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A Comparative Analysis of Virtual Education Technology, E-Learning Systems Research Advances, and Digital Divide in the Global South

Ikpe Justice Akpan [1,*], Onyebuchi Felix Offodile [2], Aloysius Chris Akpanobong [3] and Yawo Mamoua Kobara [4]

[1] Department of Information Systems and Business Analytics, Kent State University, 330 University Drive NE, New Philadelphia, OH 44663, USA
[2] Department of Information Systems and Business Analytics, Ambassador Crowford College of Business and Entrepreneurship, Kent, OH 44240, USA
[3] Faculty of Computer Science & Information Technology, Universiti Putra, Serdang 43400, Malaysia
[4] Odette School of Business, University of Windsor, Windsor, ON N9B 3P4, Canada
* Correspondence: iakpan@kent.edu; Tel.: +1-330-308-7572; Fax: +1-330-339-3321

Abstract: This pioneering study evaluates the digital divide and advances in virtual education (VE) and e-learning research in the Global South Countries (GSCs). Using metadata from bibliographic and World Bank data on research and development (R&D), we conduct quantitative bibliometric performance analyses and evaluate the connection between R&D expenditures on VE/e-learning research advances in GSCs. The results show that 'East Asia and the Pacific' (EAP) spent significantly more on (R&D) and achieved the highest scientific literature publication (SLP), with significant impacts. Other GSCs' R&D expenditure was flat until 2020 (during COVID-19), when R&D funding increased, achieving a corresponding 42% rise in SLPs. About 67% of 'Arab States' (AS) SLPs and 60% of citation impact came from SLPs produced from global north and other GSCs regions, indicating high dependence. Also, 51% of high-impact SLPs were 'Multiple Country Publications', mainly from non-GSC institutions, indicating high collaboration impact. The EAP, AS, and 'South Asia' (SA) regions experienced lower disparity. In contrast, the less developed countries (LDCs), including 'Sub-Sahara Africa', 'Latin America and the Caribbean', and 'Europe (Eastern) and Central Asia', showed few dominant countries with high SLPs and higher digital divides. We advocate for increased educational research funding to enhance innovative R&D in GSCs, especially in LDCs.

Keywords: virtual education; digital solutions; research and development; digital divide; e-Learning research advances; online learning; global south countries

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1. Introduction

Digital technology application in educational management and virtual education (VE) has become pervasive in the past few decades with the proliferation of web-based platforms and social networks. Incidentally, the outbreak of a coronavirus disease in December 2019 (COVID-19) fast-tracked digital transformation in nearly all sectors of the global economy, including education [1,2]. As the COVID-19 pandemic spread speedily in the early period of the global health pandemic (2020/2021), governments worldwide issued stay-at-home orders; people facing imminent risk of the SARS-CoV-2 infection were mandated to self-isolate, while people already infected were quarantined [3]. Consequently, business organizations hurriedly modified and digitized operational activities and processes for remote work [2,4]. Similarly, educational institutions from pre-school to university, especially in developed economies, resorted to VE implemented via digital learning platforms [1,5]. Schools, colleges, and universities that typically operate traditional face-to-face instructions in developed countries with little or no virtual learning (VL) presence improvised technologies and platforms including Teams, Zoom, social media, and cloud technologies to launch

virtual learning environments (VLEs) for academic instruction [6,7]. A list of abbreviations and meanings is presented in the Abbreviations section.

On the contrary, several Global South Countries (GSCs), especially the less developed countries (LDCs), struggled to implement similar e-learning technologies due to inherent systemic challenges, including the dearth of infrastructural facilities from inadequate power supply to limited Internet access and requisite technologies [8]. Whereas some GSCs can overcome the physical infrastructure limitations, other factors such as pedagogical, technical, social, and cultural challenges continue to hinder e-learning development progress [9–11]. On the other hand, LDCs have more complex problems, including digital and physical infrastructural deficits that hinder VE/e-learning implementations [8]. With little or no options, most educational institutions in LDCs remained under 'lock and key' for the lockdown period, especially during the COVID'19 pandemic's first and second waves in 2020, and lost significant learning days due to the inability to adapt to the new education delivery paradigm [12–14].

Several studies examine the disparity in digital education development between the global north and south (especially during the COVID-19 pandemic), highlighting the need to bridge the gap [8]. However, many research studies tend to bundle the GSCs together with the developing countries tag, thus ignoring the diversity that exists. Other publications focus on either subject-based or silo cases [15,16]. Further, Goksu [17] examined the trends in mobile learning. Others analyzed the limited use of information and communication technology (ICT) in schools in the developing regions [8,11]. Also, there are no recent studies that investigate the technological divides among the GSCs. While digital advances in the global north region are symmetrical, there are wide gaps among the GSCs, especially among the LDCs, ranging from advanced countries and well-developed digital infrastructure in East Asia and the Pacifics (EAP) to the rudimentary or non-existing essential facilities in the LDCs due to several factors. For example, Andersson and Gronlund [8] and Frehywot et al. [18] found that economic, technological, organizational, technical, and cultural factors contributed to the slow development in VE in GSCs compared to Western nations. This study focuses on the state and nature of research and development (R&D) and the impacts on e-learning advances, which are yet to attract any holistic investigation. Near-related work has attempted to address R&D-related issues on e-learning in GSCs, including LDCs compared in scholarship topics published on VE advances in developed and developing countries [8], while the gaps in the literature remain.

This study, therefore, is a pioneer attempt to evaluate VE/e-learning R&D and streams, hotspots, citation impact analysis, and digital divides among the 151 countries, classified into six regions by the United Nations Human Development Program–UNDP [19]. Specifically, our research objectives include the following:

- RO1: Examine the e-learning research productivity trends among the GSCs and regions based on scientific literature publications (SLPs) between 2000 and 2021.
- RO2: Compare VE R&D activities, publication hotspots, and citation impacts across the six global south regions during the period.
- RO3: Track and analyze the SLPs' origin and the associated citation impacts among GSC/LDC regions and the global north.
- RO4: Evaluate any potential digital divides among developing countries and regions.

The results from the above four research objectives (RO1-R04) help to accomplish the purpose of this study. The rest of the paper is structured as follows: Section 2 presents the background, focusing on the concept of VE and e-learning R&D in GSCs/LDCs. Section 3 presents the methodology, including the materials and methods. Section 4 examines findings from the study and discusses the results, while Section 5 concludes the paper with policy implications and Section 6 discusses the limitations of the study and identifies areas for future research.

2. Background

2.1. Virtual Education/E-Learning Concepts

Virtual education explains the variety of teaching or learning formats where the instructors collaborate or interface with learners through electronically mediated platforms, otherwise known as electronic (e) learning or VLE [18,20]. The interaction of teachers and students utilizes electronic devices through information and communication technologies and Internet-based channels, hence the famous label e-learning, or electronic learning [21]. This study uses the terms VL, VE, VLE, and e-learning interchangeably [9–11].

Technically, e-learning, or VLE as a platform for teaching and learning, is based on social constructivism theory and a distributed system framework. It enables social interaction through content creation, sharing, storing, and retrieval processes through which learning occurs [22]. During the first and second waves of COVID-19, which spread quickly, leading to the enforcement of community lockdown, educational institutions hurriedly employed Internet-based social interactive platforms to implement VLE and moved instruction to the virtual space to limit the human-to-human spread of the coronavirus disease. Such interactive applications and web-based audio and video conferencing include Microsoft Teams and Zoom [7,11]. Thus, the Internet offers a platform for interaction among distributed systems, humans, and machines [23].

VE has evolved significantly from a mainly asynchronous format during the early years to include synchronized learning techniques in recent times. The asynchronous method involves non-real-time connections or interactions between educators and learners [20]. On the other hand, the synchronized manner, which is increasingly becoming widespread, occurs in real time. It utilizes teleconferencing/videoconferencing, which is made possible by significantly improving bandwidth capabilities and fast computer speeds with high memory [20]. Furthermore, the possibility of live audio/video streaming of classes within the synchronized e-learning method made it a popular replacement to the traditional face-to-face instruction during the COVID-19 global pandemic, when teaching and learning moved to the virtual space [24]. According to Beckwith [20], the availability of e-learning alternatives increases the popularity of VE, especially in developed economies where resources for implementation and adoption are readily available compared to the GSCs/LDCs.

2.2. Developing Countries Classification, Regions, and Background

Several studies examining e-learning advances in (GSCs/LDCs) and other R&D tend to assume symmetrical peculiarities or similar institutional experiences among these nations. Research studies investigating e-learning advances in GSCs do not consider the differences in cultural and infrastructural development and technical capabilities in these countries and regions. In recognition of the existing differences among countries in the developing world, this section presents a brief overview of GSCs classifications based on the United Nations Human Development Program 2020 report, which identifies 151 developing nations categorized into six regions [19]. This study adopts the grouping of countries as GSC regions as given, while acknowledging the disparities among these countries as explained in the earlier Section. The six regions are the "Arab States", "East Asia and the Pacific", "Europe (Eastern) and Central Asia", "South Asia", "Latin America and the Caribbean", and "Sub-Sahara Africa" (Table 1).

Table 1. Classification of the World's Developing Regions.

United Nations Classification of the World's Developing Regions *
Arab States [AS]: 20
Algeria, Bahrain, Djibouti, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, State of Palestine, Oman, Qatar, Saudi Arabia, Somalia, Sudan, Syrian Arab Republic, Tunisia, United Arab Emirates, Yemen
East Asia and the Pacific [EAP]: 26
Brunei Darussalam, Cambodia, China, Fiji, Indonesia, Kiribati, Democratic People's Republic of Korea, Lao People's Democratic Republic, Malaysia, Marshall Islands, Federated States of Micronesia, Mongolia, Myanmar, Nauru, Palau, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Thailand, Timor-Leste, Tonga, Tuvalu, Vanuatu, Viet Nam
Europe (Eastern) and Central Asia [ECA]: 17
Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Georgia, Kazakhstan, Kyrgyzstan, Republic of Moldova, Montenegro, Serbia, Tajikistan, North Macedonia, Turkey, Turkmenistan, Ukraine, Uzbekistan
Latin America and the Caribbean [LAC]: 33
Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Plurinational State of Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Bolivarian Republic of Venezuela
South Asia [SA]: 9
Afghanistan, Bangladesh, Bhutan, India, Islamic Republic of Iran, Maldives, Nepal, Pakistan, Sri Lanka
Sub-Saharan Africa [SSA]: 46
Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo, Democratic Republic of the Congo, Côte d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tomé and Príncipe, Senegal, Seychelles, Sierra Leone, South Africa, South Sudan, Eswatini (Kingdom of), United Republic of Tanzania, Togo, Uganda, Zambia, Zimbabwe

* The classification based on UNDP data [19].

The countries listed in Table 1 above comprise 75% of the world population. It is therefore not surprising that there are significant disparities among them. In this section, we attempt to highlight the potential factors that contribute to the digital divide among the countries/regions:

- Telecommunications infrastructure, including broadband internet connectivity and access, can be challenging in several GSCs/LDCs. Providing and maintaining reliable Internet infrastructure due to geographical constraints, lack of human and financial resources, or underdeveloped communication networks [25].
- The cost of acquiring digital devices: digital devices and Internet services can be prohibitive for many individuals and communities in developing countries, including the high prices of smartphones and computers [26,27].
- Limited access to quality educational and learning resources, such as online libraries and information literacy, restricts users' ability to engage in online activities and benefit fully from digital resources [28,29].
- Lack of digital literacy skills and awareness or limited knowledge of digital tools can restrict the users' ability to engage in online activities and fully benefit from digital resources [28].
- Gender and socioeconomic disparities with women, marginalized communities, and individuals from lower socioeconomic backgrounds often face more challenges in accessing and utilizing digital technologies [30].

The countries in the developing world experience the above problems at different magnitudes. While countries in the EAP region, e.g., China, South Korea, and Indonesia, tend to overcome infrastructure limitations such as these, problems such as information literacy still hinder some users [31]. According to a recent study, students and teachers in the SA re-

gion, which includes India, tend to prefer traditional face-to-face education than e-learning, which becomes an impediment to VE implementation [32]. On the other hand, countries in the SSA and LAC tend to suffer Internet infrastructure deficits, which directly limit e-learning activities [11,25], while cultural impediments, gender disparity, and learner's preference for traditional education can significantly hinder e-learning implementation among countries in the AS region [33].

2.3. Research and Development, Scientific Discovery, and Society Advances

Since the beginning of life, humans have advanced knowledge through research and scientific discovery, either by design or default. In the first case, scientific discoveries occur when researchers compare existing designs of a widget with an alternative that might provide better utility. Conventionally, scientific discoveries in modern times occur through research, which in most cases occurs at research institutions and laboratories endowed with relevant human and technical capital [34,35]. In some instances, discoveries are typically "accidental" in an "Ah-Ha moment" for the researcher [36,37]. Every scientific discovery is revolutionary, leading to findings that enhance societal benefits and improve living standards [35]. The propensity aligns with curiosity and is an immutable part of scientific discovery since, without it, one may not even recognize the "Ah-Ha moment" when it occurs, and accidental discoveries may not even be possible [35–37]. Searching for knowledge invariably starts with experimentation and research to uncover the unknown. It involves taking risks and pushing one beyond the fringes of the known to the unknown without knowing what to expect and a willingness to accept the outcome.

Countries allocate a proportion of their annual budget for R&D activities yearly based on priorities. Such allocation is often expressed as a percentage of the gross domestic product (GDP). Several research works show that R&D positively impacts a nation's economy as a propeller of innovations and inventions [38,39]. Although the outcome of industrial automation and technological transformation and innovation can generate some externalities, such as environmental problems and change management issues, the outcome of R&D often results in positive societal transformation, growth, and development [39–41]. For example, the most recent United States Global R&D Expenditure: Fact Sheet states that R&D drives various sectors of the US economy, including job creation [40]. In particular, the report credited the USA's investment in R&D during the 20th century as the catalyst for its "global economic leadership" [40,42]. Most of the US's basic research is performed by academic institutions in fulfillment of their mission of research and education of future generations. The preponderance of these expenditures goes to universities classified as having very high research activities. These universities typically go out of their way to hire researchers who have the chops to secure the R&D dollars and disseminate their research results in top SLP journals. The dissemination of the research serves dual roles. First, it gives the academic institution visibility that enables them to secure even more R&D funds and, second, it increases the researchers' prowess and visibility that enables them to advance in rank, with some of them holding endowed positions. Further, in a study of Asian countries, Meo et al. [42] found that there is a positive correlation between R&D expenditure and number of SLPs and citations per publication. Thus, R&D expenditure enables publication productivity and economic development. But being able to realize these benefits/positive effects of R&D depends on the levels of human capital development, achievable through on-the-job training, trade-based skills acquisition, professional development, or formal education [38,39]. This observation has policy implications, especially for LDCs where R&D investments are spotty at best. Most LDCs with low R&D spending are less developed than countries with higher R&D expenditure [39]. However, there are a few exceptions where countries listed as developing spend more on R&D than several so-called developed ones. Table 2 shows the top 20 countries and their GDP and R&D expenditures, most of which are global north nations, except China, South Korea, and Taiwan, which are in the GSC regions.

Table 2. Top 20 R&D expenditures (USD billion) as percent of GDP in 2020.

Country	2020 GDP	R&D	R&D/GDP (%)
USA	20,807.27	657.5	3.16
China	15,222.16	525.7	3.45
Japan	4910.58	173.3	3.53
Germany	3780.55	147.5	3.90
S. Korea	1586.79	102.5	6.46
France	2551.45	72.8	2.85
UK	2638.3	56.9	2.16
Russia	1464.08	44.5	3.04
Taiwan	668.5	44	6.58
Italy	1848.22	38.8	2.10
Canada	1600.26	29.3	1.83
Spain	1247.46	24.9	2.00
Turkey	649.44	24.2	3.73
Australia	1334.69	22.4	1.68
Netherlands	886.34	22.3	2.52
Sweden	537.6	19.3	3.59
Israel	402	18.7	4.65
Switzerland	707.87	18.6	2.63
Belgium	515.3	18.2	3.53
Poland	594.2	17.2	2.89

[(R&D/GDP (%)) implies the country's R&D expenditure as a percentage of GDP].

3. Materials and Method

3.1. Data Sources

Web of Science, SCOPUS, and Google Scholar are some of the most popular bibliographic databases from which researchers can obtain metadata for bibliometric studies. Several previous studies have made notable conclusions about these data sources. While both Web of Science and SCOPUS possess significant quality standards above Google Scholar, which lacks "strong quality control" [43–45], SCOPUS indexes many more publications than Web of Science due to more stringent requirements [43]. For example, [43,44] showed that SCOPUS indexes many more articles than Web of Science. Based on the above conclusions, we opted for SCOPUS as the data source in this study.

The data used in this study came from the SCOPUS literature database. Our preference for SCOPUS over Web of Science, an alternative scientific literature database [43–45], is that it indexes more publications. Although SCOPUS tends to adopt slightly less stringent indexing criteria, it still maintains a good balance between quality and quantity [43]. Further, researchers from the developing countries are more likely to publish in sources indexed on SCOPUS, which is quite popular among researchers in the developing regions [46–48]. We downloaded full data from the published document as a text file for science mapping, trends, network analyses, and bibliometrics evaluation [49,50].

3.2. Search Keywords and Database Survey

Any search for bibliographic records on SCOPUS requires using indexed terms or keywords, which can come from previously known terms or concepts. For example, previous studies [8,18] that examined the use of e-learning for medical education in low- and medium-income countries identified a list of terms used to denote e-learning. Similarly, the data collection process in this study involved developing search keywords based on the terms used in the literature denoting e-learning, such as VE, VL, VLE, and more [18].

The final sets of terms included words such as "e-learning", "virtual learning", and "digital learning". We utilized the Boolean operator (OR) in between the listed words. Also, using "quotation marks" ensured retrieving the exact match from search results. At the same time, asterisks handle word stemming, e.g., "virtual learn*" can filter words matching similar meanings but in different tenses or spellings (e.g., learn, learning, or learned). The GSCs (Table 1) formed part of the query string with the Boolean operator (AND) to filter the

documents that address e-learning issues in the specified countries. The database search took place in March 2021, while the final query occurred in December 2021. The publication date was set to all years to ensure optimal results. Table 3 presents the complete search terms, the query strings, and number of documents retrieved by region.

Table 3. Bibliographic database survey criteria.

Activities/Focus	Keywords
Query String:	TITLE-ABS-KEY ("e-learning" OR "virtual learn*" OR "digital learn*" OR "virtual edu*" OR "Online Learn*"). This query string was appended with search terms representing country names for each region using the Boolean (AND). These search keywords were concatenated with the country names in each developing region (Table 1) to produce the results below.
Publications Retrieved:	Arab States [AS]: 3146 East Asia and the Pacific [EAP]: 4147 Europe (Eastern) and Central Asia [ECA]: 638 Latin America and the Caribbean [LAC]: 1097 South Asia [SA]: 1393 Sub-Sahara Africa [SSA]: 1183 Total documents retrieved: 11,604
Period Covered:	The bibliographic database survey covered: 2000–2021

3.3. Document Collection and Screening

The SCOPUS database survey produced 11,604 documents for the six regions (Table 2) before filtering and screening. The retrieved items went through further screening before inclusion in this study (Figure 1). A few published documents in VE occurred before the millennium in GSCs as follows: AS: (15); EAP: (5); ECA: (1); LAC: (3); SA; 1; SSA: (1). Some publications used the term 'distance learning' in the context of traditional brick-and-mortar open learning centers or postal mailing-based correspondence education, which are outside the scope of e-learning and this study. Publications addressing these 'out of scope topics' were excluded. Four-hundred-and-forty-seven (447) documents were discarded in the screening process, thus reducing the total to 11,157 from the six GSC regions. Figure 1 shows the data screening processes.

The SCOPUS database platform offers the options for users to retrieve the data in different formats (e.g., Excel, Text, ".CSV", and other forms). The data were downloaded as a ".CSV" file and converted to a Microsoft Excel 16.0 document for screening. EXCEL was chosen because it offers many functionalities, such as identifying duplicate entries or selecting records using set criteria through the built-in formulas and functions or user-created macros and programs. The document selection criteria include the following:

- Peer-reviewed published journal articles, conference proceedings papers, or book chapters.
- The study addresses the subject of e-learning in developing countries.

Data from non-English language publications that were formerly translated into English and indexed on SCOPUS are included in this study. However, SCOPUS counts both the translated copies and the document in the original language. The duplicate copies were removed to avoid double counting. For example, Pichugina and Artemenko [51] was initially written in Serbian but formerly translated to English on SCOPUS and included in the analysis.

The final selection included 10,655 'unique documents' from the 11,157 retrieved after discarding 447 irrelevant documents that did not meet the selection criteria (e.g., do not fall in the VE/e-learning research areas). However, 502 scholarships examined e-learning issues in multiple GSCs. These final documents were included for the individual country analysis. In contrast, aggregate analysis for countries and regions uses only the 'unique documents' count (without duplicate entries), where the same publication addresses issues in more than one country. As indicated earlier, the last database search occurred in December 2021,

covering the same period as the World Bank data on GDP and R&D for the GSCs [52,53]. It is important to note that the search output can change over time [54].

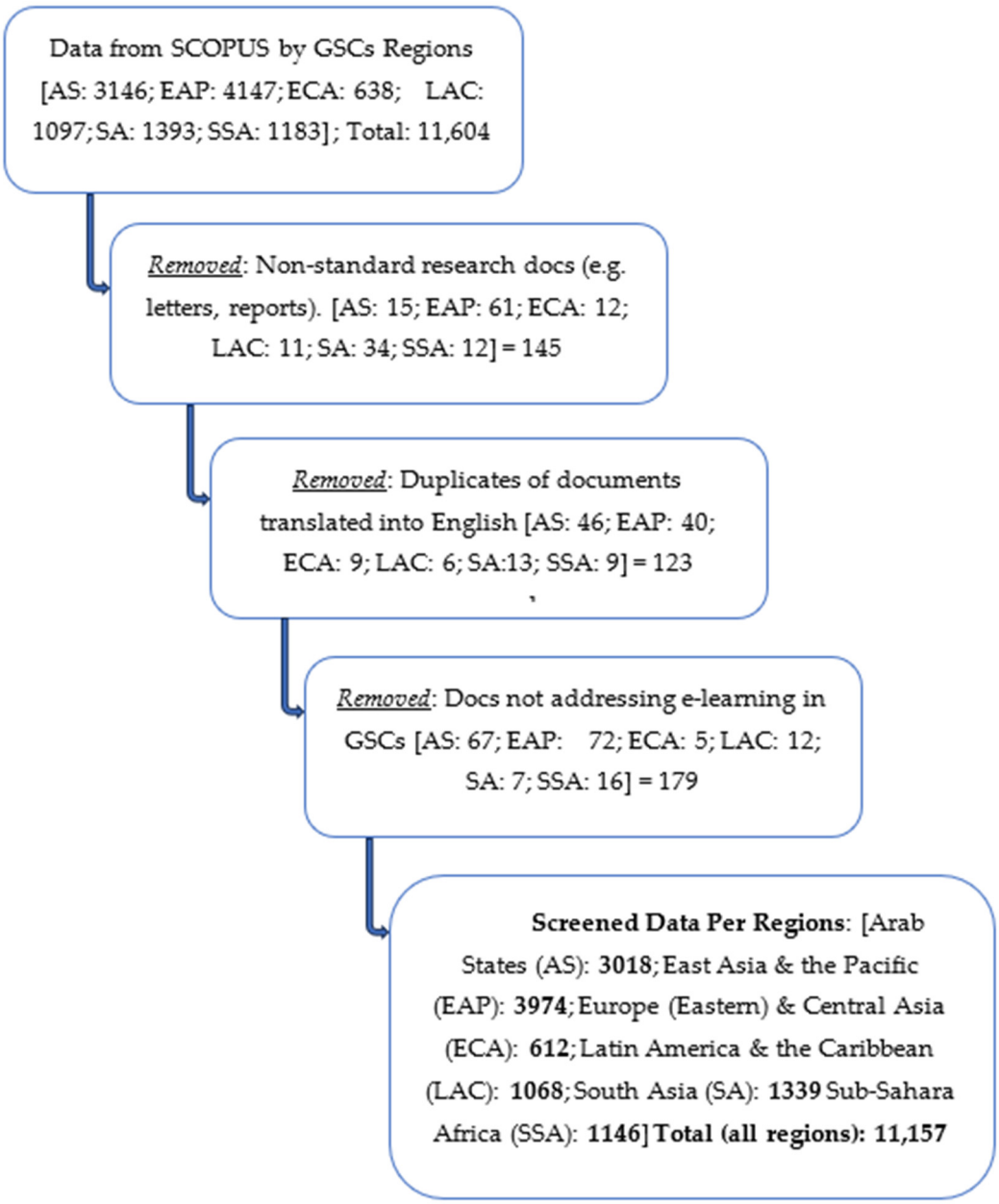

Figure 1. Data filtering, screening, and selection processes.

3.4. Bibliometric Performance Analysis and Science Mapping

Bibliometric analysis involves evaluating the body of knowledge on a topic, theme, or field of study utilizing a large volume of literature published over a period [49]. Previous studies [55,56] have identified two bibliometric procedures that are relevant and adopted in our analysis, namely, performance analysis and science mapping, as explained below:

- Bibliometric performance evaluation focuses on an empirical analysis of the SLPs, trends, and impacts. The outputs highlight the research landscape of a field and can identify the areas requiring future studies. The performance evaluation can include citation impact analysis, keyword frequency, and documents productivity and effectiveness by authors, sources, institutions, and the country as units of study [56].

- Science mapping examines the conceptual, intellectual, and social structure and associations among the scientific literature and actors (authors, institutions, and country), in a specific discipline and domains, including co-authorship, co-citation, and more [54,57]. The co-authorship can be utilized as a proxy to understanding the collaborations among authors, institutions, and countries [58].

3.5. Data Analysis Tools and Techniques

The development of computer technologies and big data analytics solutions have made bibliometric analysis, science mapping, intellectual and social structure evaluation, and visualization more seamless [59]. The choice of software applications and tools to undertake a bibliometric analysis can play a crucial role in improving the accuracy and visual presentation of the results [54]. The use of visualization enhances a clear and intuitive understanding by a wider audience and diverse backgrounds, especially as multidisciplinary studies become increasingly popular [54,56,60].

After reviewing several bibliographic software, we used an open-source library named 'Bibliometrix' for bibliographic performance analysis and science mapping, complemented by JMP 15.0, for trend analysis and creating the charts and visual effects presented in this study. The open-source package was embedded in the RStudio-2022.07.2+576 environment, which requires R programming skills or similar scripting languages [57]. On the other hand, JMP 15.0 is a proprietary statistical software, part of the SAS visual analytics solution. Microsoft (MS) EXCEL 16.0, an MS office application, was also used for trends analysis, charts, and graphs. The chosen applications possess the capacity and capability to handle a large volume of data with visual analytics capabilities.

4. Results and Discussion

4.1. Sample Discription

This study uses data extracted from published documents retrieved from SCOPUS and screened. Sections 3.2 and 3.3 explain the documents' screening and selection processes. However, when adding the number of scholarships from each country/region, the publications give 11,157 (Figure 1), about 502 (5%) of which addressed e-learning issues in multiple countries/regions. The documents were published between 2000 and 2021 and appeared in 3694 sources, with 50%, 46%, and 4%, on average, appearing as conference proceedings, journals, and edited books, respectively. The high ratio of published scholarships in non-established journals can indicate potential challenges facing researchers in developing regions, causing an inability to publish in quality/established sources indexed on SCOPUS, most of which are biased towards Western languages [46]. The two exceptions were SA and ECA, which published more articles in standard journals than conference proceedings (50.1% and 55.1%, respectively). These two regions include Turkey (ECA), and Iran and India (SA) as critical players.

Regarding popular sources and citation impacts (CIs), just a fraction (<5% or 161:3694) published more than 40% of the documents and earned over 51% of the total citations. Overall, the publications addressed diverse VE issues in the 151 GSCs/LDCS classified into six regions based on the UNDP classification, as explained in Section 2. Some of the scientific literature examined e-learning in more than one developing country. For example, Akour et al. [5] examined the changing role of e-learning from a complementary instructional education method to a mandatory technique in Saudi Arabia and Jordan during the ongoing COVID-19 global health pandemic. Also, many studies about VE in GSCs came from outside the developing regions, including the UK, USA, Germany, Australia, and more. The science mapping, data analytics, and visualization produce results that highlight these relationships and help answer the research objectives identified in this study. The complete summary of the sample of SLP volume on e-learning advances in GSCs and regions, authors' documents' information, and scholarship impacts are shown in Table 4.

Table 4. Sample summary and results of SLPs in GSCs.

Performance and Impact	Summary of Analyzed Data (Aggregate and Regional Outputs)					
	AS	**EAP**	**ECA**	**LAC**	**SA**	**SSA**
Research productivity years	2000–2021	2001–2021	2001–2021	2000–2021	2000–2021	2001–2021
Number of documents (docs) * [percent of Total]	3018 [27.1%]	3974 [35.6%]	612 [5.5%]	1068 [9.6%]	1339 [12.0%]	1146 [10.3%]
Types:						
- Journal articles	1363	1719	308	522	738	534
- Book chapters	93	118	25	30	73	56
- Conference papers	1562	2137	279	516	528	556
Sources	510	1512	360	579	774	557
Authors of single-authored docs	439	568	91	113	171	225
Authors of multi-authored docs	7462	7649	1645	3406	3519	2454
Total no. of authors	7901	8217	1736	3519	3690	2679
Authors per docs	2.62	2.07	2.84	3.29	2.76	2.34
Co-authors per docs	3.2	3.06	3.31	3.66	3.3	2.85
Docs per author	0.382	0.48	0.35	0.30	0.36	0.43
Av. citations per doc	7.77	4.8	5.75	3.79	5.08	4.93
Total citation count	24,462	19,103	3519	4045	6807	3253
Docs with no citations	1067 [35.4%]	1850 [46.5%]	261 [42.6%]	479 [44.9%]	564 [42.1%]	235 [20.5]
Authors' keywords	6496	7732	1684	2681	3311	1797
Keywords plus	11,614	11,457	2583	4519	4982	2797
Collaboration index	3.09	2.42	3.44	3.72	3.17	2.84

* About 5% of the documents studied e-learning issues in multiple countries and counted for each.

4.2. Performance Bibliometrics Analysis

This section presents bibliometrics performance analysis based on several indicators, as explained in Section 3.4. Specifically, we examine the temporal trends in annual SLP growth and the impacts of the published scholarships as pointers to the advances in e-learning research in GSCs/LDCs. The analyzed results presented in Sections 4.2.1 and 4.2.2 help address the first research objective (RO1) regarding the growth and impact of scholarships production on VE advances in developing country (DC) regions. We examine the results based on the aggregate data for all GSCs and based on regions.

4.2.1. Aggregate Analysis of the Evolution and Growth of E-Learning in the Global South

Research on VE across DC regions started gaining prominence in early 2000, which coincides with the beginning of the e-learning revolution worldwide (e.g., [61,62]). Although there are traces of earlier scholarships, specifically in the AS, EAP, SA, and ECA regions [31,63], those publications do not seem to appear in ranked sources nor are they indexed in SCOPUS or used in this study.

As stated in Section 3.3, the aggregate SLPs from all regions were 10,655 based on scholarships published between 2000 and 2021. The early years in the millennium (2000 to 2004) witnessed low SLPs, with an annual average of 35 documents. The next five-year period (2005–2009) saw an astronomical yearly average increase of more than 100%, from an annual average of 35 to 209 publications (Figure 2). The SLPs continued to increase yearly until the present. However, the last three years (2019–2021) experienced the highest accelerated growth in e-learning research, producing 1507 per year, representing more than 42% of the total SLPs in GSCs within the past 21 years. More interestingly, 32% of the total SLPs (3407:10,655) occurred during the initial years of the COVID-19 pandemic (2020–2021). Also, there is a noticeable shift in the source types that published research documents on e-learning/VE in GSCs/LDCs. Compared to the pre-pandemic era when most scholarships appeared in conference proceedings, more of them are now published in standard journals during the global health crisis (52%, 67% in 2020, 2021, respectively). Figure 2 shows the complete trend in documents published between 2000 and 2021 on e-learning from all GSCs/LDCs regions.

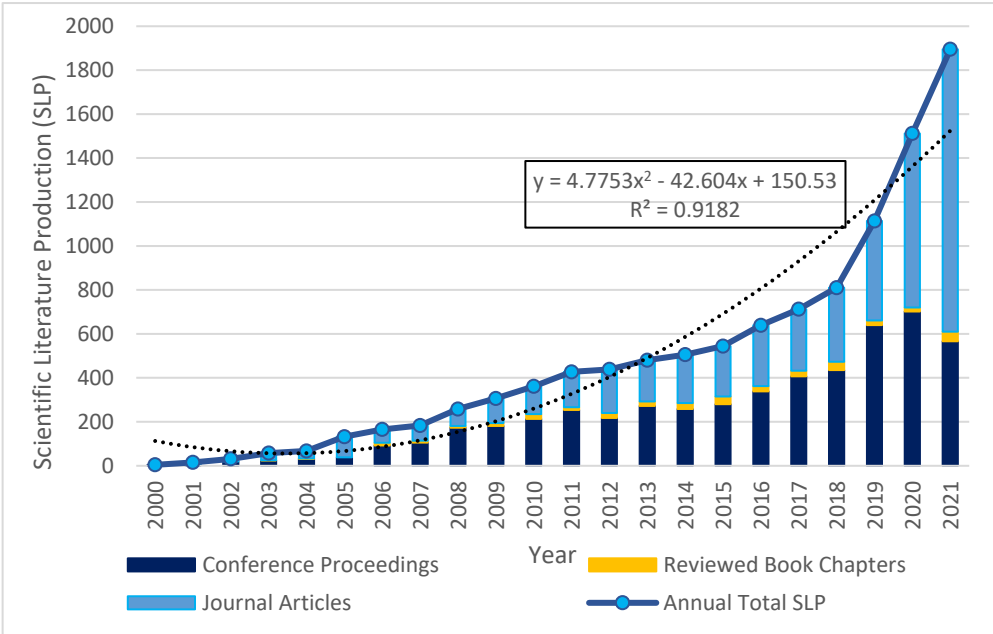

Figure 2. The evolution and growth of scientific literature production (SLP) on e-learning in developing countries/regions.

The aggregate SLP growth from the six GSC regions follows a polynomial function of degree ≥ 2. As shown in Figure 2, e-learning scholarships increased exponentially in 2000 and 2021. Also, the coefficient of determination (R^2) indicates that the function explains over 91% variation in the SLPs, pointing to a highly reliable trend line. Although SLP growth is expected into the future, the growth rate will likely slow in the post-pandemic era, bearing in mind that 32% of the SLPs resulted from the impact on education caused by the global health crisis.

4.2.2. Growth in Scientific Literature Production in the Global South

This section compares the SLPs and growth between 2000 and 2021 for the six GSC regions. The results (Figure 3) show that the six regions experienced annual increases during the period, with "EAP", "AS", and "SA", which also recorded high GDP growth in the advanced economies (e.g., China and South Korea), achieving the top three (3) spots in scholarships production (3974:35.6%; 3018:27.1%, and 1339:12%, respectively). The GSCs in "ECA" produced the fewest SLPs (612) and least growth during the period. Interestingly, the trend in SLP growth recorded by "SSA" and "LAC" followed a similar pattern. Countries in those regions (especially SSA and LAC) possess the characteristics of LDCs. Although SSA produced slightly more scholarships than LAC (1146 > 1068), the difference was insignificant. Several factors contributed to the SLP performance on VE among the six developing regions:

i. The region's total SLP is the scholarships produced by all the countries from the area. The results show that regions with more countries do not necessarily produce the most research. For example, EAP (26 countries including China, Malaysia, Thailand; Table 1) produces more than three times (3×) the SLPs output by SSA (46 countries with South Africa, Nigeria, Ghana, and others). Similarly, SA (9 countries, including India, Iran, and Pakistan) produced more than twice the research output on e-learning than ECA (17 countries, with Turkey, Georgia, and Ukraine). Thus, as articulated in Section 4.2.2 (ii) below, other factors could contribute to research productivity in each region.
ii. The availability of research funding and human capital are factors that can influence research productivity and scientific discovery, as explained in Section 2. However, the available data in this study do not provide enough information about research

funding by all 151 countries. Future studies can examine the potential impacts of the listed factors and VE development in GSCs.

iii. The overall infrastructural development of GSCs within the region and the enabling environment that enhances research and technological advances can also impact research activities and SLP.

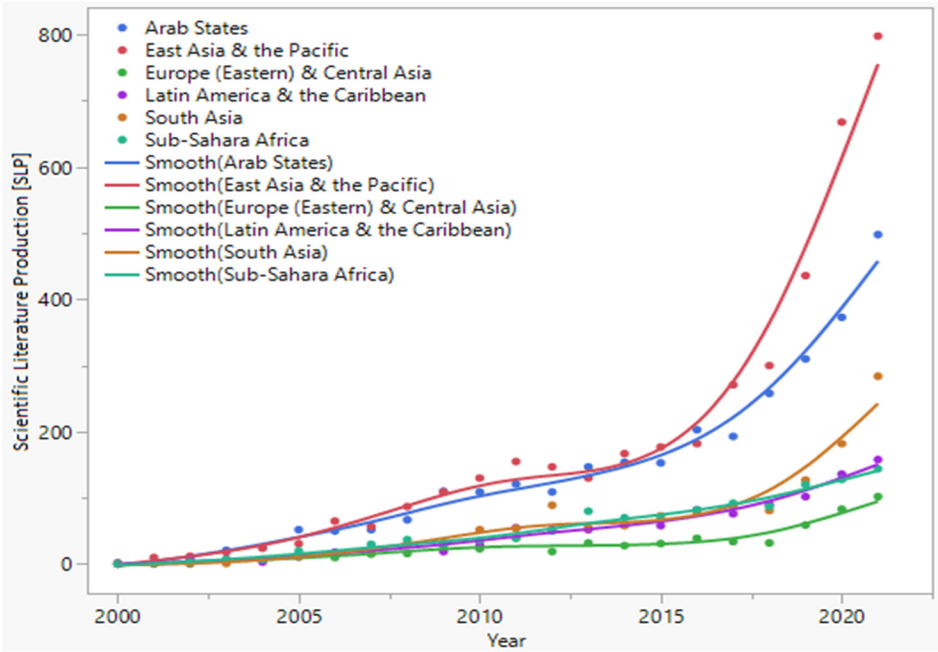

Figure 3. Comparative scientific literature production trends by developing regions.

Investigation of the relationship between these factors and increased research output is beyond the scope of this study. Reviewing the ongoing emphasis on the need for digitization of the education sector and realizing the essential nature of VE during the current global health problem caused by COVID-19, future studies can examine the impact of these factors on e-learning development in GSCs.

4.2.3. Research and Development Investment and Virtual Education Innovation

In Section 2.3, we presented the theoretical framework that explained the connection between R&D expenditure and scientific discovery, which further lead to transformation and societal advances [34]. Some studies [63,64] found that the rates of return on R&D are about 30%, and results in direct paying jobs "with average compensation 83% higher than that in the overall economy" (Breakthrough Energy, Impact of Federal R&D Investment on the US Economy, September 2020). In this section, we attempt to highlight the role of R&D expenditure on e-learning research and VE advances in the world six GSC regions.

Using the World bank data on gross domestic product (GDP) R&D expenditure, we compute the R&D expense as a percentage of GDP and present the output in Figure 4. Although the result covers the period prior to 2000, the focus of this study is 2000 to 2021. The GDP for AS, LAC, ECA, SA, and SSA were all significantly lower than that of the EAP region (Figure 4). The percentage of GDP dedicated to R&D expenditure (R&D % GDP) varies across the six GSC regions over time. We preferred to present the results in regions given the large number of countries involved in our study. Different nations allocate different proportions of their GDP based on priorities. The EAP records the highest GDP and percentage of GDP for R&D for the entire period 2002 to 2021, which is significantly higher than the other five regions. The EAP region allocated between 0.7% to 2.4% of its GDP to R&D expenditure between 2001 and 2021. All the other regions allocated less than 1% for R&D purposes, while there were no data for the AS and SSA regions (Figure 4). For

the EAP region, it does follow that the astronomical upward trend in R&D expenditure also lead to an exponential growth in the SLP over the period (Figure 3).

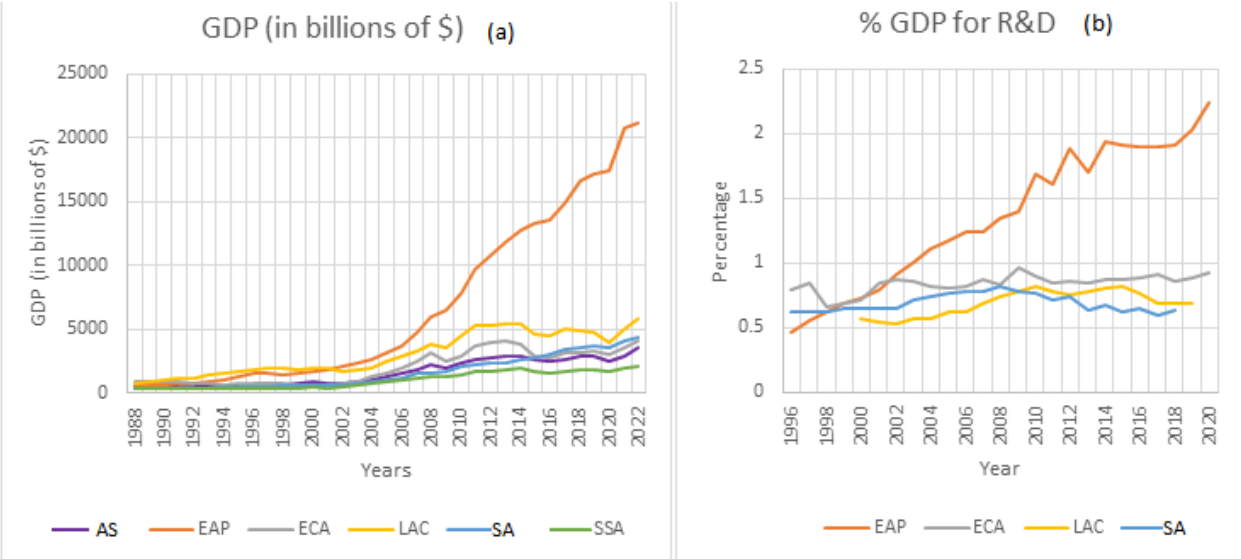

Figure 4. (**a**) Growth in GDP among GSCs, 1998–2021 [52]; (**b**) growth in R&D expenditures as % of the GDP among GSCs/Regions, 1996–2020 [53]. *Data unavailable for AS and SSA regions*.

However, the research output is not only a function of the R&D investments but also depends on factors such as the quality of research institutions, collaboration between academia and industry, the regulatory environment, and the overall innovation ecosystem of a country.

The results of this study should provide an incentive for governments of GSCs/LDCs to prioritize investments in scientific research to boost capability and productivity and enhance sustainable economic development [65,66]. The strong correlation between science and technology development and economic development is well documented [67,68]. The textbook examples of the positive impact of investment in science, technology, and infrastructure on the economic development of nations are South Korea and Israel, as gleaned from The World Bank national account data and Statista and shown in Figure 4a,b. The well-known Taiwan Miracle, in which the country's GNP and productivity grew by hundreds of percentages by the middle of the 20th century, further supports this strategy. Although much of Taiwan's growth has been attributed to government protectionism, the impact of its investments in educational and technological infrastructures is well documented. It is therefore not surprising that the countries that invest in R&D and building adequate of human capacity also produce more SLPs and impacts. Comparatively, these countries also seem to make better relative progress in VE implementation and adoption [69].

4.3. Comparative Analysis of E-Learning Research and Development Activities and Impacts GSCs

4.3.1. Research and Development Investment and Virtual Education Innovation

To undertake a comparative evaluation of R&D activities among the GSCs, we employed several units of analyses, including SLP, local research activities, and collaborations with researchers in other regions on VE research. We also examine the regional hotspots (influential and productive countries in VE research) and the impact of scholarships on e-learning literature in GSCs. These results address the second research objective (RO2).

The analysis of countries' VE research productivity and impacts employs a Bibliometrix open-source software package embedded in the R-Studio programming environment. We exported the SCOPUS data as text file(s) onto R-Studio. The evaluation in this section focuses on documents with high citation impacts. According to Cobo et al. [54], citation

count is an acceptable way to determine the impact and influence of published works. For each region, we selected the documents and citations by country. A country with at least one cited document had an equal chance of being included. However, only the top ten developing countries within a region are listed by name, otherwise they are grouped and labeled as "others". Other GSCs outside each region, and countries in the global north, also produced many scholarships about e-learning activities in several GSCs. For example, research institutions in the USA, UK, Australia, Canada, and others published significant e-learning research about GSCs either directly or through local collaboration (which should be encouraged). All GSCs benefited from such collaborations, especially in citation impacts.

This section evaluates the total SLP for each country and region in two aspects, namely, 'Multiple Country Publications' (MCP) and 'Single Country Publications' (SCPs [70,71]. MCP are publications with collaborators or co-authors across many countries. An example is Frehywot et al. [18], which investigated "e-learning development in low- and middle-income countries". The article was co-authored by nine researchers (including the corresponding author) from the global north and one co-author from the SSA region. On the other hand, SCPs are publications with collaborators or co-authors within the same country (e.g., [8], in this case, the two collaborators or co-authors were domiciled at research institutions in the global north, studying VE/e-learning development in the GSCs). In both cases, the corresponding authors were domiciled in the global north.

The two categories were identified in R-Bibliometrix open-source software package [57]. The stratification was essential in helping to map the collaborations among authors, institutional affiliations, and countries. It also highlighted GSCs' reliance on foreign researchers to solve local e-learning problems. For example, the MCP/SLP analysis helped to identify that only 49% of high-impact scholarships had a corresponding author from the sampled developing countries, while the balance (51%) had corresponding authors from the global north countries. Table 5a–f presents the results for countries in the six GSC regions, while Sections 4.3.3–4.3.8 provide more insights into the results in each region. Each country's and region's SLP = SUM = SCP + MCP is shown in Table 5a–f below.

Table 5. (a–f): Virtual education research productivity and citation impacts (CI) by developing countries.

Country	SCP	MCP	SUM	CI	CI%
(a) Arab States [AS]					
Saudi Arabia	193	47	240	1471	7.24
Jordan	109	25	134	726	3.58
Egypt	55	27	82	467	2.30
Bahrain	45	14	59	117	0.58
Morocco	47	7	54	164	0.81
Oman	30	22	52	385	1.90
Kuwait	40	4	44	302	1.49
Iraq	37	7	44	112	0.55
Qatar	22	8	30	167	0.82
Tunisia	23	6	29	100	0.49
Other AS (2)	24	10	34	155	0.76
Non-AS GSCs (10)	436	106	542	3932	19.37
Non-GSCs (25)	779	244	1023	12,206	60.12
Totals	1840	527	2367	20,304	100

Table 5. *Cont.*

Country	SCP	MCP	SUM	CI	CI%
(b) East Asia and the Pacific [EAP]					
China	791	126	917	3193	18.85
Malaysia	495	79	574	2848	16.81
Indonesia	494	43	537	1073	6.33
Korea	238	50	288	3343	19.73
Thailand	179	16	195	676	3.99
Singapore	88	20	108	1148	6.78
Philippines	97	8	105	329	1.94
Brunei	0	11	11	81	0.48
Mongolia	5	1	6	13	0.08
Fiji	3	1	4	41	0.24
Other EAP (1)	2	0	2	12	0.07
Non-EAP GSCs (17)	71	29	100	532	3.14
Non-GSCs (22)	234	165	399	3653	21.56
Totals	2697	549	3246	16,942	100
(c) Europe (Eastern) and Central Asia [ECA]					
Turkey	147	14	161	1560	50.52
Ukraine	63	7	70	305	9.88
Serbia	28	9	37	168	5.44
Kazakhstan	22	6	28	71	2.30
Bosnia	2	3	5	6	0.19
Uzbekistan	5	0	5	6	0.19
Albania	4	0	4	1	0.03
Montenegro	3	1	4	15	0.49
Kyrgyzstan	2	1	3	3	0.10
Azerbaijan	2	0	2	1	0.03
Other ECA (4)	6	2	8	4	0.13
Non-ECA GSCs (7)	10	5	15	244	7.90
Non-GSCs (28)	81	54	135	704	22.80
Totals	375	102	477	3088	100
(d) Latin America and the Caribbean [LAC]					
Brazil	198	32	230	639	17.24
Mexico	79	21	100	421	11.36
Colombia	81	13	94	215	5.80
Chile	37	23	60	470	12.68
Ecuador	30	25	55	99	2.67
Peru	30	5	35	18	0.49
Costa Rica	21	3	24	32	0.86
Argentina	17	3	20	46	1.24
Cuba	8	2	10	43	1.16
Uruguay	4	6	10	27	0.73
Other LAC (11)	24	13	37	61	1.65
Non-LAC-GSCs (9)	9	6	15	231	6.23
Non-GSCs (20)	94	91	185	1404	37.88
Total	632	243	875	3706	100

Table 5. *Cont.*

Country	SCP	MCP	SUM	CI	CI%
(e) South Asia [SA]					
India	430	43	473	1712	28.29
Iran	138	12	150	1531	25.30
Pakistan	76	18	94	584	9.65
Bangladesh	40	8	48	176	2.91
Sri Lanka	39	6	45	86	1.42
Nepal	12	4	16	30	0.50
Afghanistan	1	4	5	15	0.25
Bhutan	3	1	4	12	0.20
Other SA (0)	0	0	0	0	-
Non-SA-GSCs (15)	46	41	87	611	10.10
Non-GSCs (25)	91	88	179	1294	21.38
Total	876	225	1101	6051	100
(f) Sub-Sahara Africa [SSA]					
South Africa	298	30	328	1337	29.74
Nigeria	94	13	107	418	9.30
Ghana	30	7	37	143	3.18
Kenya	23	8	31	238	5.29
Tanzania	21	7	28	160	3.56
Botswana	23	3	26	185	4.12
Mauritius	17	4	21	28	0.62
Uganda	13	6	19	53	1.18
Senegal	14	3	17	21	0.47
Zimbabwe	7	4	11	26	0.58
Other SSA (10)	28	14	42	220	4.89
Non-SSA-GSCs (9)	15	15	30	108	2.40
Non-GSCs (21)	120	100	220	1558	34.66
Total	703	214	917	4495	100

SCP (single country publications); MCP (multiple country publications); SLP (total scientific literature publications); SUM = SLP = SCP + MCP; CI (citation impact).

4.3.2. Tracking SLP Origin and the Associated Citation Impact

This section tracks and examines where the e-learning research and publication in the GSCs' regions has originated from based on authors' institutions and country affiliation. The results were generated from the R-Bibliometrix application discussed in the earlier section. The results help to highlight a country's self-reliance or dependence level on other GSCs or the global north for e-learning R&D. This addresses the third research question (RO3). For each region, we grouped the SLP into four (4) categories (POi; i = 1. . .4) and the associated earned citations (COi: i = 1. . .4), where 1 = dominant GSCs (top 10 most productive countries), 2 = non-dominant GSCs in each region, 3 = other GSCs regions, 4 = global north countries or non-GSCs (this applies to research activities and publications on e-learning activities in the GSCs carried out by academics and researchers domiciled in the global north (e.g., [8,18]). Figure 5 presents the results of the publications and citations tracking for the six GSCs regions.

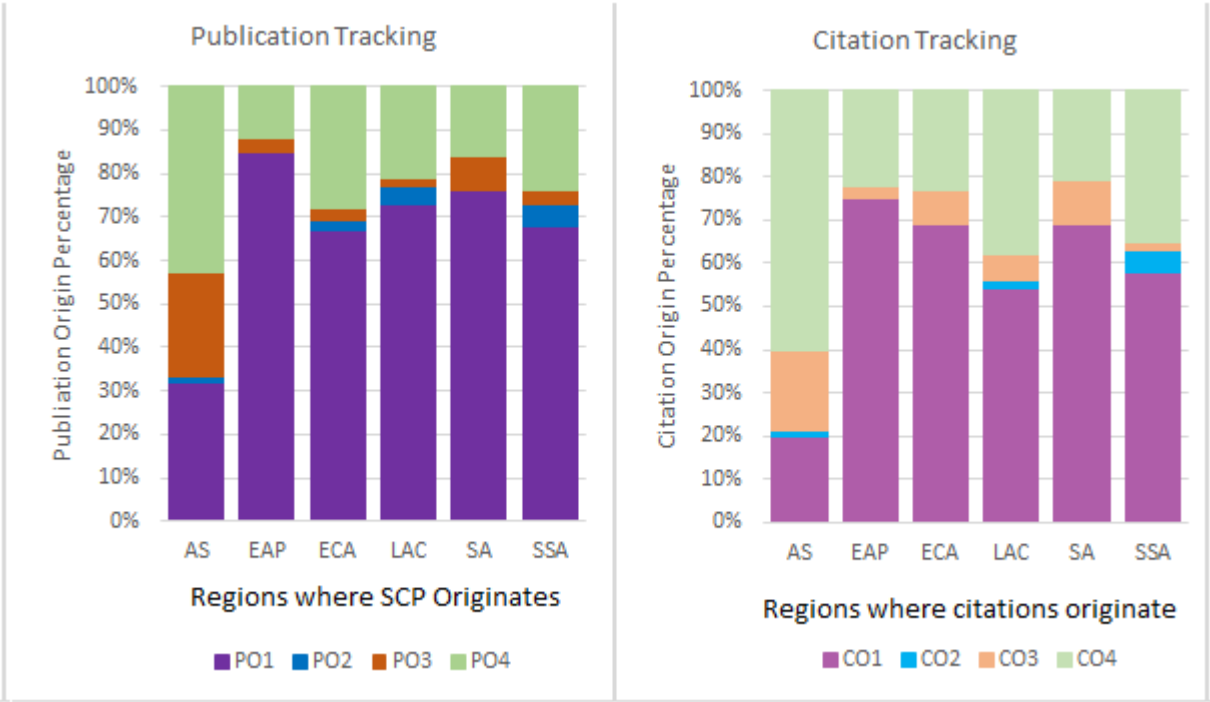

Figure 5. Tracking VE/e-learning research productivity and citation impacts for GSC regions. (POi, COi, i = 1. . .4) PO = Publication Origin; CO = Citation Origin; 1: dominant GSC within a specific region; 2: non-dominant GSCs/LDCs contributions within a specific region; 3: Other GSC regions; 4: global north countries.

4.3.3. Arab States (AS)

The Arab States (AS) region with 20 countries had 3018 SLPs on e-learning, of which 2367 (78.4%) meet the high-impact criteria. However, only 33.9% (802) of the high-impact SLPs were authored by scholars within countries in the AS region, with the top three most productive countries being Saudi Arabia, Jordan, and Egypt (240, 134, and 82, respectively: Table 5a). While 43.2% were produced from within global north countries (mostly USA, UK, Australia, and others), the remaining 22.9% originated from other GSCs (led by China, Malaysia, Singapore, and others). Also, the MCP by researchers in AS were well below the average across other GSCs (33.6% < 49%). And, while the region produces the second highest SLPs, most of the publications came from non-AS areas, including (66.1%) of high-impact e-learning scholarships. As shown in Figure 5, the publications produced locally in AS countries also earned the lowest citations compared to all the countries in other regions. Finally, although the area recorded the highest citation impacts (37.2%), the documents that made the most impact (60.1%) were authored by researchers in Western nations that investigated e-learning problems in the Arab States.

4.3.4. East Asia and the Pacific (EAP)

The bibliometric performance of the 26 member countries of the EAP region is remarkable, with the top three leading countries being China, Malaysia, and Indonesia (Table 5b). As a region with some of the most developed GSCs, including China, The Republic of Korea, Indonesia, and the Philippines, it produces the highest SLPs (3974), almost three times that of other four of the six developing regions. Also, EAP authored the most impactful scholarships (3246) compared to the other regions, with 2747 (75.69%) created within eleven EAP countries. Also, the publications initiated by countries within the EAP region earned the most citations (12,757:75.3%), as shown in Figure 5. EAP also recorded the highest MCP by researchers, well above average productivity across the regions (64.7% > 49%). Further, the EAP region also had the fewest SLPs published by other GSCs (100 or 3.08%) and the global north, including the USA and UK, which were negligible (399:12.29%) and earned

3653 (21.56%) citations, indicating a more autonomous region, creating local solutions for e-learning development.

4.3.5. Europe [Eastern] and Central Asia (ECA)

The ECA region that includes Turkey and Ukraine is relatively more developed than countries in the Sub-Sahara Africa, and Latin America and the Caribbean regions. The region's total SLPs are 612, with 78% classified as high impact. Despite the low SLPs, most documents are authored/co-authored locally (68.6%). In comparison, just a fraction (3.1%) come from authors in other DSCs and 28.3% come from Western research institutions (Table 5c), with mostly Western nations, including the USA, UK, and others, addressing VE in ECA. However, the MCP's related documents were fewer than the average across regions (43% < 49%), indicating high collaboration with other nations to solve local e-learning needs. ECA also shows similar signs of citation impact as EAP, with high citations (69.3%) earned on the scholarships created by researchers within countries in the region (Figure 5).

4.3.6. Latin America and the Caribbean (LAC)

The LAC region has 33 independent states, including Brazil, Mexico, and Argentina, among others, as detailed in Table 1. Some countries in this region also double as emerging markets, for example, Brazil. It is not surprising that Brazil is also leading the way as the most productive in e-learning research, with the most SLPs and greatest citation impact in this region. Table 5d presents the complete list of the countries with high-impact VE literature. The region has 1068 total SLPs, with 82% classified as high impact and the majority (77.1%) produced within the region. The documents with corresponding authors (MCP) domiciled within the region is higher than average (60.1% > 49%), indicating fewer external collaborations with other nations to solve local e-learning problems. LAC had the least number of documents (15 or 1.7%) created from other GSCs including China, Turkey, Philippines, and a few others, while only 21.1% (185) of the scholarships came from the global north, with 1404 (37.88%) citations led by the USA, Spain, UK, and others (Table 5d). Also, the most cited papers (55.9%) came from articles published by researchers in the region, which was higher than average (Figure 5).

4.3.7. South Asia (SA)

South Asia (SA) has the fewest member states (9), including India, Iran, Pakistan, and others. SA has a total SLP of 1339, with 82.2% classified as high impact. More than 75% of the documents came from LAC and earned 4146 (68.52%) citations. The MCP's related documents were fewer than the average (42.7% < 49%), indicating that countries in the region maintained high collaboration with other nations to solve their needs. Publications from other GSCs led by China, Malaysia, and Saudi Arabia were negligible (87 or 7.9%), earning 611 (10.1%) citations, while SLPs from non-GSCs were 179 (16.26%) and received 1294 (21.38%) citations, led by the USA, Sweden, UK, and others (Table 5e and Figure 5).

4.3.8. Sub-Sahara Africa (SSA)

The SSA region has the most member states (46) and produced 1146 e-learning SLPs, with 80% considered to be high impact. The high performers in scholarship productivity and citation impact were South Africa, Nigeria, and Ghana among sixteen other countries. Table 5f presents the complete list of the countries with high-impact VE literature. Interestingly, a majority (72.7% or 667) of the high-impact scholarships come from the region. The number of documents with corresponding authors (MCP) domiciled in the region is slightly lower than the GSCs/LDCs average (46.3% < 49%), indicating average external collaborations with other nations to solve local e-learning problems. A negligible number of documents (30 or 3.27%) were published by researchers in other DSCs, including Malaysia, China, and India, while 24% (220) came from the global north countries, earning 1558 (34.66%) citations, led by the USA, UK, and Finland (Table 5f; Figure 5).

4.4. Increased Research and Development Activities in Response to the COVID-19 Pandemic

The first two years of the COVID-19 pandemic (2020–2021) brought to light the vulnerabilities of the brick-and-mortar educational system and the importance of having multiple delivery repertoires, including e-learning, as part of every country's educational delivery toolbox. This section, therefore, evaluates the unusual response through increased research activities to address e-learning implementation and adoption challenges in GSCs.

As the pandemic spread widely, the government ordered the closure of face-to-face business activities, including schools, to limit the spread of the COVID-19 pandemic. The reality is that e-learning or VE suddenly became the only means to continue learning while the closure of the traditional schools lasted amidst challenges [72–74]. The sudden increase in SLPs in the developing regions indicates the "fire brigade" approach to addressing the e-learning problems left unattended in the previous years [8]. Increased funding to the educational sector by different levels of government in many countries enabled learning institutions to address the challenges created by the pandemic as learning and instruction moved to the virtual space [2,72,74].

4.5. Digital Divides among Developing Countries and Regions

In Section 2.2, we discussed the different factors that contribute to the digital divides among the developing regions in this study. In the final research objective (RO4), we evaluate the digital divides among the six GSCs regions. We examine the factors constituting each region's prevailing circumstances that can hinder or enhance e-learning implementation, deployment, use, and change management.

To address our final research objective (RO4) of evaluating potential digital divides among DC regions, we investigate region-specific circumstances, the issues common to the whole region and their possible impact on SLPs and development. Most scientific studies that examine e-learning advances in developing regions often assume that all GSCs have similar characteristics and prevailing circumstances, without paying adequate attention to the diversity, disparity in national income levels and GDP, and other peculiar conditions that prevail across these vast areas that make up 75% of the world population.

Among the six global south regions, the AS depend the most on the global north to undertake e-learning research in their countries/regions. About 42.3% of e-learning research and 60% of the total citations on publications about the AS region come from studies conducted by research institutions in Western countries and other GSCs. Saudi Arabia, Jordan, and Egypt are the 3 most prominent of the 20 countries that publish the most documents within the ASs region. The remaining four (4) regions are more self-reliant, led by EAP and SA, with 85% and 76% of e-learning research conducted within their territory, respectively. Further, EAP has the most dominant productive countries, led by China, Malaysia, and Indonesia, indicating little or no disparity or digital divide among countries in East Asia and the Pacific region, at least in terms of VE research and publications. Similarly, all countries in South Asia also achieved some dominant productive performance among neighboring countries in the region, led by India, Iran, and Pakistan (Figure 5 and Table 5). However, there is a remarkable difference between the two regions, with a more robust performance by EAP than SA.

ECA, LAC, and SSA share similar characteristics with some dominant countries, while several other countries in the region are less productive. For example, SSA has fewer countries prominent in e-learning SLP than all the other regions (10 out of 47), led by South Africa, Nigeria, Ghana, and seven (7) others. The results of the earned citations tracking follow a similar trend.

5. Conclusions and Policy Implications

This study aimed to evaluate VE and e-learning technology advances and the digital divide among 151 countries categorized into six regions in the global south [19]. Four research objectives have been accomplished in this article.

In the first research objective (RO1), we analyzed e-learning research productivity trends among the world's GSCs and regions based on SLPs, covering the period 2000 and 2021. Using World Bank data on gross domestic product (GDP) and R&D expenditure in the same period, we determined the R&D expenditure GDP percentage for each region (Figure 5). Also, the quantitative bibliometric performance analysis highlights interesting results, showing a positive relationship between the R&D expenditure trends and the annual e-learning SLPs. This outcome is evident in the case of EAP, where an astronomical growth in R&D investment yielded an exponential increase in SLPs between 2015 and 2021 (Figures 3 and 4). However, the R&D expenditures for the other regions remained flat most of the years before the outbreak of COVID-19, when the increased educational research funding during the two years of the global pandemic (2020/2021) also resulted in an astronomical increase in SLPs, with a 42% increase in e-learning research and publications. This result corresponds with the outcomes in previous studies [39,63].

As shown in our study, there is a connection between R&D expenditure and SLPs, with institutions that have a stronger research track record securing more R&D dollars and disseminating their results in SLPs more than those that do not [38–41,75]. And, as has been established in the literature, higher R&D expenditure is correlated with economic development. R&D funding is not a one-off, but a strategic decision made by governments in developed economies to improve their educational infrastructure and economies. The governments of LDCs can learn from this proven strategy used by their counterparts in developed countries and commit a portion of their budget to R&D expenditures for educational institutions and infrastructures. Failure to make this commitment could deem LDCs perpetually under-developed and ill-equipped to deal with future epidemics or coming pandemics, and dependent on the largess of developed countries for their VE and educational technologies and survival.

In the second research objective (RO2), we evaluated and compared the VE R&D activities, publication hotspots, and citation impacts across all countries in the six regions from 2000 to 2021. The result identifies the dominant countries in each region regarding SLPs and citation impacts. The EAP (led by China, Malaysia, and Indonesia) and SA (with India, Iran, and Pakistan as leading countries) have all countries in the two regions contributing to e-learning research and earning citation impacts. The results highlight less-pronounced digital divides and disparities among the countries. The other four regions (AS, ECA, LAC, and SSA) showed the most disparities and digital divides, where there are a few dominant countries in each region with the most SLPs and impact, while several others contribute little or nothing, highlighting a more pronounced digital divide in e-learning advances. Table 5a–f identifies the leading countries in each region. The government and research funding agencies can identify the nations lagging well behind, initiating plans and programs to kickstart a foundation for VE takeoff while helping the leading countries progress, as e-learning is here to stay. The third research objective (RO3) tracks the SLPs and citations in each region. The result identifies that despite the high SLPs on e-learning in the ASs region, a significant proportion (over 60%) of the SLPs were authored from research institutions in Western countries, showing over-dependence on the global north for VE and digital solutions for local needs. The governments and policymakers must initiate policies and programs to boost R&D activities within the region while also encouraging international collaborations. Meanwhile, over 51% of high-citation-impact SLPs were 'MCP', mainly from non-GSCs institutions. This shows the positive impacts from GSCs' collaborations with the global north. Finally, the fourth research objective (RO4) focuses on identifying forms of digital divide among countries and regions, as presented in Section 4.5 and identified in RO1–RO3 above.

Reviewing the significant jump in SLPs due to the scramble to solve e-learning problems during the COVID-19 pandemic, especially in 2020/2021, it is crucial to sustain, if not improve, the momentum in e-learning research in the post-pandemic era. Another exciting highlight is the sudden publication sources shift that saw increased e-learning publications. For the first time in the brief history of VE research in GSCs, during the

COVID-19 most studies appeared in standard journals rather than conference proceedings pandemic. While this development is attributable to different causes, some of the reasons may point to an improved quality of SLPs, support, and increased collaborations with researchers from institutions in the global north. Interestingly, a significant proportion of the research scholarships in some GSCs originated from Western institutions, as seen in (Table 5a–f) and Figure 5 (e.g., [76,77]). The significant jump in SLPs during the COVID-19 pandemic is a step in the right direction in addressing the problems of VE in GSCs, especially in the LDCs. However, to sustain that growth, the endemic problems and digital infrastructural deficits in LDCs require immediate attention. As research shows, sustainable R&D investments by government agencies, the private sector, and institutions of higher learning are essential. Since our goals include investigating research activities and scientific literature production, scholarship streams, hotspots, and impacts as measures of e-learning development, vital infrastructure and educational institutions are the bedrock of a strong R&D culture. Grossman and Helpman [78] reported that R&D expenditure is the primary driver of growth, while other infrastructures, such as electricity, transport, security, and water, are also essential.

Further, unlike developed countries, LDCs, especially in SSA and LAC, continue to face political unrest, coups, and insurgencies between competing ideologies [79]. Such instability does not encourage the inflow of foreign capital that these countries desperately need to spur growth. Further, resources in LDCs are typically directly or indirectly controlled by governments. Thus, the governments in LDCs can provide direct allocations or create policies enabling investments in primary, secondary, and higher education, especially in Science, Technology, Engineering, and Mathematics (STEM)-related disciplines. They could also influence university leaders to require that teachers and professors are qualified for the subjects they teach. Investments in educational infrastructure can also include the following:

- equipping libraries and laboratories at schools, colleges, and universities;
- instituting a merit-based review process for rewards and advancement in rank, and sponsoring professors for degrees at research and accredited institutions in LDCs and developed countries.

Finally, and to the advantage of GSCs, especially the LDCs, VE technology is readily available in the global economy, and these countries do not need to reinvent the proverbial wheel. Also, countries within and across regions in the global south can collaborate, pool resources together, and encourage public–private partnerships to acquire the needed technologies to advance their economies, productivity, and human capital. However, GSCs must be cautious in adopting technology developed elsewhere without considering local context and unique educational demands, while also considering appropriate cultural, geographical, and economic situations [80–82]. There is a need to align technology with the objectives and purpose of the local curriculum and educational goals and to customize the technology to meet the target population's learning objectives, cultural sensitivities, and linguistic diversity. In most of the LDCs listed above, people look up to the government to provide resources to implement and access e-learning [4]. The physical and technological infrastructural resources required to implement and access the e-learning system, especially in SSA, LAC, SA, and some countries in the ASs regions, are provided by the respective governments [4,83]. Since people cannot develop essential infrastructural facilities, such as electricity, broadband Internet, fiber optics, and telecommunication resources, the government or large corporations can provide those facilities and lease them to subscribers.

We call for increased educational research funding from GSCs' governments, especially the LDCs, policymakers, and international funding agencies to support VE advancement in the global south. Further, we note that going beyond increasing research funding is required for e-learning development and increased research productivity. Human capital and efficient research institutions, among other factors, are also essential. Sponsored professional developments and training, and building collaborations among GSCs with

advanced infrastructure (e.g., the EAP region), will provide researchers at LDCs access to world-class learning resources for productive research work.

6. Limitations and Recommendations for Future Research

While this study has made significant contributions to our understanding of VLE advances and the digital divide among GSCs, it is important to acknowledge its limitations. In this study, we examined VE/e-learning research productivity trends among the GSCs and regions based on SLPs and CI, and the relationships between R&D and SLPs. However, the results focus on the research activities of a few dominant countries (top ten) in a region and, rightfully so, reviewing the pioneering attempt to study all 151 countries classified into six GSCs regions. However, the efforts and contributions of smaller countries tend to be ignored. It is crucial that future studies adopt a more inclusive approach, recognizing the value of all countries' contributions and narrowing the investigation to highlight each country's situation towards narrowing the digital divide. Your work, no matter the size of your country, is vital to the field's progress.

Further studies can also examine the digital divide in VLE and compare the advances in each global south region. The dominant countries with fully functional e-learning systems can be utilized as benchmarks in studying how successful institutions overcame the inherent challenges facing LDCs. Such individual country analyses can produce comprehensive insights and an in-depth understanding of the GSCs' problems that hinder VLE research and practice.

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Abbreviations

Acronyms	Meaning
AS	Arab States
CI	Citation Impact
CO	Citation Origin (Tracking)
DC	Developing Country
DCs	Developing Countries
EAP	East Asia and the Pacific
ECA	Europe (Eastern) and Central Asia
GSCs	Global South Countries
ICT	Information and Communication Technology
LAC	Latin America and the Caribbean
LDC	Less Developed Country
LDCs	Less Developed Countries
MCP	Multiple Country Publications
PO	Publication Origin (Tracking)

R&D	Research and Development
RO	Research Objective
SA	South Asia
SCP	Single Country Publications
SLP	Scientific Literature Publication
SSA	Sub-Sahara Africa
UNDP	United Nations Human Development Program
VE	Virtual Education
VL	Virtual Learning
VLE	Virtual Learning Environment

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