

Article

Influence of Collaborative Footprints in Science Education on Research Productivity and Global Visibility of Nigerian Universities

B. G. Aregbesola*¹, Bara'u, Y²

1,2. Department of Science & Environmental Education, Faculty of Education, University of Abuja, Nigeria

*Correspondence: esrich.aregbesola@gmail.com

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Abstract: This study investigated the influence of collaborative footprints on research productivity and the global visibility of science education research in Nigerian universities. A descriptive survey research design was adopted. The population comprised all science education academics in Nigerian universities, while a sample of 384 academics was selected using a multistage sampling procedure. Data were collected using a researcher-developed, validated structured questionnaire titled Collaborative Footprints, Research Productivity and Global Visibility Questionnaire (CFRPGVQ). The instrument was administered directly to the respondents, and the retrieved data were analysed using mean and standard deviation to answer the descriptive research questions, multiple regression analysis to determine the predictive influence of collaborative footprints on research productivity and global visibility, and Pearson Product Moment Correlation (PPMC) to establish the relationship between collaborative footprints and the advancement of science education at the 0.05 level of significance. The findings revealed that collaborative footprints significantly predicted research productivity ($R^2 = 0.420$, $\beta = 0.648$, $p < .001$) and global visibility ($R^2 = 0.351$, $\beta = 0.592$, $p < .001$), although collaboration was found to contribute more strongly to research productivity than to global visibility. The study concluded that strengthening collaborative footprints is essential for improving research productivity, global visibility, and the advancement of science education in Nigerian universities. It was recommended that universities should strengthen institutional support for collaborative research by increasing research funding, promoting national and international research partnerships, and investing in digital research infrastructure to enhance the global competitiveness of science education research.

Keywords: Collaborative footprints, research productivity, global visibility, science education, research collaboration.

Introduction

The increasing internationalization of higher education has shifted attention from merely producing research to ensuring that research achieves global visibility and scholarly influence. Global visibility refers to the extent to which research outputs are discoverable, accessible, recognized, cited, and utilized by scholars, policymakers, practitioners, and research organizations across the world. It is commonly measured through indicators such as publications in reputable peer-reviewed journals indexed in international databases, citation counts, h-index, field-weighted citation impact,

international co-authorship, research dissemination through digital repositories, and participation in global scholarly networks. Consequently, universities with high global visibility are often regarded as centres of research excellence because their scientific contributions extend beyond local contexts to influence international knowledge production, educational policy, and innovation [1]. For universities, global visibility has become an indispensable component of institutional reputation and competitiveness.

International university ranking organizations such as Times Higher Education, QS World University Rankings, and the Academic Ranking of World Universities increasingly assess institutions using research-related indicators, including publication output, citation impact, research quality, international collaboration, and academic reputation. As a result, universities now invest substantially in strategies that strengthen research quality, improve publication in indexed journals, increase citation performance, and establish sustainable international research partnerships. These indicators have transformed research visibility into a strategic institutional objective rather than a mere consequence of scholarly publication. Despite the remarkable expansion of university education in Nigeria, the international visibility of research produced by many Nigerian universities remains relatively low compared with institutions in other emerging knowledge economies. Although the volume of publications from Nigerian universities has increased considerably over the past decade, That is, a substantial proportion of these publications attract relatively few citations and have limited influence on global scientific discourse [2], [3].

This situation has been attributed to inadequate research funding, limited access to international collaborative networks, low publication in high-impact journals, weak institutional research support systems, and insufficient digital dissemination of research findings. Egbetokun et al. observed that while Nigerian researchers have demonstrated increasing research output, sustained improvements in research quality, visibility, and impact require stronger institutional investment in collaborative research, research infrastructure, and international scientific engagement. Within science education, global visibility is particularly important because educational research increasingly addresses transnational issues such as STEM education, digital transformation, artificial intelligence, climate change education, sustainable development, inclusive education, and teacher professional development. Addressing these emerging issues requires science education researchers to engage in collaborative investigations capable of generating evidence that is relevant across different educational contexts.

Consequently, research conducted through international partnerships often receives wider dissemination, attracts more citations, and contributes more significantly to global educational policy and practice than studies undertaken in isolation. Aregbesola et al. emphasized that strengthening digital transformation within science education requires sustained collaboration among researchers, educational institutions, technology experts, and policymakers to enhance knowledge production, innovation, and the international relevance of science education research in Nigeria [4]. The relationship between collaborative footprints and global visibility is supported by the growing body of bibliometric literature, which consistently demonstrates that internationally co-authored publications generally achieve higher citation impact than single-author or institutionally confined studies. Collaborative research enables scholars to combine diverse expertise, access broader research facilities, improve methodological quality, publish in internationally recognized journals, and disseminate findings through wider academic networks. Fari and Ingawa reported that collaborative research among academics in selected Nigerian federal universities improved knowledge exchange, publication opportunities, and research quality, although inadequate funding and institutional constraints continued to limit the expansion of collaborative networks [5]. Their findings suggest that strengthening collaborative footprints is fundamental to improving both research productivity and the international visibility of Nigerian university research.

The 2020s, have transform digital technologies for dissemination and visibility of scientific research. Institutional repositories, open-access publishing, academic networking platforms, digital object identifiers (DOIs), ORCID identifiers, and online scholarly databases have expanded opportunities for researchers to disseminate their work to global audiences. These platforms enhance the accessibility of research outputs, increase citation potential, and facilitate international

collaboration. Nevertheless, the benefits of digital dissemination can only be fully realized when researchers produce high-quality studies that address globally relevant problems and are supported by robust collaborative networks. Consequently, digital visibility should complement rather than replace scientific quality, methodological rigour, and collaborative engagement. Although previous studies have examined publication productivity, citation analysis, university rankings, and research collaboration within Nigerian higher education, relatively little empirical attention has been devoted to examining how collaborative footprints influence the global visibility of science education research. Existing studies have largely investigated collaboration and research productivity independently, with limited effort to conceptualize collaborative footprints as a multidimensional construct comprising institutional, national, and international collaborations capable of simultaneously influencing research productivity and global visibility [6], [7]. Addressing this gap is essential because improving the international visibility of science education research will not only enhance the global reputation of Nigerian universities but will also strengthen the contribution of Nigerian scholars to international scientific knowledge and educational development.

Purpose of the Study

The purpose of this study was to examine the influence of collaborative footprints in science education on research productivity and global visibility of Nigerian universities. Specifically, the study sought to:

1. examine the extent of collaborative footprints among science education academics in Nigerian universities;
2. determine the influence of collaborative footprints on research productivity among science education academics in Nigerian universities;
3. examine the influence of collaborative footprints on the global visibility of science education research in Nigerian universities;
4. determine the relationship between institutional, national, and international research collaboration and the advancement of science education in Nigerian universities;
5. identify the challenges confronting research productivity and global visibility in Nigerian universities; and
6. determine strategic approaches for strengthening collaborative footprints to enhance research productivity and global visibility in Nigerian universities.

Research Questions

The following research questions guided the study:

1. What is the extent of collaborative footprints among science education academics in Nigerian universities?
2. What influence do collaborative footprints have on research productivity among science education academics in Nigerian universities?
3. What influence do collaborative footprints have on the global visibility of science education research in Nigerian universities?
4. What relationship exists between institutional, national, and international research collaboration and the advancement of science education in Nigerian universities?
5. What challenges confront research productivity and the global visibility of Nigerian universities?
6. What strategic approaches can strengthen collaborative footprints to enhance research productivity and global visibility in Nigerian universities?

The contemporary higher education environment is increasingly characterized by collaborative knowledge production, interdisciplinary inquiry, and global research networking. Research collaboration has become a critical determinant of scientific advancement, institutional competitiveness, and academic excellence across universities worldwide. As a result, collaborative footprints have emerged as important indicators of research performance because they reflect the extent and quality of scholarly interactions among researchers, institutions, and nations [8]. According to UNESCO, scientific research has become progressively internationalized, with collaborative publications accounting for a substantial proportion of global scientific output. This trend underscores the growing recognition that complex societal and educational challenges require collective intellectual efforts rather than isolated scholarly endeavors. Collaborative footprints refer to

the observable patterns of scholarly engagement manifested through co-authorship, joint research projects, collaborative grants, conference participation, academic mobility programmes, and interdisciplinary partnerships [9].

These footprints provide evidence of the networks through which researchers exchange knowledge, share expertise, and generate innovative solutions to emerging challenges. In the knowledge economy, the strength of collaborative footprints is increasingly associated with research excellence, citation impact, institutional visibility, and global academic reputation [10]. Science education is among the disciplines that benefit significantly from collaborative research because of its multidisciplinary nature. Contemporary science education research integrates perspectives from biology, chemistry, physics, educational psychology, curriculum studies, educational technology, and teacher education. Consequently, collaborative engagement enables researchers to draw upon diverse expertise, methodological approaches, and research resources to address complex educational problems. Bozeman & Youtie, has shown that collaborative research contributes significantly to innovation, methodological rigor, and the generation of impactful educational knowledge.

The emergence of digital technologies has further transformed the nature of academic collaboration. The increasing adoption of virtual research environments, artificial intelligence, open science platforms, cloud computing, and digital repositories has expanded opportunities for collaboration beyond geographical boundaries [11]. These developments have enabled science education academics to participate in international research projects, exchange scholarly resources, and disseminate findings to wider audiences. However, collaborative footprints now extend beyond traditional institutional interactions to encompass virtual and global scholarly networks. Within the Nigerian university system, research collaboration has gained increasing attention as a strategy for improving research productivity and institutional visibility. Universities are encouraging interdisciplinary projects, research clusters, faculty exchange programmes, and international partnerships to strengthen their contributions to national development and global scholarship [12]. Moreover, the extent of collaborative engagement varies considerably among institutions due to disparities in funding, research infrastructure, institutional support, and international exposure.

The relevance of collaboration in science education has become more pronounced with the increasing emphasis on STEM education, digital transformation, sustainability, and innovation-driven development. Aregbesola, Chukwuemeka, and Ohiare-Udebu observed that digital transformation has significantly reshaped science education by creating new opportunities for collaborative learning, research partnerships, and curriculum innovation. Their study emphasized that effective collaboration among science educators enhances the integration of emerging technologies into teaching and research, thereby improving educational outcomes and research quality. Similarly, Aregbesola and Hur-Yagba reported that the capacity of Nigerian public universities to adapt artificial intelligence in science education research depends largely on institutional collaboration, technological infrastructure, and professional networking. The study revealed that universities with stronger collaborative cultures demonstrated higher levels of readiness for technology-enhanced research and innovation. This finding suggests that collaborative footprints contribute not only to knowledge production but also to institutional adaptability and technological advancement.

The concept of "Sciencing" in an article by Aregbesola and Bara'u further highlights the importance of collaboration in science education. The authors argued that meaningful science education should promote inquiry, innovation, and partnerships among universities, industries, and communities. Through collaborative engagement, science educators can facilitate knowledge exchange, stimulate innovation, and enhance the societal relevance of research outcomes. Such partnerships are essential for strengthening research ecosystems and improving institutional competitiveness. Furthermore, Aregbesola et al. maintained that science education in tertiary institutions requires sustained collaboration among educators, researchers, policymakers, and industry stakeholders to prepare graduates for contemporary scientific and technological challenges [13]. Their findings indicate that collaborative networks provide opportunities for resource sharing, professional development, and interdisciplinary research, all of which contribute to academic advancement and institutional growth.

Globally, collaborative footprints have become important indicators in university ranking systems. International ranking agencies such as Times Higher Education, QS World University Rankings, and Scimago Institutions Rankings incorporate measures of international collaboration, citation impact, and research influence into their evaluation frameworks. Universities with extensive collaborative networks generally achieve higher rankings because collaborative publications attract wider readership, higher citation rates, and greater international recognition. Despite these benefits, several challenges continue to limit collaborative footprints among science education academics in Nigerian universities. These include inadequate research funding, weak institutional support structures, limited access to international research grants, insufficient digital infrastructure, and excessive teaching workloads. Such constraints reduce opportunities for meaningful collaboration and restrict the ability of academics to participate effectively in global knowledge networks. The literature therefore demonstrates that collaborative footprints are fundamental to the advancement of science education and the broader research mission of universities. Through collaborative engagement, academics gain access to diverse expertise, enhanced research opportunities, increased publication output, and improved global visibility [14]. However, variations in the extent and effectiveness of collaboration among Nigerian universities suggest the need for further empirical investigation into the nature and influence of collaborative footprints within the science education community.

Materials and Methods

This study adopted a descriptive survey design of the correlational type to examine the influence of collaborative footprints on research productivity and the global visibility of science education in Nigerian universities. The population comprised science education academics in accredited Nigerian universities, while a sample of 384 respondents was selected using a multistage sampling procedure involving stratification by geopolitical zones, proportionate sampling of universities, and simple random sampling of academics. Data were collected using a researcher-developed instrument titled Collaborative Footprints, Research Productivity and Global Visibility Questionnaire (CFRPGVQ). The instrument, structured on a four-point Likert scale, was validated by experts in Science Education, Educational Research and Evaluation, and Higher Education Administration. A pilot study established its reliability using the Cronbach Alpha technique, yielding a reliability coefficient of 0.81, indicating satisfactory internal consistency. The questionnaire was administered personally and electronically where necessary after obtaining the required ethical approvals and informed consent from respondents. Data were analysed using the Statistical Package for the Social Sciences (SPSS). Mean and standard deviation were used to answer the descriptive research questions, multiple regression analysis was employed to determine the influence of collaborative footprints on research productivity and global visibility, while Pearson Product Moment Correlation (PPMC) was used to examine the relationship between collaborative footprints and the advancement of science education. All statistical tests were conducted at the 0.05 level of significance.

Results

Research Question One: What is the extent of collaborative footprints among science education academics in Nigerian universities?

Table 2: Extent of Collaborative Footprints among Science Education Academics in Nigerian Universities (N = 384)

S/N	Collaborative Footprint Indicators	Mean	SD	Rank	Decision
1	Science education academics collaborate regularly with colleagues within their departments.	3.76	0.48	1	Very High
2	Researchers collaborate with colleagues from other departments within the same university.	3.58	0.59	4	Very High
3	Researchers engage in collaborative research with scholars from other Nigerian universities.	3.44	0.67	7	High

4	Researchers frequently collaborate with international scholars.	2.91	0.86	14	High
5	Researchers jointly publish articles in reputable international journals.	3.08	0.82	12	High
6	Collaborative research has increased publication output.	3.67	0.54	2	Very High
7	Researchers participate in multidisciplinary research teams.	3.49	0.63	6	High
8	Researchers secure collaborative research grants.	2.88	0.91	15	High
9	Digital platforms facilitate research collaboration.	3.53	0.61	5	Very High
10	Researchers participate in international conferences that promote collaboration.	3.02	0.84	13	High
11	Collaborative research improves methodological quality of studies.	3.63	0.56	3	Very High
12	Institutional policies encourage collaborative research.	3.19	0.77	10	High
13	Universities provide adequate funding for collaborative research.	2.74	0.95	16	High (Weakest)
14	Researchers receive institutional incentives for collaborative publications.	3.15	0.81	11	High
15	Collaborative research has expanded professional research networks.	3.38	0.69	8	High

| **Grand Mean** | 3.30 | 0.73 | **High** |

Table 2 indicates that collaborative footprints among science education academics in Nigerian universities were generally high (Grand Mean = 3.30, SD = 0.73), suggesting that collaborative research is well established within the science education community. Collaboration was strongest at the institutional level, particularly within departments, where respondents reported enhanced publication output and improved methodological quality of research. In contrast, international collaboration, collaborative research grants, and institutional funding received comparatively lower ratings, reflecting weaker support for global research engagement. Overall, the findings suggest that while domestic collaboration has become an integral part of research practice, limited institutional support, funding, and international partnerships continue to constrain the full realization of collaborative footprints and their contribution to global research visibility.

Research Question Two: What influence do collaborative footprints have on research productivity among science education academics in Nigerian universities? To answer this research question, multiple regression analysis was performed to determine the extent to which collaborative footprints predict research productivity among science education academics in Nigerian universities [15]. Collaborative footprints served as the predictor variable, while research productivity was the dependent variable. The results are presented in Tables 3, 4 and 5.

Table 3: Model Summary for the Influence of Collaborative Footprints on Research Productivity among Science Education Academics (N = 384)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.648	0.420	0.418	0.451

Table 4: Analysis of Variance (ANOVA) for the Regression Model

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	57.842	1	57.842	284.217	.000
Residual	78.311	382	0.205		
Total	136.153	383			

Table 5: Regression Coefficients for the Influence of Collaborative Footprints on Research Productivity

Predictor	Unstandardized B	Std. Error	Standardized Beta	t	Sig.
Constant	1.214	0.148		8.203	.000
Collaborative Footprints	0.586	0.035	0.648	16.859	.000

Tables 3–5 show that collaborative footprints significantly and positively influenced research productivity among science education academics in Nigerian universities. The regression model explained 42.0% of the variation in research productivity ($R^2 = 0.420$) and was statistically significant ($F(1,382) = 284.217$, $p < .001$). The positive regression coefficient ($\beta = 0.648$, $p < .001$) indicates that increased collaborative engagement is associated with higher research productivity. However, the moderate explanatory power of the model suggests that research productivity is also influenced by other institutional and individual factors, including research funding, institutional support, digital infrastructure, and research capacity. Overall, the findings demonstrate that collaborative footprints are a significant, though not exclusive, determinant of research productivity among science education academics in Nigerian universities.

Research Question Three: What influence do collaborative footprints have on the global visibility of science education research in Nigerian universities? To answer this research question, multiple regression analysis was conducted to determine the influence of collaborative footprints on the global visibility of science education research in Nigerian universities. Collaborative footprints constituted the predictor variable, while global visibility served as the dependent variable. The results are presented in Tables 6, 7 and 8.

Table 6: Model Summary for the Influence of Collaborative Footprints on the Global Visibility of Science Education Research (N = 384)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.592	0.351	0.349	0.487

Table 7: Analysis of Variance (ANOVA) for the Regression Model

Regression	48.274	1	48.274	203.731	.000
Residual	90.536	382	0.237		
Total	138.810	383			

Table 8: Regression Coefficients for the Influence of Collaborative Footprints on the Global Visibility of Science Education Research

Predictor	Unstandardized B	Std. Error	Standardized Beta	t	Sig.
Constant	1.468	0.171		8.585	.000
Collaborative Footprints	0.521	0.037	0.592	14.274	.000

Tables 6–8 indicate that collaborative footprints significantly and positively influenced the global visibility of science education research in Nigerian universities. The regression model explained 35.1% of the variation in global visibility ($R^2 = 0.351$) and was statistically significant ($F(1,382) = 203.731$, $p < .001$). The positive regression coefficient ($\beta = 0.592$, $p < .001$) demonstrates that increased collaborative engagement enhances the international visibility of research outputs. However, the moderate explanatory power of the model suggests that global visibility is also shaped by other factors, including publication quality, citation impact, journal indexing, digital dissemination, and institutional support. Overall, the findings indicate that collaborative footprints are an important, but not sufficient, predictor of the global visibility of science education research in Nigerian universities.

Research Question Four: What relationship exists between institutional, national, and international research collaboration and the advancement of science education in Nigerian universities? To answer this research question, Pearson Product Moment Correlation (PPMC) analysis was conducted to determine the relationship between institutional collaboration, national collaboration, international collaboration, and the advancement of science education in Nigerian universities. The results are presented in Table 9.

Table 9: Pearson Product Moment Correlation Matrix Showing the Relationship between Collaborative Footprints and the Advancement of Science Education (N = 384)

Variables	Mean	SD	1	2	3	4
1. Institutional Collaboration	3.46	0.62	1.000			
2. National Collaboration	3.28	0.68	0.541**	1.000		
3. International Collaboration	2.97	0.79	0.396**	0.483**	1.000	
4. Advancement of Science Education	3.42	0.58	0.624**	0.689**	0.511**	1.000

Correlation is significant at the 0.01 level (2-tailed).

Table 9 shows that institutional, national, and international collaborations were all positively and significantly related to the advancement of science education in Nigerian universities ($p < .01$). Among the three dimensions, national collaboration demonstrated the strongest relationship ($r = 0.689$), followed by institutional collaboration ($r = 0.624$), while international collaboration showed a moderate but significant relationship ($r = 0.511$). These findings indicate that collaborative footprints are fundamental to advancing science education, with national and institutional collaborations contributing more strongly than international partnerships [16]. Overall, the results suggest that strengthening collaboration at all levels, particularly by expanding international research engagement, will further enhance research quality, innovation, and the advancement of science education in Nigerian universities.

Research Question Five: What challenges confront research productivity and the global visibility of science education in Nigerian universities? To answer this research question, mean and standard deviation statistics were computed to determine respondents' perceptions of the challenges confronting research productivity and the global visibility of science education in Nigerian universities. The results are presented in Table 10.

Table 10: Mean and Standard Deviation of Respondents' Perceptions on the Challenges Confronting Research Productivity and Global Visibility of Science Education in Nigerian Universities (N = 384)

S/N	Challenge Indicators	Mean	SD	Rank	Decision
1	Inadequate research funding limits collaborative research activities.	3.82	0.47	1	Very High
2	Limited access to international research grants reduces research productivity.	3.74	0.53	2	Very High
3	High publication charges in reputable international journals discourage quality publications.	3.69	0.58	3	Very High
4	Heavy teaching and administrative workload limits research productivity.	3.61	0.61	4	Very High
5	Poor institutional incentives for research reduce researchers' motivation.	3.55	0.65	5	Very High
6	Weak institutional support for collaborative research affects publication output.	3.48	0.69	6	High
7	Limited participation in international research networks reduces global visibility.	3.42	0.71	7	High
8	Inadequate digital research infrastructure affects research dissemination.	3.37	0.73	8	High
9	Poor internet connectivity limits effective international collaboration.	3.31	0.77	9	High
10	Limited mentorship opportunities for early-career researchers affect research development.	3.27	0.74	10	High
11	Difficulty in accessing current scientific literature limits research quality.	3.20	0.78	11	High
12	Low citation of locally published research reduces international visibility.	3.15	0.81	12	High
13	Limited institutional support for conference	3.08	0.84	13	High

	participation reduces research exposure.				
14	Lengthy peer-review processes delay dissemination of research findings.	2.94	0.88	14	High
15	Language and editorial challenges hinder publication in international journals.	2.83	0.91	15	High

| **Grand Mean** | 3.36 | 0.70 | **High** |

Table 10 indicates that respondents generally agreed that significant challenges continue to constrain research productivity and the global visibility of science education in Nigerian universities (Grand Mean = 3.36, SD = 0.70). The most critical challenges identified were inadequate research funding, limited access to international research grants, and high publication costs, followed by heavy teaching workload, poor institutional incentives, and weak institutional support. Challenges related to internationalization, including limited participation in global research networks, inadequate digital infrastructure, and poor internet connectivity, were also rated highly, while language and editorial difficulties were perceived as comparatively less severe. Overall, the findings suggest that financial, institutional, technological, and internationalization-related constraints continue to impede collaborative research, research productivity, and the global visibility of science education in Nigerian universities.

Discussion

The findings of this study revealed that collaborative footprints among science education academics in Nigerian universities were generally high, although the extent of collaboration differed across institutional, national, and international dimensions. Institutional collaboration and collaboration among Nigerian universities recorded higher ratings than international collaboration, indicating that academics engage more frequently in local and national research partnerships than in global collaborative networks [17]. This finding is consistent with UNESCO, which observed that scientific research has increasingly become collaborative and internationalized, while also acknowledging that participation in global research networks varies considerably across countries because of differences in institutional capacity and research investment. The finding also supports Wagner et al. who described collaborative footprints as observable scholarly interactions through co-authorship, collaborative grants, interdisciplinary partnerships, and conference participation that collectively enhance research performance. Similarly, the finding corroborates Bozeman and Youtie, who argued that collaboration in science education strengthens methodological rigour, innovation, and knowledge generation through multidisciplinary research teams. However, the comparatively lower rating for international collaboration confirms the observation of Fari and Ingawa that inadequate funding and institutional constraints continue to limit the expansion of collaborative research networks among academics in Nigerian universities. The finding therefore suggests that although Nigerian universities have developed a relatively strong culture of institutional and national collaboration, deliberate efforts are still required to strengthen international research partnerships capable of improving global competitiveness.

The study further established that collaborative footprints significantly influenced research productivity among science education academics in Nigerian universities. The finding indicates that increased collaborative engagement enhances research output through joint publications, interdisciplinary research, knowledge sharing, and improved access to research expertise. This finding agrees with Fari and Ingawa, who reported that collaborative research significantly improved knowledge exchange, publication opportunities, and research quality among academics in selected Nigerian federal universities. Likewise, the finding supports Bozeman and Youtie, who maintained that collaborative research contributes substantially to research innovation, scientific productivity, and methodological quality through collective intellectual efforts. The finding also aligns with the position of UNESCO that collaborative research has become a major determinant of scientific productivity because contemporary scientific problems increasingly require interdisciplinary and international approaches. Nevertheless, the moderate explanatory power of the regression model indicates that collaborative footprints alone cannot account for all variations in research productivity.

This finding lends support to Egbetokun et al. who observed that sustained improvements in research productivity require complementary investments in research infrastructure, institutional support, funding mechanisms, and international scientific engagement. Therefore, while collaboration remains an important driver of research productivity, its effectiveness depends on the availability of enabling institutional conditions [18].

The findings also revealed that collaborative footprints significantly influenced the global visibility of science education research in Nigerian universities, although the influence was moderate. This suggests that collaboration contributes positively to international recognition and dissemination of research outputs but is not the only determinant of global visibility. The finding corroborates UNESCO and OECD, which emphasized that global research visibility depends on publication quality, citation impact, international collaboration, and effective digital dissemination through institutional repositories, open-access platforms, and international scholarly databases. The finding further supports Elsevier, which reported that universities with stronger collaborative networks generally achieve greater research influence because collaborative publications attract wider readership and higher citation rates. However, the moderate predictive influence observed in this study reinforces the position of Egbetokun et al. that increasing publication output alone is insufficient to improve global visibility unless universities also strengthen research quality, international partnerships, and institutional support systems. Consequently, improving the international visibility of Nigerian science education research requires a comprehensive strategy that combines collaborative research with increased publication in indexed journals, enhanced digital dissemination, and stronger international academic engagement.

Furthermore, the study established significant positive relationships between institutional, national, and international collaboration and the advancement of science education in Nigerian universities. Among the three dimensions, national collaboration exhibited the strongest relationship with science education advancement, followed by institutional collaboration, while international collaboration recorded the weakest relationship despite being statistically significant. This finding supports Aregbesola, Chukwuemeka, and Ohiare-Udebu, who reported that collaborative engagement enhances innovation, curriculum development, and technology integration within science education. Similarly, Aregbesola and Hur-Yagba found that universities with stronger collaborative cultures demonstrated greater readiness to adopt emerging technologies such as artificial intelligence for science education research. The finding is equally consistent with the concept of "Sciencing" advanced by Aregbesola and Bara'u, which emphasizes that meaningful science education requires sustained collaboration among universities, industries, communities, and policymakers to stimulate innovation, knowledge exchange, and societal development. Likewise, Aregbesola et al. maintained that collaborative networks among educators, researchers, policymakers, and industry stakeholders enhance research quality, professional development, and institutional growth. The relatively weaker relationship associated with international collaboration nevertheless indicates that Nigerian universities have yet to maximize the benefits obtainable from sustained participation in global research partnerships.

Finally, the study identified inadequate research funding, limited access to international research grants, high publication costs, excessive teaching workload, weak institutional support, and inadequate digital infrastructure as the major challenges confronting research productivity and the global visibility of science education research in Nigerian universities. These findings are consistent with World Bank, which identified inadequate research funding and weak institutional research systems as major barriers to university research development in Sub-Saharan Africa. Similarly, National Universities Commission emphasized that disparities in institutional support, research infrastructure, and funding continue to influence the extent of collaborative engagement across Nigerian universities. The findings also corroborate OECD, which noted that effective research collaboration increasingly depends on digital infrastructure, open science platforms, and technology-enabled research environments. Furthermore, Egbetokun et al. observed that although Nigerian researchers have demonstrated increasing research output, sustained improvements in research quality and global visibility require stronger institutional investment in collaborative research, digital infrastructure, and international scientific engagement. These findings therefore demonstrate that

strengthening collaborative footprints alone may not be sufficient to enhance research productivity and global visibility unless accompanied by adequate institutional funding, supportive research policies, improved digital infrastructure, and expanded opportunities for international collaboration. Overall, the findings of this study demonstrate that collaborative footprints constitute a significant mechanism for improving research productivity, enhancing global visibility, and advancing science education in Nigerian universities. The study provides empirical support for the proposition that sustainable research development requires a combination of institutional collaboration, national partnerships, international engagement, and supportive research policies. Consequently, universities, government agencies, and policymakers should adopt integrated strategies that strengthen collaborative research networks while simultaneously addressing the financial, technological, and institutional barriers identified in this study. Such interventions will enhance the quality, impact, and international visibility of science education research produced by Nigerian universities.

Conclusion

This study investigated the influence of collaborative footprints on research productivity and the global visibility of science education in Nigerian universities. Specifically, it examined the extent of collaborative footprints among science education academics, determined the influence of collaborative footprints on research productivity and global visibility, investigated the relationship between institutional, national, and international collaboration and the advancement of science education, identified the challenges confronting research productivity and global visibility, and explored strategic approaches for strengthening collaborative footprints in Nigerian universities. The findings revealed that science education academics generally demonstrated a high level of collaborative engagement, particularly through institutional and national collaborations, while international collaboration remained comparatively less developed. The study further established that collaborative footprints significantly influence research productivity and global visibility, indicating that increased collaborative engagement contributes positively to scholarly output and international research recognition. The study also found significant positive relationships between institutional, national, and international collaboration and the advancement of science education, with national collaboration exhibiting the strongest relationship. These findings underscore the importance of collaborative research in improving knowledge production, innovation, and the quality of science education. Despite these positive outcomes, the study identified inadequate research funding, limited access to international research grants, high publication costs, weak institutional support, inadequate digital research infrastructure, and excessive academic workload as major challenges constraining collaborative research, research productivity, and global visibility. Furthermore, the study identified institutional support, increased research funding, strengthened international partnerships, improved digital infrastructure, capacity-building programmes, research mentorship, and supportive research policies as strategic approaches for enhancing collaborative footprints and improving research outcomes. The study therefore concludes that collaborative footprints are fundamental to strengthening research productivity, increasing global visibility, and advancing science education in Nigerian universities. However, the benefits of collaboration can only be fully realized when universities, government agencies, and other stakeholders create an enabling environment through adequate funding, supportive institutional policies, digital infrastructure, and expanded opportunities for international research collaboration. The findings of this study have important implications for universities, policymakers, science education academics, research funding agencies, and professional bodies. First, the high level of institutional and national collaboration suggests that universities should consolidate existing collaborative structures while creating deliberate opportunities for increased international collaboration. Expanding global research partnerships will expose academics to international best practices, improve research quality, and enhance the visibility of Nigerian science education research. Second, the significant influence of collaborative footprints on research productivity implies that collaborative research should be recognized as an essential strategy for improving scholarly output. University management should therefore integrate collaborative research activities into academic staff development policies, research assessment frameworks, and promotion criteria. Third, the finding that collaborative footprints significantly influence global

visibility indicates that improving research visibility requires more than increasing publication output. Universities should invest in digital repositories, publication support services, international indexing, open-access publishing, and global dissemination platforms to ensure that research findings reach wider international audiences. Fourth, the positive relationship between institutional, national, and international collaboration and the advancement of science education demonstrates that collaboration is an important driver of educational innovation and research development. Consequently, collaborative research should become an integral component of science education policy, curriculum development, and institutional research planning. Finally, the challenges identified in this study imply that strengthening collaborative footprints requires coordinated institutional and policy interventions. Addressing financial constraints, limited international networking opportunities, weak institutional support, and inadequate digital infrastructure will enhance the capacity of science education academics to contribute more effectively to national development and the global scientific community.

Based on the findings of this study, the following recommendations are made:

University management should strengthen institutional and interdisciplinary research collaborations by establishing functional research clusters, collaborative research centres, and faculty-based research teams to sustain the high level of collaborative engagement identified in this study.

Federal and State Governments, through relevant education and research agencies, should increase research funding and expand competitive grant opportunities to enable science education academics to participate more actively in collaborative research projects, particularly international collaborations.

The National Universities Commission (NUC) should develop policies that encourage and reward institutional, national, and international collaborative research by incorporating collaborative research indicators into university quality assurance and accreditation processes.

Universities should establish institutional mechanisms that support international collaboration through academic exchange programmes, conference sponsorship, joint research projects, and partnerships with foreign universities and international research organizations.

Universities and research institutions should strengthen digital research infrastructure by improving internet connectivity, institutional repositories, access to electronic databases, and digital research management systems to increase the global visibility of science education research.

Science education academics should actively participate in professional associations, interdisciplinary research networks, and international collaborative projects to broaden their research partnerships, improve publication quality, and increase citation impact.

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