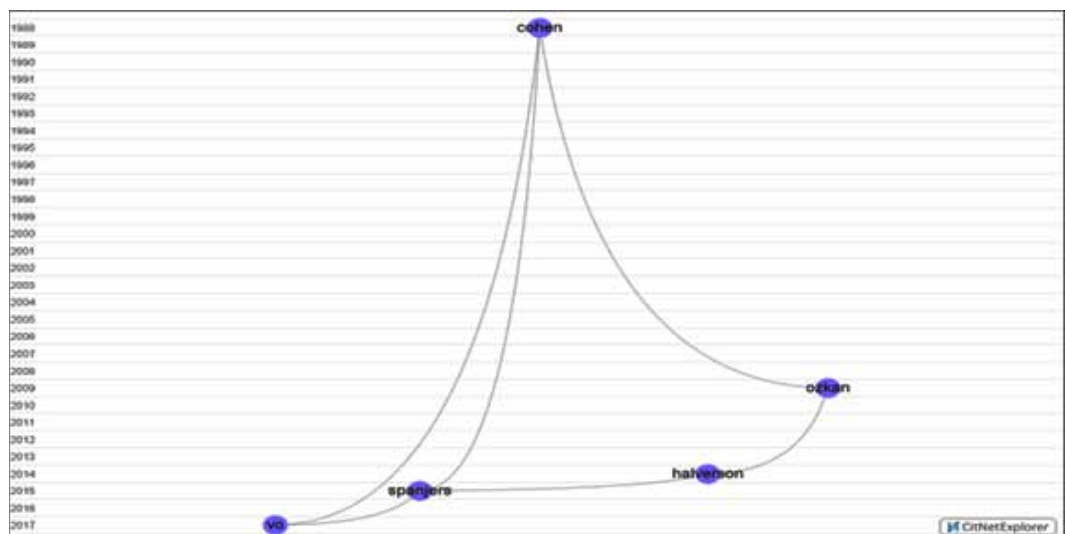
learning, improve service quality, and enhance their skill mastery and knowledge acquisition. With blended methods, on-site teachers and plentiful learning resources were necessary since learners could obtain timely and flexible instruction and plentiful resources easily from online platforms (Khurshid et al., 2020). Blended learning based on ICTs and video conferencing could greatly improve learning skills, enhance professional knowledge, and rectify learning attitudes in Rwanda. Learners felt satisfied with blended learning due to enhanced perceived ease of use, convenient access, affordability, digital literacy, proper computer devices, and interactive activities (Ngenzi et al., 2021).

A sustainable educational model could improve ICT-assisted blended learning effectiveness. ICT technology-integrated e-learning might bring about disruption due to both unintelligible and intelligible factors which might finally and gradually lead to dramatic changes in traditional educational methods (Heilesen & Josephsen, 2008). While ICTs could improve learning and teaching effectiveness, their use in higher education brought about disruption to traditional learning and teaching methods (Shen & Ho, 2020). Therefore, to avoid the disruption, blended learning could merge in-person interactions, field investigation, live video delivery, video conferences, seminars, and other forms of use of ICTs to enable learners and teachers to establish sustainable education (Jain et al., 2013). Construction of the sustainable model, an effortful task, needs to consider various influencing factors and strike a balance between them.

How to Improve ICT-Assisted Blended Learning Environments?

Numerous factors could be considered to improve ICT-assisted blended learning environments. Hybrid instructional methods, rather than either purely teacher or student-centered method, could cultivate blended learning environments (De Kock et al., 2004; Smit et al., 2014). Online interactions such as peer review and discussion could foster blended learning environments and enhance self-directed learning outcomes. Online and in-person interaction and collaboration could strongly improve blended learning environments (Adinda & Mohib, 2020). Blended learning could improve availability of learning resources despite the barriers to time and space, and cultivate effective blended learning environments through a three-step design. The design process included identification of design problems, selection of proper ICTs, and autonomous and scaffolding learning in blended contexts (Lazem, 2019). Teachers and educational institutes may organize regular shifts between online and in-person learning modes to enhance self-regulation and motivation of learners.

How to Address the Challenges in ICT-Assisted Blended Learning?

Educators can design learning system management platforms to supervise learning behaviors, enhance learners' self-regularity, and train teachers' digital literacy. Teachers, especially those with long-term teaching experience, tend to object to the pedagogical change from the traditional approach to the blended mode which needs the mastery of computer skills. Educators and designers can explicate the must and benefits of blended learning using ICTs, and provide technological training and support. The assessment methods could be well designed to encourage learners to engage in blended learning and evaluate their blended learning performance properly (De George-Walker & Keeffe, 2010). The individualized assessment can be carefully investigated and designed to maintain fairness and integrity of blended learning outcomes. Teachers could also enhance interactivities with students through social media platforms such as WeChat, Whatsapp, and Twitter (Yu et al., 2022). Through the platforms, teachers can provide timely feedback on learners' questions and learners can resort to teachers when they feel convenient.

How to Select Proper Research Methods to Explore ICT-Assisted Blended Learning?

Both qualitative and quantitative methods can be used to investigate the effect of ICTs on blended learning outcomes. A body of literature summarized ICT-assisted blended learning effectiveness through meta-analyses (e.g. Vo et al., 2017; Spanjers et al., 2015; Ozkan & Koseler, 2009). Despite

the advantages of meta-analyses, there are still challenges to this method. Examples are the publication bias, small sample sizes, various treatments, and heterogeneous estimates. There are also many other research methods such as observation, surveys, interviews, experiments, and mixed designs. The selection of research methods relies on the research objectives. It is also subject to other factors such as time for data collection, data analyses, qualitative or quantitative natures. The data collection method is horny since the data is hard to collect from blended learning contexts. A smart online learning management system may be beneficial to data collection and analyses.

CONCLUSION

This concluding section aims to summarize the major findings, identify the limitations of this study, and provide implications for future research.

Major Findings

In this study, both qualitative and quantitative methods were utilized to investigate the integration of ICTs into blended learning contexts. The research employed bibliometric analyses and visualization tools such as VOSviewer and CitNetExplorer to identify the most frequently cited authors, organizations, countries, sources, and keywords in ICT-based blended learning. These findings provide valuable references for future researchers in this field. Despite some challenges documented by prior research, most studies reported that the integration of ICTs into blended learning can improve learning efficacy and enhance learning environments. Furthermore, this study recommends key research methods for examining ICT-assisted blended learning using meta-analytical methods to establish a citation network in the longest path.

The practical significance of ICT-based blended learning lies in its efficacy and efficiency of education. By integrating ICT into blended learning, learners can access course materials and interact with instructors and peers from anywhere at any time, providing greater flexibility and convenience. Moreover, ICT-assisted blended learning facilitates personalized learning, as students can tailor their learning experiences to meet their individual needs and preferences. Additionally, ICT-based blended learning enables the integration of multimedia resources and other interactive features into course design, which promotes learner engagement and motivation. Ultimately, the practical significance of ICT-based blended learning can be seen in its ability to enhance learning outcomes and improve educational experiences through the seamless integration of technology into the learning process.

Limitations

Although this bibliometric analysis is rigidly designed, it is limited to several aspects. Firstly, the sample, limited to library sources, cannot include all the literature. Secondly, the bibliometric analysis may be limited to the reliability of the findings retrieved from the longest paths and citation networks. Thirdly, many advanced papers are published in this regard although this study adopts innovative research methods.

Future Research Directions

Future researchers can highlight the ways to investigate the mechanisms to improve ICT-assisted learning effectiveness. Joyfulness, knowledge sharing, and teamwork activities may be beneficial to ICT-assisted blended learning outcomes. Teachers could experience enough training of digital skills to enhance their mastery of ICTs used for blended pedagogical approaches (Lin et al., 2020) since they tended to be resistant to the change of pedagogical approaches. Educational institutes can also provide training services for learners before they implement the blended learning program. Teachers can also design the coursework with collaborative and interesting components to reduce learners' dropout rates and increase their engagement in blended learning.

In the future, researchers can develop a framework to measure blended learning outcomes and teaching readiness to prepare learners and teachers for blended education. Blended learning gained tremendous momentum in North America and many places across the world, which dwarfed enough training and adaptation of learners and teachers. In this way, teachers and learners could familiarize themselves with the advantages and disadvantages when using blended educational modes (Archibald et al., 2021). Educational administration can investigate how to enhance learners' and teachers' competence and readiness to accept the ICT-assisted blended learning model using advanced technologies such as augmented reality (Yu, 2023a), gamification technologies (Yu, 2023b), and virtual labs (Douar & Harous, 2023). Designers of ICTs can integrate encouraging components into blended learning models to stimulate learners' interest in blended learning assisted with ICTs.

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