Language Learning & Technology
ISSN 1094-3501
October 2021, Volume 25, Issue 3
pp. 151–185

ARTICLE

Twenty-five years of computer-assisted language learning: A topic modeling analysis

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Abstract

The advance of educational technologies and digital devices have made computer-assisted language learning (CALL) an active interdisciplinary field with increasing research potential and topic diversity. Questions like "what topics and technologies attract the interest of the CALL community?," "how have these topics and technologies evolved?," and "what is the future of CALL?" are key to understanding where the CALL field has been and where it is going. To help answer these questions, the present review combined structural topic modeling, the Mann-Kendall trend test, and hierarchical clustering with bibliometrics to investigate the research status, trends, and prominent issues in CALL from 1,295 articles over the past 25 years ending in 2020. Major findings revealed that Social Sciences Citation Indexed journals such as Computer Assisted Language Learning, Language Learning & Technology, and ReCALL contributed most to the field. Topics that drew the most interest included mobile-assisted language learning, project-based learning, and blended learning. Topics drawing increasing research interest include mobile-assisted language learning, seamless learning, wiki-based learning, and virtual world and virtual reality. Additionally, the development of mobile devices, games, and virtual worlds continuously promote research attention. Finally, the review showed that scholars and educators are integrating different technologies, such as the mixed use of mobile technology and glosses/annotations for vocabulary learning, and their application into various contexts; one such context being the integration of digital multimodal composing into blended project-based learning.

Keywords: *Computer Assisted Language Learning, Structural Topic Modeling, Bibliometrics, Mobile Assisted Language Learning*

Language(s) Learned in This Study: *English*

APA Citation: Chen, X. L., Zou, D., Xie, H. R., & Su, F. (2021). Twenty-five years of computer-assisted language learning: A topic modeling analysis. *Language Learning & Technology*, *25*(3), 151–185. http://hdl.handle.net/10125/73454

Introduction

Computer-assisted language learning (CALL)[1] covers diverse topics regarding pedagogical design and instructional innovations and is an important field in language education (Beatty, 2013). CALL was initially defined as "the search for and study of the computer applications in language teaching and learning" (Levy, 1997, p. 1). With the advance of diverse information and communication technologies (ICTs) and the increasing use of various digital devices/resources inside and outside language classrooms, CALL was re-defined as "the development and use of technology applications in language teaching and learning" (Levy & Hubbard, 2005, p. 143). A broader definition considers CALL as "learners learning language in any context with, through, and around computer technologies" (Egbert, 2005, p. 4), emphasizing "any computer technology" used in a "language learning context" (Hubbard, 2009, p. 2).

This extended definition, which implied any learning context, showed that CALL was no longer restricted to educational technology applied only in formal learning contexts. Rapidly developing mobile and broadband technologies promoted ubiquitous learning with diverse online resources that can be used anywhere and anytime, while various types of technologies, (e.g., interactive whiteboards, automatic speech recognition [ASR], and digital games), were emerging to assist language education (Adolphs et al., 2018). CALL is now an international discipline exploiting the application of digital technology in language education (Gillespie, 2020). Although learning via mobile devices and social media has not been fully integrated into language education as expected (Hubbard, 2009), CALL has become part of life for most language learners. According to Gimeno-Sanz (2016), there have always been opportunities for CALL developers/authors to find optimum ways to pedagogically exploit technological developments "as long as technology continues to evolve, and new gadgets keep appearing on the market" (p. 1102). The core goal of today's CALL is to identify ways to optimally use existing technologies in language education. The evolution of CALL's definition partly reflects the development of CALL research. One important feature of the transient meaning of CALL is that all unstructured meaningful resources are assembled together into language education and implemented by teachers into daily teaching practice (Gimeno-Sanz, 2016). This study employs a broad definition of CALL that includes any digital technology used in formal or informal learning inside or outside language classrooms.

Literature Review

An increasing number of studies on CALL have called for reviews of the field. Some representative reviews are summarized in Table 1 of the Appendix. They fall into broad categories: overviews of CALL development and technologies used in CALL as a whole, or reviews focusing on specific types of technology, such as mobile-assisted language learning (MALL), digital game-based language learning (DGBLL), and multimedia.

We identified four broad overview studies on CALL. Bax's early review (2003) identified the main CALL approach as "Open CALL," where students mostly interacted with computers and occasionally their classmates and teachers, during which new technologies were supplementary to the syllabus and learners' needs. Bax predicted CALL would become "Integrated CALL" via "normalizing" under which technology is invisibly embedded in students' everyday practice. As CALL rapidly evolved with technological advances, Levy and Hubbard (2005) argued for the acceptance of the term "CALL." As they reported, CALL was widely recognized in "evaluating new language learning tutors and tools" (Levy & Hubbard, 2005, p. 147), with many journals, including *Computer Assisted Language Learning* (*CALL*) and *CALICO Journal*, attesting to its professional status. Another important review (Gimeno-Sanz, 2016), extending Bax, predicted CALL's future by recalling the evolution of technology-enhanced language learning (TELL) during 1990–2016. Gimeno-Sanz reviewed CALL software, like CD-ROMs, and CALL-dedicated authoring tools, like InGenio, in the 1990s and 2000s, respectively. From 2010 onwards, the concept of "atomised CALL" was proposed based on "Integrative CALL" (Bax, 2003), suggesting pedagogy-driven learning where the choice of technology depended on driving factors like mobility requirements and connectivity capabilities. Recently, Gillespie (2020) synthesized 777 CALL articles from 2006 to 2016 in *ReCALL*, *CALICO Journal*, and *CALL*. Gillespie found CALL internationally popular, with writing as the most investigated topic, followed by computer-mediated communication (CMC), vocabulary, and speaking; interpreting and content and language integrated learning were the least investigated. Small-scale projects increased across the three journals, with English being the most investigated language. Gillespie's study is similar to ours in its focus on the evolution of technology in CALL.

Other reviews have investigated the main types of applied technology. Liu et al. (2002) reviewed 246 CALL studies during 1990–2000, identifying computer technology's potential in foreign language education (FLE) (e.g., increased self-esteem, vocational preparedness, and language proficiency), software tools' effectiveness (e.g., multimedia authoring and word processing software), skills acquisition, and software design considerations (e.g., meeting learners' goals and needs). Macaro et al.

(2012) reviewed 117 articles during 1990–2010 to explore the use of post-2000 technologies (e.g., multimedia, CMC, and the web), in English language education. Golonka et al. (2014) reviewed 350 articles during 1996–2010, categorizing technologies (i.e., schoolhouse/classroom-based technologies, individual study tools, network-based social computing, and mobile and portable devices) for FLE and revealing their effectiveness in improving learning efficiency, motivation, communication frequency, and language knowledge/skills. Chun (2016) reviewed research during 1995–2015 on computer technology in FLE, identifying commonly used technologies (e.g., CMC, eye-tracking, and wikis) and their contributions to satisfactory learning outcomes. Chun envisioned a future "Ecological CALL" where computers would be used for global communication. A recent study by Zhang and Zou (2020) reviewed 57 TELL articles during 2016–2019, identifying five state-of-the-art topics, namely, mobile learning, multimedia learning, socialized learning, speech-to-text or text-to-speech recognition, and game-based learning (GBL). The impacts of these technologies on language education were overall positive for facilitating practices and interactions, delivering instructional content, and restructuring teaching methods.

Some reviews have focused on MALL (e.g., personal digital assistants, MP3 players and e-book readers). Sung et al. (2015) investigated MALL's effectiveness via a meta-analysis of 44 articles during 1993–2013. They reported overall positive effects of mobile technology on language education and identified moderating variables, such as learning stages, hardware, software, teaching methods, learning skills, and target language. Hwang and Fu (2019) summarized MALL's effects on language skills and knowledge, affective state, and knowledge or content learning by reviewing 93 studies during 2007–2016.

The popularity of digital games has also instigated a few DGBLL reviews. Hung et al. (2018) investigated DGBLL's influences via a review of 50 papers during 2007–2016. They found that immersive and tutorial games for promoting language acquisition and affective states were mostly played on personal computers, which were the most popular gaming devices. Acquah and Katz (2020) explored digital games' influence on FLE for primary/high-school students based on 26 articles during 2014–2018. Partly corroborating Hung et al., Acquah and Katz reported researchers' preferences for learning-driven DGBLL with positive effects on language acquisition and affective states.

Finally, there were reviews focusing on specific technologies. Gamper and Knapp (2002) reviewed 40 ICALL systems during 1994–2002, identifying several types, including expert systems, intelligent tutors, user modeling and adaptivity, natural language processing (NLP), machine translation, and ASR. Most were developed for training reading/writing skills with grammar and vocabulary as the elements which were most targeted. Gamper and Knapp described cutting-edge artificial intelligence (AI)-supported technologies, offering possibilities to improve CALL systems. Mohsen and Balakumar (2011) reviewed multimedia glosses in CALL based on 19 articles during 1993–2009, reporting their effectiveness in improving vocabulary acquisition in reading and listening comprehension activities. Mohsen (2016) found that captioning/subtitling, annotations, and scripts helped facilitate listening comprehension and incidental vocabulary acquisition based on 24 articles during 1990–2015. Parmaxi and Zaphiris (2016) explored CMC in CALL by reviewing 163 articles during 2009–2010. Parmaxi and Zaphiris (2017) synthesized 41 articles concerning Web 2.0-enhanced CALL during 2009–2013, identifying promising technologies (blogs, wikis, social networks, and digital artifact sharing platforms) for improving language skills/competences. Barrot (2018) reported Facebook's effectiveness in enhancing language proficiency and productive skills by analyzing 41 articles during 2010–2017. Reinhardt (2019) synthesized 87 focal pieces on social media use during 2009–2018, reporting social media's affordances for FLE regarding developing intercultural/sociopragmatic awareness and learners' identities/literacies.

Although these reviews have comprehensively covered CALL's many aspects during 1990–2020, they are limited in several aspects. First, they have not traced the developmental trends of CALL issues and thus offer little guidance for future research. Second, most adopted time-consuming systematic analysis and meta-analysis of a relatively small sample of articles (n = 20–350), failing to produce a comprehensive analysis of the general CALL field. Accordingly, a large-scale analysis using

bibliometrics appears timely.

Bibliometrics and Topic Modeling for Review Studies

Bibliometrics has been used to analyze scientific output by treating literature characteristics as research objects (Chen et al., 2020b). Bibliometric analysis compares the contributions of different countries, institutions, and publication sources. It also provides approaches for examining the impact and evolution of topics over time in a given field. Topic modeling, another method for large-scale literature review, can explore hidden thematic structures within a corpus of text documents, identify a set of typical topics, and measure the degree to which each document is related to those topics (Chen et al., 2020c). Structural topic modeling (STM) has been developed for social scientists to sort terms according to the probabilities with which they co-occur across observations in a dataset (Roberts et al., 2019). The probabilities are informed by the use of the structured data contained alongside text variables.

As bibliometrics and topic modeling have not been applied to thoroughly review the field of CALL, we combined STM, a nonparametric Mann-Kendall (M-K) trend test, and hierarchical clustering with bibliometrics in the present review to investigate the status, trends, and prominent issues of CALL in the past 25 years. This review can assist researchers and practitioners in understanding the development of the CALL field, its community, and the main research interests. The findings can also identify the main research issues and gaps in the current literature with implications for future CALL practice and research. These may guide researchers in their topic selection for future projects and decision-makers when they prioritize the granting of funding. Moreover, researchers, educators, and students can be informed about the major contributors in the field for potential collaboration.

The research questions (RQs) for our review of CALL articles from 1995 to 2019 are as follows.

RQ1: What was the annual frequency of CALL articles and citations?

RQ2: Who were the representative journals, countries/regions, and institutions for CALL research?

RQ3: What were the most frequently investigated topics in CALL, and how did research interests evolve over time?

RQ4: How did the identified research topics correlate?

RQ5: How were the identified research topics distributed across representative countries/regions and institutions ranked by the Hirsch index (H-index)?

Data and Methods

Derivation and Formation of Search Terms

The search terms used in this study **(**see Table 2 of the Appendix) were developed based on previous CALL reviews (Cushion & Townsend, 2019; Major et al., 2018; Nagendrababu et al., 2019; Hwang & Fu, 2019; Zhang & Zou, 2020; Sharifi et al., 2018) (see Table 3 of the Appendix) by merging and integrating their search terms. Compared to previous reviews, we adopted general terms to ensure a broader coverage of data. For example, the term "computer" covered studies on a wide range of topics like computer-aided language instruction and computer-assisted learning; the term "web" covered studies on topics like Web-enhanced language-learning, WebCT, World Wide Web, and WebQuest; the term "online" covered topics such as online learning and online chat. This strategy helped us include the terms used in previous reviews while allowing a more comprehensive coverage of potential CALL studies.

Data Collection and Selection

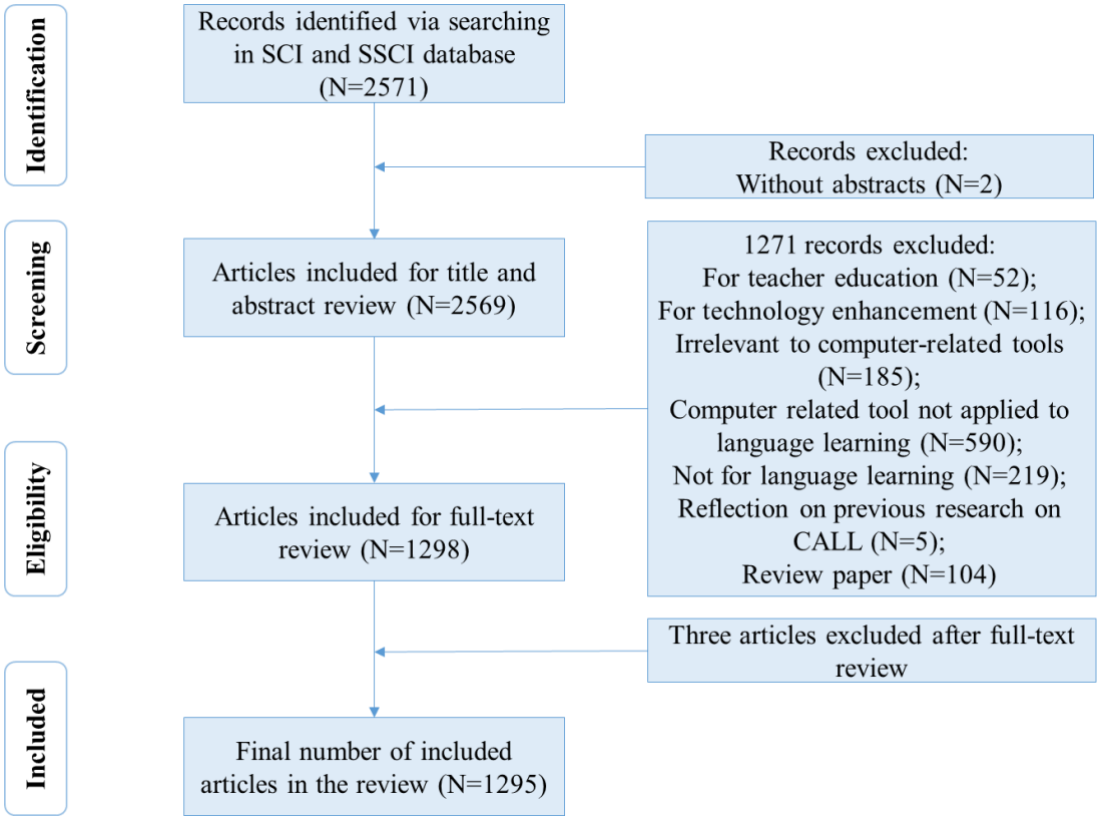
We searched the Web of Science (WoS) database on January 1, 2020 using the developed search terms. Figure 1 presents the selection procedure. Each article was examined based on four inclusion criteria. Specifically, the included papers had to be (a) an original research article, (b) published during

1995–2019, (c) related to the application of computer-related tools in language learning, and (d) in English.

This generated 2571 articles that are indexed by Social Sciences Citation Index (SSCI) or Science Citation Index (SCI). Initially, two articles without abstracts were excluded. Then, we screened the remaining 2569 articles and excluded 1271 articles based on the exclusion criteria. Subsequently, full texts of the remaining papers were downloaded and examined again based on the same criteria. Two authors checked each article independently to determine its relevance to the research topic. Disagreements were resolved via discussion within the research team. After this round of full-text review, another three articles were excluded.

Figure 1

Literature Selection Process



Data Analysis

We answered RQ1 by counting the articles and citations published in each given year. Polynomial regression analysis was conducted to fit the trends of annual article and citation counts. We used polynomial regression analysis as it allows for the modeling of the non-linear relationship between the year as the independent variable x and the total publication or citation counts as the dependent variables y and z.

For RQ2, we used bibliometric indicators which were calculated based on each article's publication source, author address information, and citations. First, we used Svensson's (2010) article and citation count method to measure the productivity and influence of journals, countries/regions, and institutions. The article counts were achieved by totaling the number of contributed articles by an actor, and the citation counts were the sums of the citations received by each of the articles the actor collaborated on.

Second, average citations per article (ACP) of a particular actor equaled the citation count divided by the article count. Third, the H-index was adopted to evaluate the academic level of actors from quality and quantity perspectives, indicating that *h* of an individual's publications have at least *h* citations each.

We applied STM and the M-K trend test (Mann, 1945) to answer RQ3. STM followed three steps. We first extracted terms from titles and abstracts and preprocessed them by removing numbers, punctuations, and stop words. Then, a term frequency-inverse document frequency model was adopted for term selection. Next, we ran candidate models with topic numbers ranging from five to 30. Two experts independently compared the candidates based on representative terms and articles determined by the topic-document and term-topic proportion matrix that showed the relevance probability of a document or term to a topic. We decided that the model with 15 topics (i.e., the 15-topic model) was optimal with the greatest semantic consistency within and exclusivity between topics.

For the 15-topic model, we evaluated the proportion of each topic by summing up the proportions of each article by topic (see Equation 1). P_k is the proportion of the k_{th} topic and $\theta_{d,k}$ its proportion in the d_{th} article. D is the total number of reviewed articles, 1295. This allowed us to measure the popularity of each topic. The proportion of the k_{th} topic in year t was calculated using Equation 2, where Y_d represents the publication year of the d_{th} article and D_t the number of articles in year t. The developmental trend of each topic was evaluated using the M-K test based on its annual proportions to identify topics receiving increasing/decreasing attention with a statistically significant test result (p <=.05).

$$P_k = \frac{\sum_d \theta_{d,k}}{D} \quad (1)$$

$$P_{k,t} = \frac{\sum_{d|Y=t} \theta_{d,k}}{D_t} \quad (2)$$

We answered RQ4 through hierarchical clustering analysis, aiming to explore topic correlation based on a document-level cosine similarity matrix. Given D documents, the assignment of topic k to them is represented by $VD = (\theta_{k,1}, \theta_{k,2}, \ldots, \theta_{k,D})$, where $\theta_{k,i}$ is the assignment probability of topic k to document i. The document-level similarity between topics k and l was calculated using Equation 3, based on which we conducted clustering with a complete-linkage agglomerative algorithm to identify potential inter-topic research directions, which were similar to the interdisciplinary analysis. An inter-topic direction is generated when two or more topics jointly form a cluster. This indicates that these topics were frequently discussed in the same studies (Chen et al., 2020b) and it would be promising to jointly consider them in one study.

$$\cos_{document}(k,l) = \frac{\sum_{i=1}^{D} \theta_{k,i} \times \theta_{l,i}}{\sqrt{\sum_{i=1}^{D} (\theta_{k,i})^2} \times \sqrt{\sum_{i=1}^{D} (\theta_{l,i})^2}} \quad (3)$$

To answer RQ5, we visualized the topic distribution of major countries/regions/institutions ranked by H-index. We first calculated the proportion of the k_{th} topic for actor a using Equation 4, where A_d is the countries/regions/institutions of the d_{th} article and D_a the number of articles for actor a. We then drew and compared the research foci of the involved countries/regions/institutions using Cluster Purity Visualizer[2], d3.v3.js[3], and clusterpurityChart.js[4].

$$P_{k,a} = \frac{\sum_{d|A=a} \theta_{d,k}}{D_a} \quad (4)$$

Results

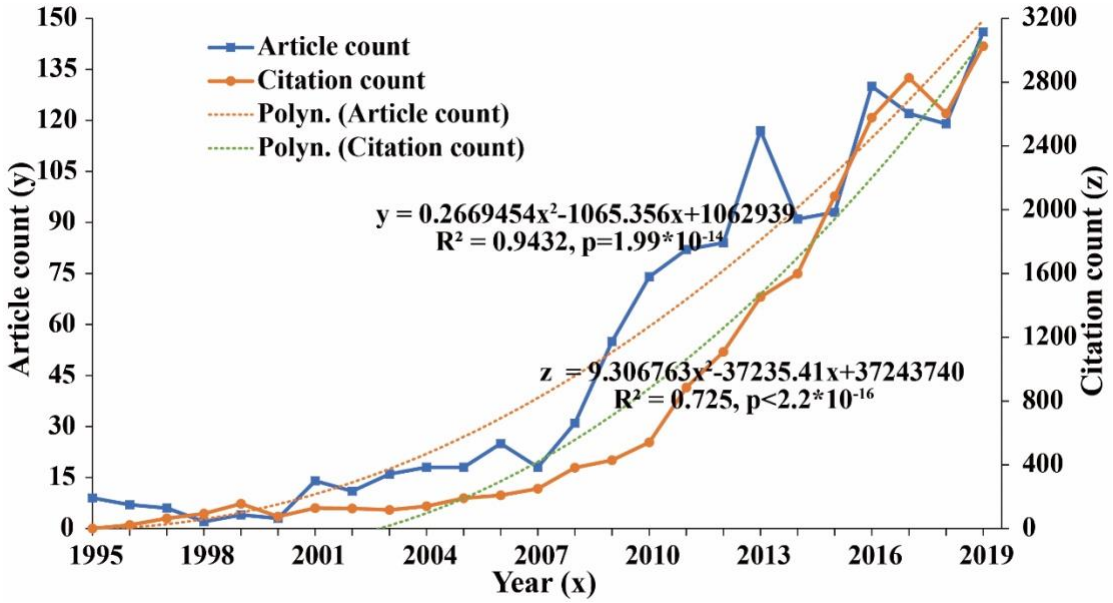
The results of the STM-based bibliometric analysis of the CALL studies are presented here related to the multiple criteria in the RQs.

Annual Trends of Articles and Citations (RQ1)

RQ1, which concerned the number of annual CALL articles and their citations over time, was answered by trend visualization and regression analysis (see Figure 2). The solid blue line shows there was a slow increase in the number of CALL articles during 1995–2007 and a rapid increase thereafter. For example, the number of articles in 2012 was 5.3 times more than that of 2007. The total number of articles reached its first peak in 2013 after a one-year surge. The number of studies had both steep downward and upward trends after 2013 and peaked again in 2016. Although the number of CALL studies fluctuated in the decade ending in 2019, the article counts generally increased, rising nearly tenfold in the past 25 years. The solid orange line depicts the three-stage development of the annual citation counts with a slow increase from 1995 to 2010, and a rapid growth thereafter, reaching 2800 citations in 2017 followed by a slight drop in 2018 and a new peak in 2019. These results indicate that, regardless of the changes in the article and citation counts, their annual trend curves grew similarly, especially from 2003 to 2017.

Figure 2

Trends of Annual Articles and Citations



Top Journals, Countries/Regions, and Institutions (RQ2)

RQ2, which concerned the profile of top journals, countries/regions, and institutions, is answered from the perspectives of H-index, article count, citation count, and ACP. A total of 254 SCI/SSCI-indexed journals contributed to the 1295 analyzed articles (see Table 4 of the Appendix**)**. The article and citation counts in most journals were low during 1995–2009, but rapidly increased beginning in 2010. The articles and citations in *Language Learning & Technology* (*LLT*) were always ranked at the top while the rankings of *ReCALL*, *Educational Technology & Society*, *System*, *Australasian Journal of Educational Technology*, and *Interactive Learning Environments* increased more than three levels during 2010–2019 as compared to 1995–2009.

In most cases, the article count of a journal was largely influenced by its citation count. For example, *LLT* and *CALL* were the top two in terms of both article and citation count, whereas journals such as *British Journal of Educational Technology*, *Language Learning* and *Interactive Learning Environments* sometimes had large differences between the rankings of the two criteria. For example, *Interactive Learning Environments* was ranked 9th in article count but 17th in citation count. The journals tended to have small differences in their article count but large differences in their citation count. For example, *CALL* published more articles than *LLT*, although it had around 1000 fewer citations. In another case, the

article count of *Computers & Education* and *Foreign Language Annals* were both 54, but the citation count of the former was 1658 while the latter was 685. This is perhaps because of their differences in academic impact. Such results indicate that a greater article count does not necessarily lead to a greater citation count.

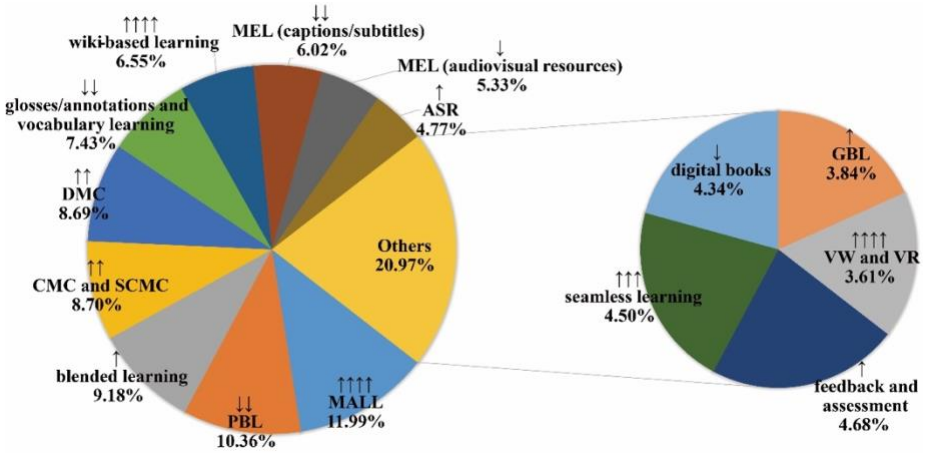
The top countries/regions and institutions measured by H-index are presented in Tables 5 and 6 in the Appendix. Scholars from the USA had the highest article and citation count while Taiwan and the UK ranked in second and third place, respectively. The differences of H-index values among the top three were over ten; however, the gaps between H-index values of other countries/regions were not as great as the top three. The results also reveal that the article count of a country/region was closely related to its citation count and that a greater article count normally led to a greater citation count. Additionally, the article and citation count of most countries and regions increased largely in the most recent decade. Notably, the article count of Singapore increased from zero (during 1995–2009) to 22 (during 2010–2019) with 362 citations, indicating a breakthrough. The article and citation count of all the listed institutions increased in the most recent decade.

Most Frequently Investigated Topics of CALL and Their Evolution (RQ3)

To answer RQ3, we used STM to identify the 15 most frequently investigated topics and the trend test to further indicate their evolution during 1995–2019. Figure 3 shows six main findings. First, six topics attracted increasing attention, namely, *digital multimodal composing* (*DMC*), *MALL*, *seamless learning*, *CMC and synchronous CMC* (*SCMC*), *wiki-based learning*, and *virtual world and virtual reality* (*VW and VR*). Second, four topics received slightly increasing interest over the years: *blended learning*, *feedback and assessment*, *GBL* and *ASR*. Third, *project-based learning* (*PBL*), *multimedia-enhanced learning* (*MEL*) *captions/subtitles*, and *glosses/annotations and vocabulary learning* declined in research interest. Fourth, researchers' interest in *MEL audiovisual resources* and *digital books* somewhat decreased as well. Fifth, in terms of topic proportion, *MALL* (11.99%) ranked first, followed by *PBL*, *blended learning*, *CMC and SCMC*, and *DMC*. Finally, the least investigated topic was *VW and VR*, which has been an emerging topic in recent years. Table 7 of the Appendix presents representative terms for each topic.

Figure 3

Topic Proportions, Topic Labels, and Developmental Trends



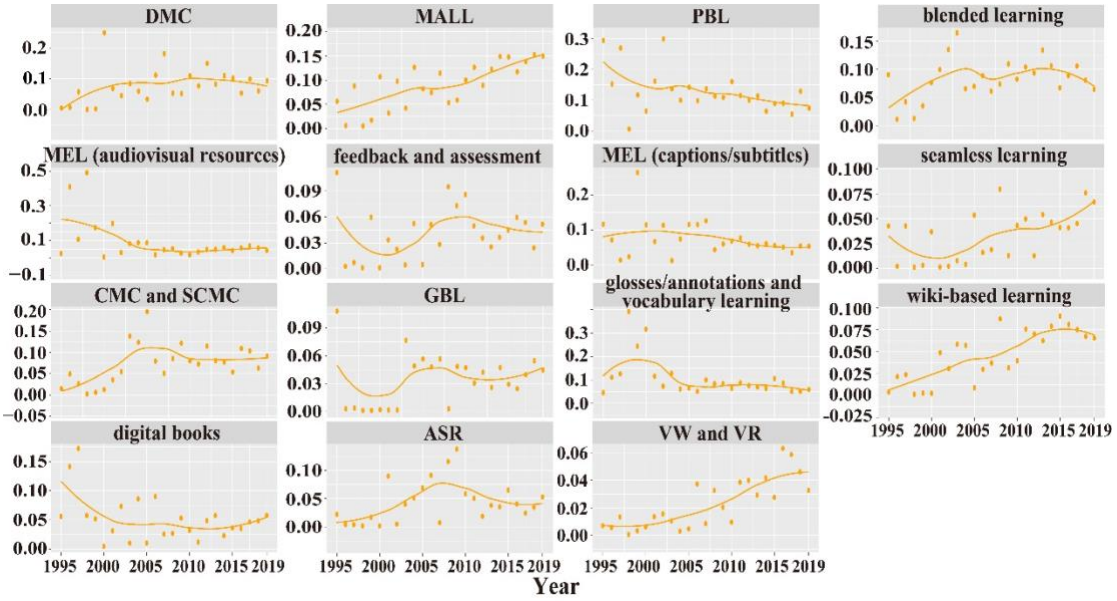
Note. (↑ (↓): increasing/decreasing trends but not significant ($p > 0.05$); ↑↑/↓↓, ↑↑↑/↓↓↓, and ↑↑↑↑/↓↓↓↓: significantly increasing/decreasing trends ($p < 0.05$, 0.01, and 0.001)).

Figure 4 illustrates the trends of 15 topics during the 25-year period. Over the years, researchers became less interested in *MEL audiovisual resources*, *digital books*, *MEL captions / subtitles*, *glosses /*

annotations and vocabulary learning, *PBL*, and *feedback and assessment*, which is consistent with the trend test results. On the contrary, researchers' interest in *MALL*, *seamless learning*, *wiki-based learning*, and *VW and VR* increased.

Figure 4

Annual Topic Proportions

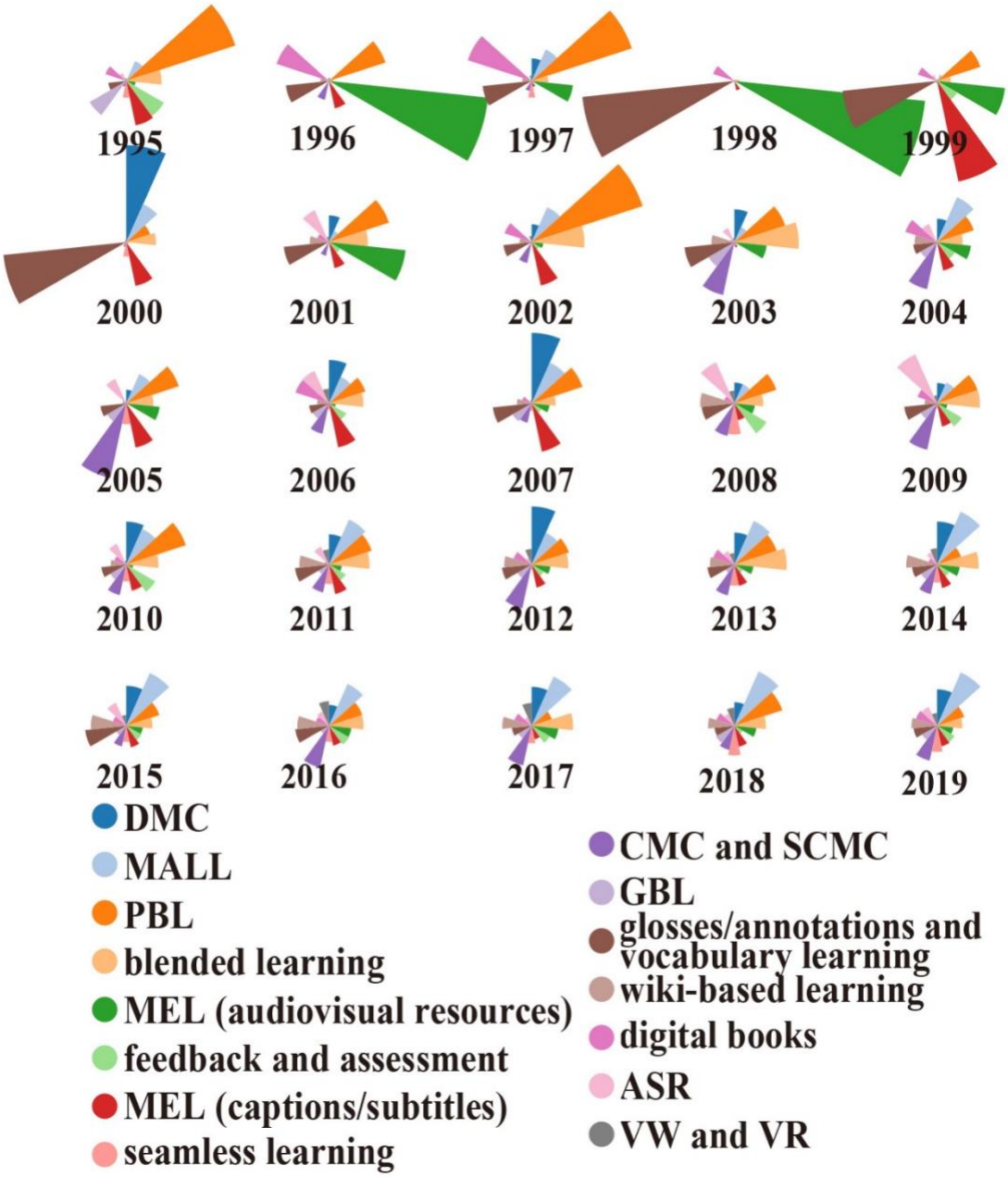


Note. X-axis as year, Y-axis as the annual topic proportion %

Figure 5 visualizes the topic proportion distributions by year. There were two main phases, one from 1995 to 2002, and the other from 2003 to 2019. This classification into two phases is based on the observation that the field seemed to be dominated by certain topics before 2003, while the proportion of various topics became more balanced thereafter. Six topics (i.e., *PBL*, *MEL audiovisual resources*, *MEL captions/subtitles*, *glosses/annotations and vocabulary learning*, *digital books* and *DMC*) dominated in the first phase but received less attention after 2003. The remaining topics consistently drew more attention from 2003. In this way, many topics gradually shared a similar proportion of research interest. Additionally, *CMC and SCMC* and *blended learning* abruptly became popular and then remained almost evenly distributed thereafter. *MALL* continued to receive the most research interest in the final decade.

Figure 5

Topic Proportion Distributions by Year

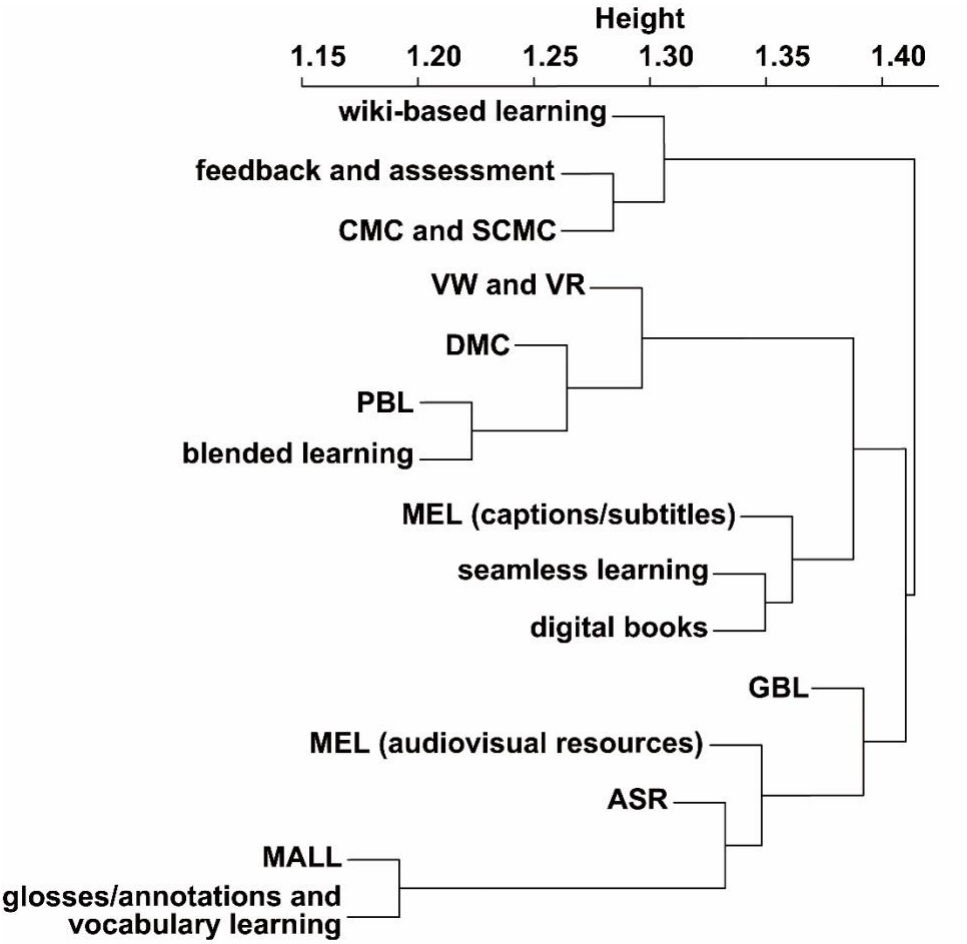


Topic Correlation Analysis (RQ4)

RQ4 explored the correlation among the identified topics using hierarchical clustering. Several clusters are presented in Figure 6: *MALL*, *glosses/annotations and vocabulary learning*, *ASR* and *MEL audiovisual resources*; *MEL captions/subtitles*, *seamless learning* and *digital books*; *DMC*, *PBL*, *blended learning*, and *VW and VR*; and *wiki-based learning*, *CMC and SCMC* and *feedback and assessment*. For example, the cluster formed by *MALL* and *glosses/annotations and vocabulary learning* indicates that articles concerning *MALL* tended to investigate *glosses/annotations and vocabulary learning* simultaneously.

Figure 6

Hierarchical Clustering Results



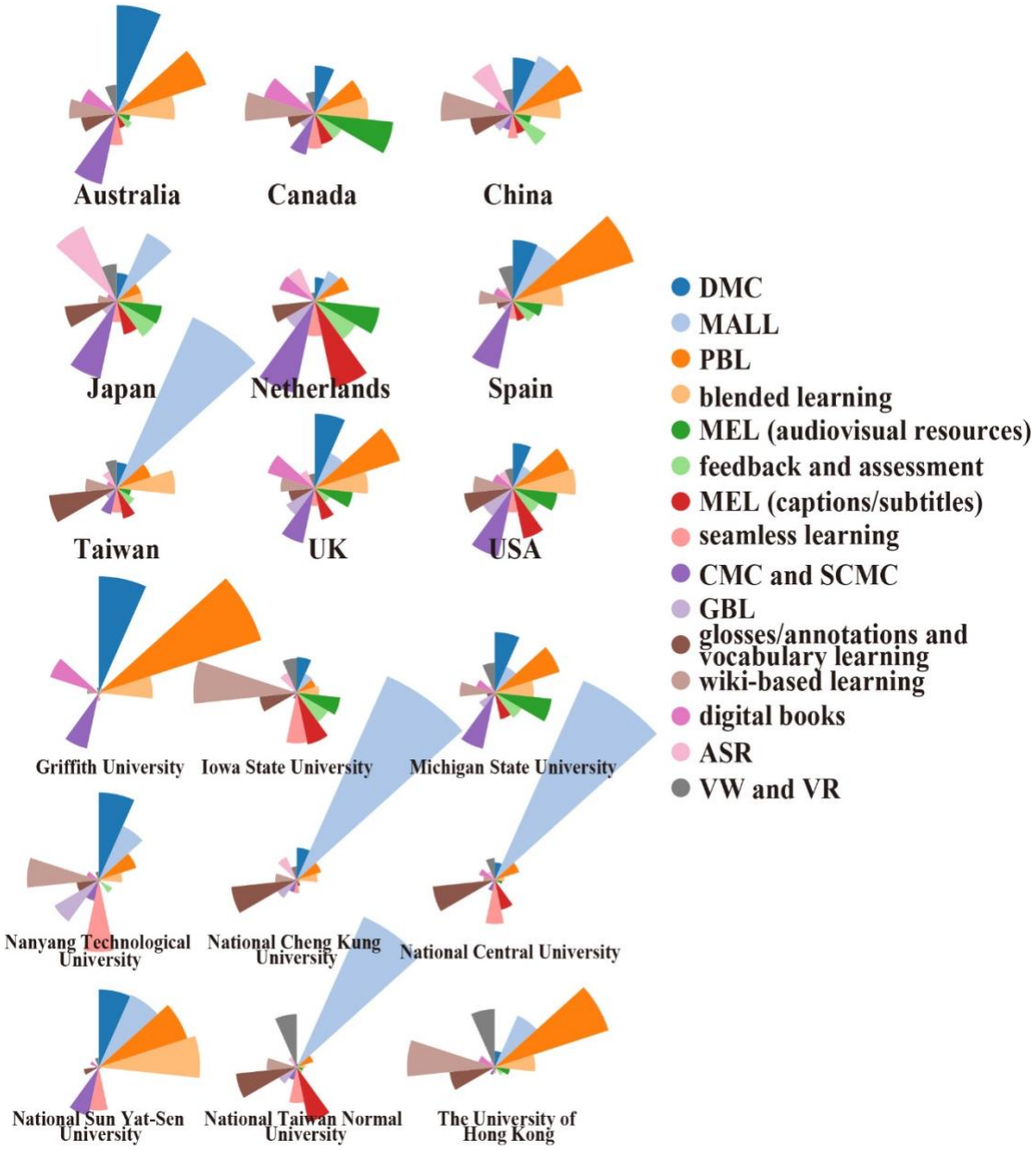
Note. The "Height" refers to the distance between two clusters.

Research Concerns Among Countries/Regions and Institutions (RQ5)

RQ5 concerned the research strengths of the top ranked countries/regions and institutions by H-index. RQ5 was answered by visualizing topic proportion distributions (Figure 7), which revealed each country/region and institution had different research preferences. The colors represent different topics with triangle size indicating topic popularity. Overall, *DMC*, *PBL*, *CMC and SCMC*, *MALL*, and *glosses/annotations and vocabulary learning* were popular issues. Canadian and Chinese researchers frequently researched *wiki-based learning*, while *MEL audiovisual resources* was a topic often investigated by Canadian and Dutch researchers. The USA and Taiwan's National Sun Yat-Sen University showed particular interest in *blended learning*. *MEL captions/subtitles* and *ASR* were mainly investigated by Dutch and Japanese researchers. Spain was interested in *PBL*, Taiwan in *MALL*, and Australia in *DMC*. In general, relatively less interest was evident for *VW and VR* and *GBL*. Among institutions, Griffith University and the University of Hong Kong were interested in *PBL*, while several institutions (e.g., National Cheng Kung University and National Central University) were interested in *MALL*. The other countries/regions and institutions had comparatively evenly distributed interests.

Figure 7

Topic Distributions of Influential Countries/Regions/Institutions



Discussion

The results of the article and citation counts show that CALL gained increasing interest over the period. This may be because CALL's many features are especially good for facilitating interactions among students and teachers, which is particularly important in the current language learning era with social interactions at its core (Beatty, 2013). Another possible reason is that CALL supports synchronous and asynchronous learning at a distance while also providing abundant learning resources and promoting learning effectiveness and efficiency (Zhang & Zou, 2020). Such dynamism naturally attracted researchers looking to uncover CALL's effectiveness and applicability, which has led to research impact. Our analysis indicated that CALL-related journals were highly recognized, with *LLT* at the top based on H-index. This is partially because *LLT* has been an open online journal since its inception in 1997.

Journals such as *CALL* or *ReCALL*, however, may not have acquired a reputation for high quality in their early years because they were behind paywalls and may not have been included in WoS. The top two countries/regions and institutions ranked by H-index were the USA and Taiwan, and National Taiwan Normal University and National Sun Yat-Sen University, respectively. The significant roles of *CALL*, *ReCALL*, the USA, and Taiwan in CALL research were also highlighted by Gillespie (2020).

We identified diverse research topics and their popularity evolutions over the 25 years. In the next subsections, we discuss the results of topic detection and evolution. We first compare our findings with previous CALL reviews. Then, based on the results of evolution analysis, we discuss technologies and their evolution in language education over five periods, namely, 1995–1999, 2000–2004, 2005–2009, 2010–2014, and 2015–2019. By dividing the 25 years into five periods, we aim to investigate the most frequently studied topics in CALL during subsequent periods of time and analyze how the topics evolved in the past 25 years. We then describe the latest advances in technology for further investigation in CALL. Additionally, we present assumptions and limitations concerning the data and methodologies.

Comparing With Previous CALL Reviews

One area of similarity between our results and earlier reviews was regarding the technologies used in CALL (i.e., Bax, 2003; Chun, 2016; Gillespie, 2020; Golonka et al., 2014; Zhang & Zou, 2020). These technologies include *web*, *games*, and *multimedia*. However, we reviewed newer studies and found *DMC*, *mobiles*, *wiki*, *CMC*, *SCMC*, and *VW and VR* were prevalent. We also analyzed how research topics evolved. Details of the comparisons are summarized in Table 8 in the Appendix.

Most of the technologies that we identified were similar to those identified by Golonka et al. (2014) and Chun (2016), including *electronic glosses and annotations*, *ASR*, *digital games*, *CMC*, *wikis* and *mobiles*. Golonka et al. stated that mobile technologies were mainly used to support text messaging and image sharing; however, MALL has now expanded to mobile games for language learning, mobile VR/AR-enhanced language learning and self-regulated mobile language learning. Both Golonka et al. and Chun found students' perceptions or affective status frequently was investigated, while we found that the contemporary CALL community investigated issues such as the effectiveness of virtual-related technologies on students' language knowledge/skills and higher-order thinking skills, authentic and synchronous communication, and task-based learning. Advances in digital technology that enrich language learning on mobile devices in various ways may be leading to more diversified MALL and CALL research than before.

Similar to Zhang and Zou (2020), we found that *mobiles*, *digital games*, *multimedia* and *ASR* were widely applied. However, because of our more extensive coverage, we also found state-of-the-art technologies like *DMC*, *CMC/SCMC*, *wikis* and *VW/VR* were investigated. Moreover, we discovered other CALL issues/strategies such as *PBL*, *blended learning* and *feedback and assessment*.

Echoing Gillespie (2020), we also identified the uses of *CMC*, *Web 2.0-related technologies*, *multimedia*, *mobiles*, *digital games*, *VR* and *ASR* in language learning. Gillespie, however, found few MALL studies, while our results show MALL as the most prevalent topic. The recent rapid uptake of mobile devices may explain this difference as Gillespie's study focused on published CALL studies only up to 2016.

Apart from the above findings, our study identified the topics that received increasing or decreasing interest in CALL by using a nonparametric trend test, unlike previous reviews that only chronologically identified the applications of technologies in language learning. This better enabled us to provide suggestions on future directions for CALL research. For example, the results showed the increasing use of *mobiles*, *DMC*, *CMC/SCMC*, *wikis*, *ASR*, *digital games* and *VW/VR* for language learning and the declining popularity of *multimedia*, *digital books* and *glosses/annotations*. This result indicates the direction CALL is heading and what technologies may emerge. Second, we analyzed topic correlations, finding the joint use of diverse technologies for language learning and their applications in different contexts. An example is the mixed use of mobile technologies and glosses/annotations for vocabulary learning and the integration of DMC into blended PBL.

In sum, by using big data and rigorous machine learning techniques, our study sheds light on current and future CALL research more comprehensively than previous reviews.

Technologies in CALL 1995–1999

Our results revealed that in the first five years from 1995, multimedia was popular in CALL; prevalent topics included *MEL captions/subtitles*, *MEL audiovisual resources* and *glosses/annotations and vocabulary learning*. This was in line with "an explosion of interest in multimedia learning" (Plowman, 1996, p. 93) in the late 90s when multimedia was in vogue in CALL (Bordeleau et al., 2000).

Since the 1980s, with an increasing number of textbooks with multimedia interactive language learning courseware, many top CALL journals published regular software reviews to familiarize language teachers with the features and contents of this type of courseware. Most language teachers believed that videos exposed learners to authentic learning materials and provided cultural contexts for using the target language (Swaffar & Vlatten, 1997). During the period, developing authoring systems incorporating multimedia expanded the ways that CALL was conceptualized. Additionally, multimedia glossing or annotations for foreign language reading and vocabulary acquisition was considered better than text/picture-only glosses for enhancing comprehension as it built referential connections between pictorial and written information (Zhang & Zou, 2021).

Technologies in CALL 2000–2004

Our results revealed that during 2005–2009, in addition to multimedia, CMC became popular in CALL, with studies on *MEL audiovisual resources*, *Glosses/annotations and vocabulary learning* and *CMC and SCMC* appearing frequently.

Multimedia as a Pedagogical Practice

With the increase of ICTs and curricular requirements to implement multimedia in language classrooms, researchers gained interest in using multimedia as a pedagogical practice. In addition to the interest in multimedia glosses for facilitating vocabulary learning, other directions appeared. For example, Plass et al. (2003) showed that learners' verbal/spatial abilities and limited capacity of working memory might influence multimedia effectiveness. In addition to multimedia research on CALL among post/secondary-school students, researchers began to focus on elementary schools, with Nutta et al. (2002) and Segers and Verhoeven (2002) respectively focusing on computer-enhanced multimedia language instruction and story pictures for enhancing early literacy skills. Researchers also began to examine how hypermedia effectiveness varied across learner characteristics, with evidence indicating hypermedia's superiority when scaffolding PBL for gifted students compared to those with lower academic levels (Liu, 2004).

CMC Facilitating Authentic Communication

Given the growing interest in social interactivity, the application of CMC in CALL was greatly influenced by learner autonomy, which emphasized social interaction and situated learning. Situated language learning engages students in authentic exchanges in the target language, which was highlighted by CALL enhanced CMC tools (Saito & Ebsworth, 2004).

The advent of computers contributed to CMC's global application in CALL, under which fourth-generation distance language education emerged (Wang & Sun, 2001). Internet-based real-time technology fostered "spontaneous communication and interaction" (Wang & Sun, 2001, p. 554), addressing the previous limited exposure students experienced in oral-visual interactions due to physical distance.

Research in FLE began to investigate the application of different types of CMC, driven by the arguments cautioning against discussing CALL as a homogenous entity (Harrington & Levy, 2001). According to Smith et al. (2003), the effectiveness of CMC on language learning should be evaluated based on the unique features of various sub-technologies. Some studies investigated negotiations in networked discussions between language learners or between native speakers and learners in SCMC activities and

the impact of CMC from cognitive and psycho-linguistic perspectives (e.g., connections between working memory and language production, text-based CMC for amplifying students' attention to linguistic form).

Technologies in CALL 2005–2009

Predominant technologies during 2005–2009 included mobile and ASR, in addition to multimedia and CMC. This was evidenced by the prevalence of studies on *MALL*, *MEL captions/subtitles*, *CMC and SCMC, glosses/annotations and vocabulary learning* and *ASR*.

CMC Combining Web 2.0 Tools

Web 1.0 technologies, the first generation of the world wide web with static Web pages and limited interactivity such as email and chat, were often integrated into CMC for FLE. Compared to that previous period, there was an increase in teachers who used Web 2.0 tools, "web-based utilities and technology tools that focus on social, collaborative, user-driven content and applications" (Paily, 2013, p. 39), for CMC purposes in language classrooms (Godwin-Jones, 2005). This move was mainly driven by the advanced Web 2.0 technologies (e.g., podcasting and blogging), enabling easier and more flexible social networking via the target language (Lin, 2014).

More empirical CALL studies involved CMC focusing on learning products/processes combining quantitative, qualitative, or mixed methodologies with participants at varied educational levels, ages, and backgrounds. SCMC, asynchronous CMC and face-to-face interaction for facilitating FLE remained popular during the period.

Mobile Technology for Instruction and Material Delivery

Mobile phones, as handheld "computers" that blurred the boundaries between the concept of computers and mobile devices, proved promising for language learning in any context (Yang, 2013). Technologically, the growth of MALL was a result of a merging between well-established personal computers and mobile internet-accessible devices, along with improvements in processing power and storage capacities, extending the capabilities of mobiles to new educational uses.

Early MALL studies mainly applied cell phones, tablet personal computers, MP3 players, personal digital assistants, and iPods for instruction and material delivery purposes. The underlying concept of these applications was similar to Web 1.0. Alongside the advent of Web 2.0, mobile technologies enabled students to share with peers and reflect on learning experiences in the target culture by uploading self-created materials.

ASR for Speaking Development

With the advance of AI and the increasing maturity of NLP, the application of ASR, a subfield of NLP, was an important part of computer-assisted pronunciation training software to improve pronunciation and develop communication skills. ASR was commonly used to analyze learners' utterances and intent, and to detect common language errors.

Technologies in CALL 2010–2014

Dominating technologies during 2010–2014 included DMC, wikis, mobile technologies and CMC, witnessed by the prevalence of *CMC and SCMC*, *MALL*, *DMC* and *wiki-based learning*.

Mobile Technology for Social, Context-Aware, and Personalized Learning

During this period, Mobile 2.0, which supports user-created content and collaboration, was increasingly investigated given the advance of wireless network technology and the emphasis on social learning, context-aware ubiquitous learning and personalized learning in CALL. These pedagogical innovations benefited from affordances/features of mobile devices, particularly social connectivity/interaction, context sensitivity, and individuality (Sung et al., 2015).

Social connectivity/interaction using mobile devices was enhanced by the emergence of "mobile

computer-supported collaborative learning" (Zurita et al., 2005), which highlighted synchronous/asynchronous functions for supporting collaborative language learning through information sharing, real-time interaction, and collaboration. With the advance of sensor technologies, real-world contexts were combined with learning systems. The concept of "context-aware ubiquitous learning" emphasized learning the "right content" at the "right time" and the "right place" (Chen et al., 2019). This exploited the context sensitivity of mobile technologies, allowing language learning to be contextualized with learners' physical surroundings.

Driven by the continuously growing individualization of learning, personalized language learning (PLL) prevailed in MALL. The personalization of MALL systems via the PLL experience was able to exploit data stored within learner profiles or learning logs.

DMC as an Innovative Literacy Activity

The popularity of DMC was mainly driven by its ability to address the dissonance between learners' language-centered learning activities in classrooms and their outside-school multimodal experience. DMC together with multi-representational digital technology-enabled content catered more effectively to varied learning styles and preferences among diverse learners. DMC's incorporation into blended learning for enhancing students' writing skills was another key development during the period.

Wikis as a Form of CMC in the Web 2.0 Era

The application of CMC in language education during this period was demonstrated in diverse contexts, with an increased use of wikis for collaborative language learning. This was mainly driven by Web 2.0, which was progressively put into pedagogical practice, which in turn, shifted CMC from Web 1.0 to Web 2.0 (Lee & Markey, 2014). Wikis helped with the development of language and literacy skills through asynchronous online collaboration and communication, providing more opportunities for reflection, and focusing on language output (Lee, 2010). Wikis made giving and receiving feedback easier and quicker, as seen from the close correlation between *wiki-based learning* and *feedback and assessment*. The integration of immediate and individualized feedback and wikis into writing courses took advantage of the strengths of different CALL pedagogies.

Technologies in CALL 2015–2019

During 2015–2019, VW and VR and digital games grew in importance in addition to DMC, mobile technologies, CMC, and wikis, as the prevalence of *DMC*, *MALL*, *CMC and SCMC*, *wiki-based learning*, *VW and VR*, and *GBL* increased.

Mobile Integration With VR/VW and Multimedia Annotations

There was an increasing trend integrating virtual-related technologies into MALL, which was driven by using VW and VR tools in language education. In cognition theory, VR tools empower MALL by creating contextualized authentic learning.

The increasing use of mobile-assisted multimedia annotations for vocabulary learning was evidenced by the close correlation between *MALL* and *glosses/annotations and vocabulary learning*. Textual/audio annotations for description/explanation enabled learners to capture related resources in authentic contexts (e.g., photo-taking and audio-recording), assisting learners to better understand the meaning of vocabulary while facilitating learner autonomy. The increasing use of mobile devices encouraged autonomous learning, which helped bridge formal and informal settings in CALL.

Wikis for Diverse Collaborative Writing Activities

In this period, more empirical studies appeared examining wiki-based collaborative language learning, with the focus on learning outcomes in diverse learning contexts. The investigated topics included: (a) comparisons of various wiki-based instructional strategies (e.g., worked examples, grouping and peer assessment); (b) language and intercultural exchange; (c) English writing for specific subjects (e.g.,

business English writing); (d) changes in interaction patterns during the learning process; and (e) collaborative dialogue analysis.

CMC for Intercultural Awareness Development

CMC provided the potential to develop intercultural awareness by engaging learners worldwide with the goal to increase intercultural awareness via FLE (Godfroid et al., 2017; Ortega, 2017). Other research directions included: (a) influential factors related to CMC's effectiveness such as pair types, task complexity, and communication mode; (b) CMC's potential to develop deaf learners' literacy skills while providing follow-up clarification via comments; (c) the commercial use of Skype-based CMC; (d) learning styles and task performances in SCMC; and (e) learner perceptions of multimodal SCMC.

DMC for Multiliteracy Development

The integration of DMC into FLE was powered by the expansion of "the repertoire of resources for text construction" (Hafner, 2015, p. 486) and the increasing need for the development of multimodal competency. DMC for multiliteracy development, particularly concerning digital video as a potential means for multimodal writing, attracted research interest. When participating in DMC, students assumed a range of identities that were normally unavailable in traditional language classrooms. Such experience with different forms of DMC in contemporary everyday literacy practices helped prepare learners for a future literate life in a digitally oriented world (Jiang et al., 2021). As an ongoing and increasingly important area in CALL, DMC for multiliteracy development was well-documented. However, the way it facilitated English learning and teachers' engagement with it still needs further exploration.

VW and VR for Immersive Language Learning

Driven by the need for immersive and authentic language learning, VW and VR have increasingly been adopted to immerse learners in meaningful contexts and increase their learning engagement. VW and VR applications remove the limitations of decontextualized FLE classrooms where students have limited opportunities for authentic interactions and communication (Lee & Park, 2020; Chen, 2016).

The integration of VR into CALL provides ample opportunities not only for improving language skills but also competences essential for 21st century learners such as teamwork, critical thinking, and cultural awareness. However, there are challenges to be addressed, including: (a) the limited use of fully immersive VR; (b) technology and pedagogy assistance regarding VR's integration into teaching practices; and (c) better alignment of VR's affordances with teaching and learning theories to allow pedagogically sound applications.

Digital Games for Immersive Language Learning

The benefits of DGBLL, such as immersive exposure to the target language context, reduction of affective barriers to language learning, and the increase of target language use for interaction (Yang & Quadir, 2018), were recognized during this period. The implementation of various digital games in language education helped to create complex real-life social networks to facilitate situated learning and anchored instruction and discovery-centered learning. Positive effects were reported on language-related skill/knowledge acquisition and improvements in self-efficacy, collaboration, engagement, and motivation.

Some issues regarding DGBLL deserve further discussion, such as the design of educational digital games. For example, given that affective elements are increasingly important in DGBLL, more research on how games impact users' emotions is needed. Additionally, as learner characteristics, e.g., competition preference, is significant in explaining differences in learning outcomes (Cho et al., 2019), more research concerning their impact in DGBLL appears necessary.

Technologies Needing More Investigation

Our review revealed two of the latest technologies; specifically, *AI* (Chen et al., 2020a; Yang et al., 2021)

and *learning analytics* (LA), have been insufficiently explored. According to Romero and Ventura (2020), advances in AI technology (i.e., deep learning) and LA have contributed to the recent trend of personalized learning and precision education. However, our review found few published studies in this area. Further, the C4.5 classification algorithm is effective in facilitating the diagnosis, prediction, and reduction of reading anxiety based on personal reading annotations for learners with different levels of learning anxiety (Chen et al., 2016). Artificial neural networks also enable English teachers to understand factors regarding learners' overall competence and to find aberrant learners (Yang et al., 2019). Bidirectional recurrent neural networks with long short-term memory is another type of AI effective for proper word choice based on sentential contexts in various writing tasks (Makarenkov et al., 2019).

More advanced deep learning algorithms (e.g., deep belief networks and generative adversarial networks) and their variations are also effective in many educational research fields (e.g., learner affect detection, adaptive gameplay design, and student performance prediction) and should be considered in language education. For example, a generative adversarial network has the potential to recommend reading/writing materials of different styles and transform reading/writing materials from one style to another based on learners' needs, which facilitates PLL (Yuan & Huang, 2020). In sum, with the increasing need for PLL, attention should reach beyond computer technologies to cutting-edge AI technologies and their uses to enhance PLL.

Another line of future CALL research is LA for PLL. In Bull and Wasson (2016), visual analytics enhanced the exploration of learners' current competence, helping them to reflect on and monitor their learning, and supported instructors' decision-making during instruction. In Gelan et al. (2018), learning dashboards were implemented to visualize learners' online behavior based on which instructors provided them with personalized recommendations about learning strategies and resources to improve their performance.

Although LA is currently in the early stages of enhancing language education, it has demonstrated effectiveness in monitoring student behavior, predicting learner performance patterns, and customizing educational experiences and assistance. With affordances emerging in the fields of data collection, processing, storage, data analysis and interpretation, pattern detection, and learning visualization, LA may be increasingly accepted as an aid to PLL for visualizing and intuitively displaying data.

Assumptions and Limitations

In addition to identifying specific journals, bibliometrics has often been used for evaluating a specific field (e.g., technology-enhanced classroom dialogue and technology-enhanced higher education), with positive effects reported. However, compared to investigating journals where the data corpus is readily specified, research field evaluation using bibliometrics requires a judicious selection of articles.

Accordingly, we developed our search terms based on the extant CALL-related reviews to cover as many eligible studies as possible. However, a few relevant terms (e.g., CD-ROM, hypertext, and HyperCard) were not included. Nevertheless, it is always a challenge to include all possibilities in a literature review. In our study, we adopted the most commonly accepted strategy by referring to similar reviews and integrated the search terms that were used in them. Hence, compared to previous reviews, our search terms are more complete, making our dataset more comprehensive than most previous studies. However, some possible omissions, particularly those pertaining to CALL practices in the late 1990s and early 2000s were inevitable. Future research can consider including more relevant terms to gain a more comprehensive dataset.

Compared to previous searches focusing on specific journals, our selection of relevant CALL journals was generated only after our keyword search was completed, rather than before. In this way, our strategy had an advantage in providing more comprehensive results as it covered more eligible data. Considering that our aim was to provide a comprehensive review of CALL research, a database search was more suitable, efficient and comprehensive than a journal search.

This study reviewed only SCI/SSCI-indexed publications, which may have excluded some important CALL journals (e.g., *CALICO Journal*). However, we reviewed SCI/SSCI-indexed publications because they have been widely reported as the most rigorous among research journals (Chee et al., 2017; Xie et al., 2019). Nevertheless, it would be interesting to explore how research trends in CALL vary when adding articles from a wider range of journals or even proceedings from CALL conferences.

Results of top journals should be interpreted with caution since a journal's impact can be affected by many factors (e.g., behind a paywall or not, established or new, or inter-disciplinarity or not). We therefore adopted other common bibliometric indicators such as article count and ACP to measure journals from different perspectives. These considerations also apply to our results on top countries/regions/institutions. Additionally, although topic models may not lead to strict conclusions, they have advantageous information-processing capabilities in understanding overall trends of scientific fields. Future research may consider applying text-mining approaches to complement well-established educational research methodologies.

Conclusion

This study was the first in-depth review to examine the status, trends, and particularly the thematic structure of CALL research during 1995–2019 using a STM-based bibliometric strategy. Results revealed that technology played an important role in facilitating FLE throughout all stages. CALL began expanding from limited applications, such as multimedia in the early stages, to a growing number of technologies (e.g., mobile technologies, CMC, and ASR) in the middle stages, to finally the diverse applications and tools including DMC, wikis, VW/VR, and digital games presently being applied. The use of these diverse applications in language education is encouraged by pedagogical and technological advances. The development and advance of sensor and networking technologies and Web 2.0, as well as the pedagogy needed for ubiquitous, immersive, blended, and collaborative learning, was shown to contribute to the increasing application of advanced technologies to facilitate language learning. Although various new technologies (e.g., mobile technologies, VW/VR, digital games, CMC, DMC, and wikis) are evident in the CALL literature, the application of the very latest technological advances remains limited. With the increasing prevalence of personalized learning, CALL scholars are advised to stay abreast of the latest AI technological trends, such as deep learning and LA, and explore how to integrate them into language classrooms to construct knowledge, develop critical thinking, and promote better learning outcomes.

Acknowledgements

We are grateful for the anonymous reviewers' helpful comments and suggestions on earlier drafts of this paper. This research was funded by the Teaching Development Grant (102489) from Lingnan University, and the Internal Research Grants (RG15/20-21R, KT16/20-21) from the Education University of Hong Kong.

Notes

1. A summary of abbreviations is presented in Table 9 of the Appendix.

2. https://gist.github.com/nswamy14/e28ec2c438e9e8bd302f

3. https://d3js.org/d3.v3.js

4. https://bl.ocks.org/nswamy14/raw/e28ec2c438e9e8bd302f/clusterpurityChart.js

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Appendix

Table 1

Reviews on CALL and its Relevant Topics

Dimension	Reviewer(s) and year	No. of articles	Methods	Reviewed period	Main topics/findings
Overview of CALL	Bax (2003)	Not specified	Not specified	Till 2003	Integrative CALL
	Levy and Hubbard (2005)	Not specified	Not specified	Till 2005	The definition of CALL
	Gimeno-Sanz (2016)	Not specified	Not specified	1997–2016	Atomised CALL
	Gillespie (2020)	777	Synthesis	2006–2016	The synthesis of CALL publications from *ReCALL*, *CALICO*, and *CALL*
General technologies used in CALL	Liu et al. (2002)	249	Not specified	1990–2000	Computer technologies used in second language learning till 2000: multimedia authoring software, word processing software, Internet, speech recognition software
	Macaro et al. (2012)	117	Systematic review	1991–2010	Popular technologies till 2010: multimedia, CMC, the Internet
	Golonka et al. (2014)	350	Synthesis	1993–2010	Four categories of technologies: schoolhouse/classroom-based technologies, individual study tools, network-based social computing, and mobile and portable devices
	Chun (2016)	Not specified	Synthesis	Till 2015	Ecological CALL
	Zhang and Zou (2020)	57	Systematic review	2016–2019	Technology-enhanced language learning: mobile learning, multimedia learning, socialized learning, speech-to-text recognition and text-to-speech recognition, and digital game-based learning
Mobile technologies used in CALL	Sung et al. (2015)	44	Meta-analysis	1993–2013	The effectiveness of mobile devices for language learning
	Hwang and Fu (2019)	93	Systematic review	2007–2016	Mobile assisted language learning
Specific technology type	Gamper and Knapp (2002)	40 systems	Not specified	1994–2002	Intelligent CALL systems
	Mohsen and Balakumar (2011)	19	Systematic review	1993–2009	Multimedia glosses
	Mohsen (2016)	24	Synthesis	Till 2015	Help options
	Parmaxi and Zaphiris (2016)	163	Systematic review	2009–2010	CMC
	Parmaxi and Zaphiris (2017)	41	Synthesis	2009–2013	Web 2.0
	Barrot (2018)	41	Systematic review	2010–2017	Facebook
	Reinhardt (2019)	87	Synthesis	2009–2018	Social media
Digital games	Hung et al. (2018)	50	Scoping review	2007–2016	Applications of immersive and tutorial games
	Acquah and Katz (2020)	26	Systematic review	2014–2018	Digital games for K–12 education

Table 2

Search Terms for Computer Assisted Language Learning

("spoc" or "Internet" or "twitter" or "Google Docs" or "WhatsApp" or "Skype" or "wearable device" or "hyperlink*" or "smartphone*" or "game" or "automatic speech recognition" or "speech-to-text recognition" or "clicker" or "smart watch" or "smartwatch" or "e-portfolio" or "social network" or "online communit*" or "e-book" or "intelligent tutoring system" or "multimedia" or "video" or "ipod" or "digital" or "web 2.0" or "augmented reality" or "wechat" or "facebook" or "flipped classroom" or "moodle" or "MOOCS" or "blackboard" or "google doc, google classroom, google drive" or "skype" or "e-learning" or "self-instruction program" or "programmed learning" or "blended learning" or "web based" or "web-based" or "machine learning" or "online" or "educational software" or "virtual reality" or "blog" or "chat" or "computer" or "technology" or "electronic discussion groups" or "interactive whiteboard" or "iPad" or "Laptop" or "messaging" or "microblog" or "micro-blog" or "microblogging" or "mobile" or "padlet" or "social media" or "tablet" or "wiki" or "ubiquitous") AND ("literacy learning" or "language learning" or "second language")

Table 3

Search Terms Related to CALL in Recent Reviews

Search terms	Review period	Ref.
"technology-enhanced"	2010 and 2016	Cushion & Townsend (2019)
"blog" or "chat" or "computer" or "computer uses in education" or "computer-supported collaborative learning" or "CSCL" or "digital technology" or "education technology" or "educational technology" or "electronic discussion groups" or "information communication technology" or "ICT" or "interactive whiteboard" or "iPad" or "IWB" or "interactive" or "laptop" or "learning technology" or "messaging" or "microblog" or "micro-blog" or "microblogging" or mobile technology" or "padlet" or "PC" or "online" or "online chat" or "social media" or "tablet" or "web" or "wiki"	2000–2016	Major et al. (2018)
"computer" or "e-learning" or "self-instruction program" or "programmed learning" or "blended learning" or "web based" or "machine learning" or "online" or "technology" or "educational software" or "virtual reality"	Until May 2018	Nagendrababu et al. (2019)
"language learning" or "literacy learning"	2007–2016	Hwang & Fu (2019)
"technology" and "language" and "learning"	2016–2019	Zhang & Zou (2020)
"computer-assisted learning" or "distance education" or "e-learning" or "blended learning" or "online learning" or "distributed learning" or "technology" or "Internet" or "software"	1990–2016	Sharifi et al. (2018)

Table 4

Top Journals Ranked by H-index

Journal	H	A (R)	C (R)	ACP	1995–2009		2010–2019	
					A (R)	C (R)	A (R)	C (R)
Language Learning & Technology	32	129 (2)	3121 (1)	24.19	31 (1)	319 (2)	98 (2)	2802 (1)
Computers & Education	24	54 (4)	1658 (3)	30.70	13 (3)	82 (5)	41 (5)	1576 (3)
Computer Assisted Language Learning	24	152 (1)	2016 (2)	13.26	13 (3)	7 (23)	139 (1)	2009 (2)
ReCALL	19	85 (3)	1263 (5)	14.86	5 (8)	3 (32)	80 (3)	1260 (4)
Foreign Language Annals	15	54 (4)	685 (9)	12.69	28 (2)	142 (3)	26 (7)	543 (8)
Journal of Computer Assisted Learning	15	35 (8)	1130 (6)	32.29	13 (3)	80 (6)	22 (9)	1050 (5)
Educational Technology & Society	14	51 (6)	917 (7)	17.98	5 (8)	5 (26)	46 (4)	912 (6)
Modern Language Journal	13	27 (9)	891 (8)	33.00	10 (6)	141 (4)	17 (11)	750 (7)
System	13	39 (7)	359 (12)	9.21	1 (32)	0 (52)	38 (6)	359 (11)
Computers in Human Behavior	12	20 (12)	425 (11)	21.25	5 (8)	73 (8)	15 (12)	352 (12)
Australasian Journal of Educational Technology	11	21 (11)	333 (14)	15.86	1 (32)	0 (52)	20 (10)	333 (13)
British Journal of Educational Technology	10	19 (13)	219 (19)	11.53	4 (12)	10 (20)	15 (12)	209 (17)
Language Learning	9	12 (20)	436 (10)	36.33	5 (8)	43 (10)	7 (23)	393 (10)
Interactive Learning Environments	8	27 (9)	245 (17)	9.07	1 (32)	0 (52)	26 (7)	245 (16)

Note. R: ranking position; H: H-index; A: total articles; C: total citations; ACP: average citations per article.

Table 5

Top Countries/Regions Ranked by H-index

Country/Region	H	A (R)	C (R)	ACP	1995–2009		2010–2019	
					A	C	A	C
USA	45	404 (1)	8512 (1)	21.07	99	1868	305	6644
Taiwan	31	218 (2)	3717 (2)	17.05	35	115	183	3602
UK	19	104 (4)	1304 (3)	12.54	19	77	85	1227
Australia	19	71 (5)	1011 (5)	14.24	12	96	59	915
Netherlands	18	43 (10)	932 (7)	21.67	9	52	34	880
China	18	127 (3)	1255 (4)	9.88	14	20	113	1235
Japan	15	65 (6)	949 (6)	14.60	9	50	56	899
Spain	14	64 (7)	647 (9)	10.11	6	10	58	637
Canada	13	48 (9)	537 (10)	11.19	11	44	37	493
Turkey	13	54 (8)	506 (12)	9.37	8	14	46	492
Sweden	11	26 (13)	519 (11)	19.96	4	1	22	518
Germany	11	26 (13)	756 (8)	29.08	7	173	19	583
Singapore	11	22 (15)	362 (15)	16.45	0	0	22	362
South Korea	10	37 (11)	412 (13)	11.14	3	3	34	409

Note. R: ranking position; H: H-index; A: total articles; C: total citations; ACP: average citations per article.

Table 6

Top Institutions Ranked by H-index

Institution	H	A (R)	C (R)	ACP	1995–2009		2010–2019	
					A	C	A	C
National Taiwan Normal University	12	36 (1)	453 (5)	12.58	2	1	34	452
National Sun Yat-Sen University	12	16 (7)	402 (7)	25.13	6	20	10	382
Nanyang Technological University	11	20 (4)	356 (9)	17.80	0	0	20	356
National Central University	11	28 (2)	320 (13)	11.43	0	0	28	320
The University of Hong Kong	11	22 (3)	379 (8)	17.23	2	15	20	364
National Cheng Kung University	10	15 (8)	196 (33)	13.07	1	0	14	196
Michigan State University	8	18 (5)	215 (28)	11.94	3	13	15	202
Iowa State University	8	12 (11)	411 (6)	34.25	2	2	10	409
Griffith University	8	11 (14)	262 (17)	23.82	4	35	7	227
University of Washington	7	10 (16)	323 (12)	32.30	3	16	7	307
University of Melbourne	7	10 (16)	180 (37)	18.00	3	6	7	174
University of Amsterdam	7	8 (33)	332 (11)	41.50	2	16	6	316
University of Hawaii	7	10 (16)	247 (22)	24.70	1	2	9	245
National Taiwan University of Science and Technology	7	14 (9)	257 (19)	18.36	0	0	14	257
The Open University	7	12 (11)	264 (16)	22.00	2	0	10	264
University of South Florida	7	10 (16)	204 (32)	20.40	1	3	9	201

Note. R: ranking position; H: H-index; A: total articles; C: total citations; ACP: average citations per article.

Table 7

Top Discriminating Terms for Each Topic

Labels	Representative terms
DMC	dmc, identity, networking, community, gaming, fan, digital, project, space, socialization, intercultural, situated, site, science, engagement, affordances, literacy, urban, construction, social
MALL	mobile, anxiety, achievement, device, phone, attitude, motivation, flipped, mall, courseware, mobile-assisted, game-based, elementary, ubiquitous, smart, app, adaptive, efl, esp, context-aware
PBL	technology, self-directed, heritage, adoption, computer, family, teaching, professional, project-based, use, french, laboratory, methodology, need, technological, become, field, style, university, innovative
blended learning	blog, course, forum, blogging, reflective, undergraduate, cultural, blended, thinking, culture, metacognitive, discussion, class, semester, journal, questionnaire, enrolled, online, cross-cultural, project
multimedia enhanced learning-audiovisual resources	discrimination, training, e-books, vowel, exposure, treatment, improvement, forword, identification, audiovisual, temporal, listener, trained, week, production, av, high variability, lli, masking, talker
feedback and assessment	cf, feedback, corrective, correction, explicit, error, uptake, provision, received, correct, metalinguistic, audioblogs, grammatical, essay, grammar, structured, implicit, immediate, response, icall
multimedia enhanced learning-captions/subtitles	caption, subtitle, listening, captioning, comprehension, l1, video, l2, processing, pronoun, viewing, syntactic, test, organizer, reliance, clip, lexical, sentence, memory, resolution
seamless learning	deaf, preschool, seamless, sign, flashcard, collocation, emotion, ar, storybook, augmented, facial, home, image, phase, cfl, application, object, noun, technology-assisted, content
CMC and SCMC	scmc, dyad, interaction, negotiation, chat, synchronous, telecollaboration, cmc, recasts, computer-mediated, interactional, text-based, face-to-face, telecollaborative, communicative, communication, exchange, discourse, fluency, complexity
GBL	player, playing, game, idiom, contextual, warcraft, play, artificial, acquired, multiplayer, gameplay, variation, autism, parallel, action, statistical, network, adult, nssl, word
glosses/annotations and vocabulary learning	reading, vocabulary, annotation, reader, glossing, retention, presentation, dictionary, gloss, mode, load, cognitive, format, character, multimedia, read, text, comprehension, hypermedia, verbal
wiki-based learning	wikis, writing, writer, wiki, keyboarding, corpus, collaborative, prewriting, search, composition, revision, write, mt, wiki-based, google, kong, hong, collaboration, wrs, wrote
digital books	story, literacy, girl, narrative, multimodal, robot, early, authenticity, nonverbal, author, boy, argues, medium, tutorial, act, child, digital, methodological, claim, book
ASR	asr, mispronunciation, detection, pronunciation, automatic, speech, agent, capt, utterance, tone, recognition, dialog, system, evaluation, articulator, locus, verify, classification, method, non-native
VW and VR	virtual, autonomy, world, sl, chatbot, autonomous, interest, recording, life, immersion, task-based, instant, telepresence, vr, messaging, immersive, reality, profile, weekly, partner

Table 8

Comparisons of Bax (2003), Golonka et al. (2014), Chun (2016), Zhang and Zou (2020), and Gillespie (2020)

Reviewer(s) and year	Main results	No. of articles	Methods	Period
Bax (2003)	Three general historical periods of CALL: restricted CALL (1960s-1980), open CALL (1980s until 2003), and integrated CALL.	Not specified	Not specified	Until 2003
Golonka et al. (2014)	Technologies: course/learning management system, interactive white board, ePortfolio, corpus, electronic dictionary, electronic glosses and annotations, intelligent tutoring system (ITS), grammar checker, automatic speech recognition and computer-assisted pronunciation training, VW/serious game, chat, asynchronous CMC, social networking, blog, Internet forum and discussion/message boards, wiki, tablet PC and PDA, iPod, cell phone/smartphone	350	Systematic analysis	1993–2010
Chun (2016)	Technologies: CMC, ASR, wikis, chat, eye-tracking; multimedia glosses, audio recordings, SCMC and ACMC, subtitles and transcripts, video captioning, hypermedia, computers, mobile phones, video, audio, captions, Internet reading program, multimedia, social network	Not specified	Synthesis	Until 2015
Zhang and Zou (2020)	Technologies: mobile-assisted language learning, multimedia language learning, socialised language learning (e.g., online platforms or communities and social networks), speech-to-text recognition and text-to-speech recognition assisted language learning, gamified language learning	57	Systematic analysis	2016–2019
Gillespie (2020)	• Most studied topics: CMC, NLP, Web 2.0 • Less studied topics: MALL, multimedia, VR, blended learning, games • Scarcely studied topics: web, VLEs • Least studied topics: IWBs, MOOCs	777	Bibliometrics	2006–2016

Our study	• Technologies: DMC, mobile devices, multimedia, captions/subtitles, audiovisual resources, CMC and SCMC, digital games, glosses/annotations, wiki, digital books, ASR, VW and VR • Pedagogical issues: PBL, blended learning, feedback and assessment • Significantly increasing topics: DMC, MALL, seamless learning, CMC and SCMC, wiki-based learning, VW and VR • Clusters of topics: MALL and glosses/annotations and vocabulary learning; DMC, PBL, and blended learning; CMC and SCMC, wiki-based learning, and feedback and assessment	1295	Topic modeling and bibliometrics	1995–2019

Table 9

Abbreviations in the Main Text

Abbreviations	Full names
CALL	computer-assisted language learning
ICTs	information and communication technologies
ASR	automatic speech recognition
MALL	mobile-assisted language learning
DGBLL	digital game-based language learning
TELL	technology-enhanced language learning
CMC	computer-mediated communication
FLE	foreign language education
GBL	game-based learning
NLP	natural language processing
AI	artificial intelligence
STM	structural topic modelling
M-K	Mann-Kendall
RQ	research questions
WoS	Web of Science
SSCI	Social Sciences Citation Index
SCI	Science Citation Index
ACP	average citations per article
H-index	Hirsch index
LLT	Language Learning & Technology
DMC	digital multimodal composing
SCMC	synchronous computer-mediated communication
VW	virtual world
VR	virtual reality
PBL	project-based learning
MEL	multimedia-enhanced learning
PLL	personalized language learning
LA	learning analytics

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