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COMPUTER GRAPHICS EDUCATION RESEARCH REVIEW AND BIBLIOMETRIC ANALYSIS

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Abstract Educational Computer Graphics (CG) has evolved as an interdisciplinary research area. The literature is however scattered. This paper conducts a bibliometric and thematic analysis of 95 articles from 2016 to 2025. Research trends, geographical distribution, and intellectual structure are explored using mixed methods. Publication activity remains constant during the study period. Conference papers make up 60% of the literature. Most papers come from the US and New Zealand. Six major research themes are highlighted. They consist of pedagogy, e learning, automatic assessment, immersive technology, artificial intelligence, and game based learning. Traditional pedagogy continues to dominate. Artificial intelligence and VR/AR become popular after 2020. Citation impact is minimal, with 66.3% having less than five citations. Advanced technologies are studied individually. Multi-site validation and theoretical basis continue to be rare. This paper recommends multi site validation of integrated learning ecosystems via context sensitive and longitudinal studies.

Keywords: Computer graphics, education, Bibliometric analysis, Thematic synthesis, Computing pedagogy, Artificial intelligence, Information Systems, Applied Mathematics, Computational Mathematics, Big data, Data science, Machine learning, Deep learning.

AMS Mathematics Subject Classification: 97U50, 97Q70, 68U05.

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1 Introduction

CG education has become an interdisciplinary field of research. The reformation of the curriculum and advances in technologies have broadened its range. Previous works deal with modeling, rendering, animation, and computer graphics programming. New research topics include pedagogy, online education, automatic assessment, immersion, and AI-based education [1]. More stress is being laid on the development of visual reasoning skills, computational problem solving, and design abilities [2, 3]. Both pedagogical and technological issues affect the present research. More student-centered and applied approaches are considered. Technologies enhance educational techniques and learning environments. At the same time, there is no integration of pedagogy and technology in education. Most developments are assessed separately in various settings and methods [4, 5, 6]. CG pedagogies and curricula continue to dominate the research efforts. Research topics include content of the curriculum, structure of the course, and design of instruction. Courses at introductory levels concentrate mostly on rendering. Other aspects of CG such as geometric modeling, perception, and human-centered design are not as prevalent [2]. Geometric modeling needs sophisticated techniques due to the complexity of the surfaces used in engineering applications [7]. Project-based and experience-based learning is emphasized more than ever. Both methods enhance the process of engagement and learning through meaningful tasks [3]. Yet the support for curriculum innovations through large-scale and theory-based research is still scarce [6, 3]. E-learning and mobile multimedia also constitute another important field of study. Researches have been conducted about flexible delivery models and visual aids for learning. The use of multimedia and mobile technology enhances the reach of complicated spatial and engineering knowledge. Mobile CAD applications, microlearning, and computer aided models help enhance learning engagements and learning in the short run [14, 19]. Most researches however base their findings on small data sets or description of the tool used [22]. E-learning research demonstrates great promise in terms of educational validation but little evidence to prove it. The new forms of instructions are usually applied without any thorough evaluation. It is also typical for automatic testing research. The auto-grading techniques are designed to solve the problems related to many students and save teachers' time [11, 30]. Moreover, recent works also consider such aspects as formative feedback, learning journals, and sandboxes [16, 29]. However, most of the works evaluate only the performance of the developed techniques. A fourth topic that has been extensively researched involves immersive 3D, VR, and AR technologies. These technological approaches create an environment where spatial learning occurs interactively. Education in medical, anatomical, and design domains have been extensively studied [15, 17]. While usability and short term results have been considered as priorities for research, the long term effectiveness of these technologies has not been adequately validated. Multisite and longitudinal studies on educational applications of immersive learning have not yet been conducted enough [20, 22]. The literature also highlights game based learning as an important area of CG education. Digital games are used for concept instruction, project development, and collaborative learning. These methods support visual interaction, spatial reasoning, and iterative problem solving [13, 18]. Serious games are also applied in neuroanatomy and early childhood education [27, 28]. Reported benefits include higher engagement and learner motivation. However, stronger evidence for conceptual learning remains limited. Learning outcomes are often evaluated less rigorously than engagement measures. We conclude that game based learning shows strong educational value when course objectives, game design, and assessment remain closely aligned. AI has emerged as an important field of research in CG education. AI is used for graphics-based learning and engineering design systems [10]. Evaluation of AI models is also done for assessment in CG. Recent research proves that GPT 4 and GPT 4o exhibit good performance in structured tasks. Nevertheless, visual reasoning, contextual understanding, and problem-solving skills are not as reliable [4, 5]. This suggests that while AI can be beneficial for education, it cannot substitute professional teaching experience. Additional problems have emerged with respect to assessment quality, integrity, and AI literacy [23, 9, 21]. Several patterns can be identified based on the examined literature. CG education is not only limited to the traditional teaching methodology but rather includes wider use of technologies. Progressions are mostly limited to such fields as curricula development, e-learning, computerized testing, immersive learning, games, and AI. In addition, strong integration within these fields is rare. Finally, all works are based on local implementation and limited time period of evaluation. Thus, experimental proof is more abundant than long-term validation [9, 3]. Hence, we find fragmentation of the research landscape with limited integration on theoretical and cross-domain levels. Therefore, it is necessary to conduct a bibliometric and thematic review. The review will show publication trends, citation patterns, thematic trends, and gaps in research. In addition, the review will give a systematic representation of CG education research between 2016 and 2025.

2 Materials and Methods

2.1 Study design and analytical approach

This study adopts a bibliometric descriptive and thematic review approach [31]. Computer graphics education research published between 2016 and 2025 is examined. Publication trends, research themes, and technological developments are analyzed. Bibliometric analysis, thematic classification, and trend visualization are applied together. The refined dataset is evaluated through quantitative and qualitative methods. Publication patterns and thematic frequencies are first identified. The studies are then classified according to their dominant educational or technological focus. This approach provides statistical evidence and thematic interpretation. Leading themes and emerging research directions are also identified.

2.2 Thematic categorization procedure

Classification of the literature uses a keyword-based manual system. Keywords, titles, and themes of the study form the basis of categorization. Papers with common themes are put into same categories. This type of classification captures the common educational and technical themes found in the literature. There are six major themes in the literature. They include CG pedagogy and curricula, e-learning and mobile multimedia, automated grading and feedback, immersive 3D, VR, and AR training, use of AI in graphics and computing education, and gaming and playfulness. Papers that address more than one theme are categorized based on the major theme.

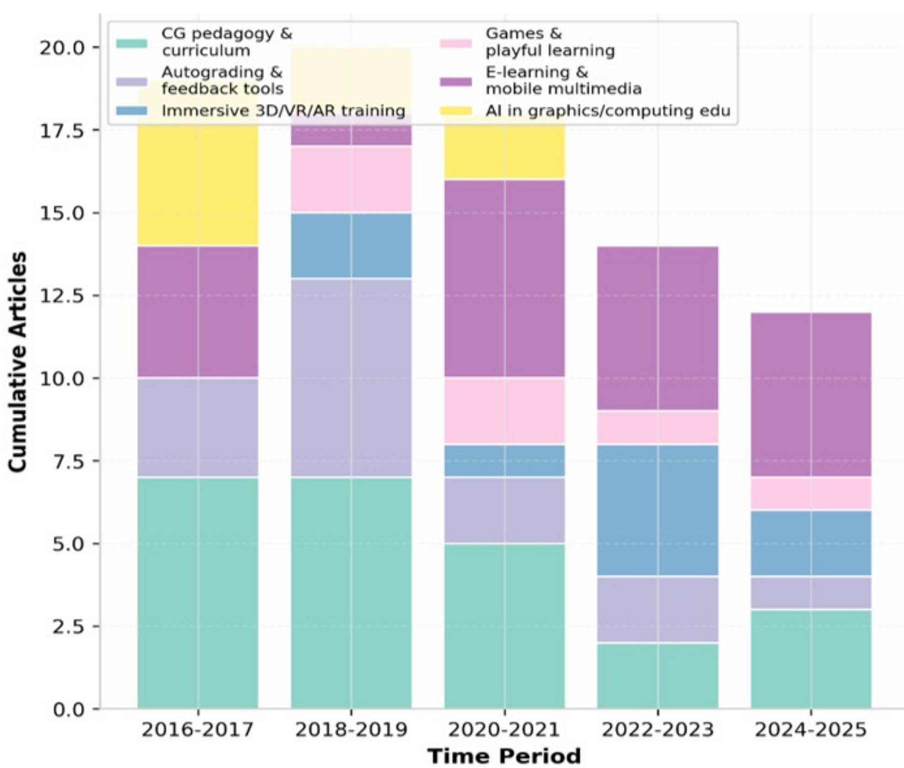

Figure 1: Research theme Evolution over time (Approximate Distribution)

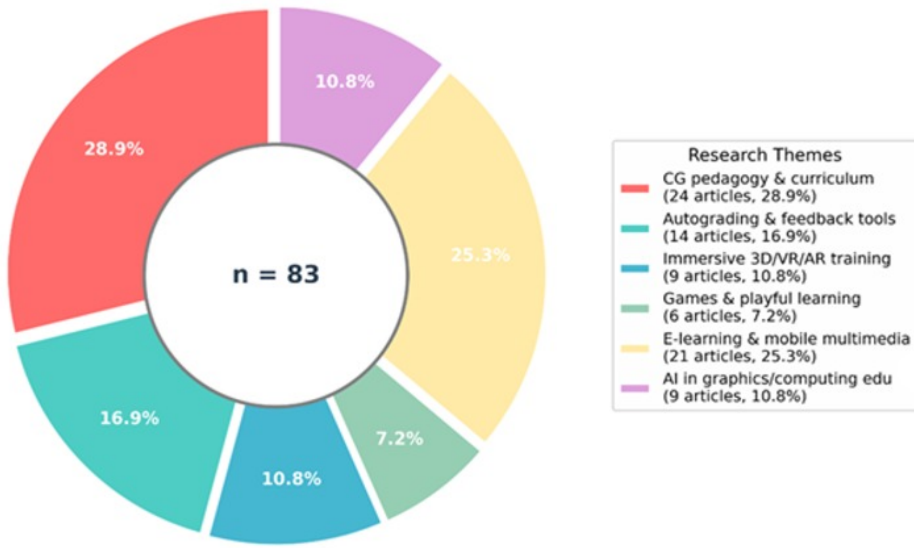

Figure 2: Distribution of Research themes (Excluding overlapping Categories)

2.3 Visualization tools and data presentation

To improve clarity and interpretation, several visualization methods are used. Different chart types are selected for specific analytical purposes. A donut chart presents the distribution of the six research themes across 83 classified studies in Figure 1. This chart allows rapid comparison of thematic proportions. A stacked timeline chart illustrates thematic changes across five time periods in Figure 2. This chart shows that pedagogy and e learning remain dominant, while AI and immersive learning receive greater attention in recent years. Ranked bar charts and simplified thematic comparison figures are also used. These visualizations support clear identification of dominant themes, emerging research areas, and long term trends. These figures have been created using digital analysis and visualization software. In this case, RStudio and Python have been utilized to organize the data, perform thematic counting, and generate charts. These software programs facilitate the creation of frequency analyses, proportions, and time-related comparisons. Additionally, the visualization software was used to polish the layout and produce the figures. In turn, regular software programs were used to format and present the figures. This methodology includes bibliometrics, thematic classification, and various types of visualizations. Consequently, the research area is depicted in a structured and understandable manner.

3 Results

As per the methodology discussed in the Materials and Methods, the bibliometric database spans from 2016 to 2025. The database comprises 95 papers from 69 sources. The annual growth rate over this ten-year period is 0%, indicating that the volume of publications has remained generally stable, without showing a clear upward or downward trend. The dataset contains 2788 cited references, reflecting the large knowledge base underlying the retrieved literature. In terms of subject descriptions, the authors provided 399 author keywords, indicating a wide thematic diversity and a relatively fragmented vocabulary across studies.

3.1 Publication trends by year

Figure 3 shows the yearly distribution of publications between 2016 and 2025. The number of publications stays at a relatively high level during the first few years. The total number of publications is increasing from 11 articles in 2016 to 13 in 2017 and 2018. There is a decrease in the number of publications to 8 in 2019. It starts to recover in 2020 with 12 articles published. The lowest number of publications is 5 in 2021. The number of publications is then recovered to 8 in 2022. It decreases slightly to 6 in 2023. The growth continues in 2024 with 8 articles and 11 in 2025. There is a slight decrease seen in the trend line.

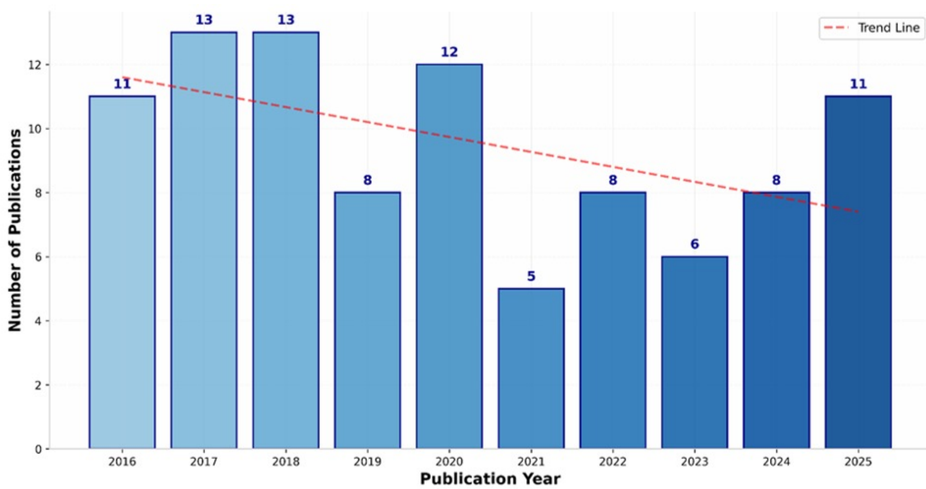

Figure 3: Computer graphics education research publications by year (2016-2025)

3.2 Document types

Figure 4 represents the distribution of publications in this dataset by document type ($N = 95$). The largest group of publications is represented by scientific papers (57 papers, 60.0%). It shows that the conferences are the most popular places for publishing the research in CG education. The second largest group is formed by the journal papers (30 papers, 31.6%). Other publication types have low numbers. The dataset includes 4 reviews (4.2%), which means there are few summary papers. There are 2 early access papers (2.1%). Editorials and hybrid classifications both have only one paper (1.1%).

3.3 Geographic distribution of publications

As illustrated in Figure 5 the 15 major contributing countries in computer graphics education research have been examined among 42 countries. The United States is on the top having 18 papers. The next is the United Kingdom followed by New Zealand each having 12 publications. The above three countries have produced a big chunk of the output and thus are in the center of influence. Japan ranks fourth having 6 publications and makes up the second category. Oman and Brazil have contributed 5 papers each. Spain, Portugal, Malaysia, India, and Germany have contributed 4 papers each. Canada, Austria, Russia, and Italy have contributed 3 papers each.

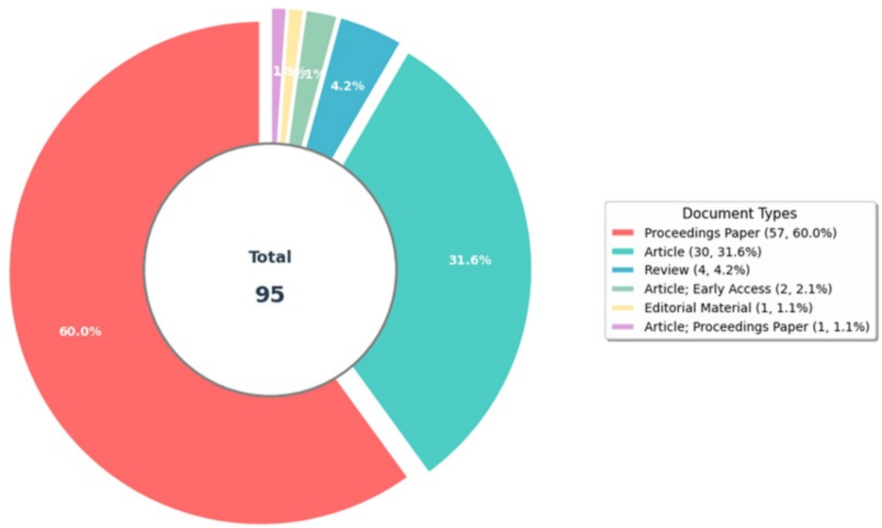

Figure 4: Distribution of Publications by document type CG education research

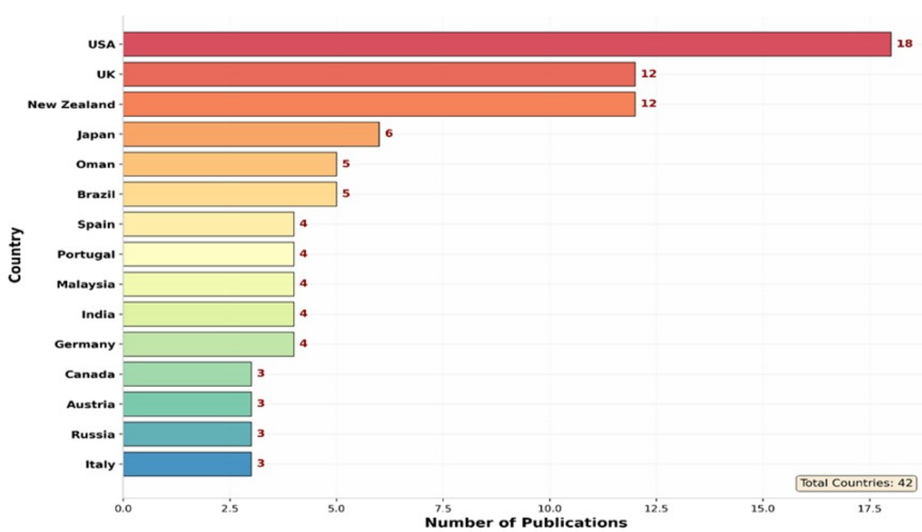

Figure 5: CG education research Top 15 countries by publication count

3.4 Citation distribution and impact profile

Figure 6 depicts the citation distribution of 95 papers and shows a clear right-skewed pattern, where most publications have low citation counts, while only a small proportion have high citation counts. More than a third of the papers are uncited (35 papers; 36.8%) and an additional 28 papers (29.5%) fall into the 1 - 4 citation range. Together, these two groups account for 66.3% of the dataset, indicating that the majority of publications have paid limited attention to citations to date. The average citation rate was observed for the 20 papers (21.1%) with 5 - 9 citations. High-impact papers are relatively rare: 7 papers (7.4%) have 10 - 19 citations and 5 papers (5.3%) fall into the 20 - 49 citation range. Notably, no paper has more than 50 citations (0%), suggesting that there are no "blockbuster" papers that have been highly cited in this dataset and time frame yet. The statistics support this interpretation: the average number of citations is 4.2, with a median of 1, suggesting that the average impact is driven up by a small number of better cited publications. The maximum number of citations is 33, and only 12 papers (12.6%) have 10 or more citations, highlighting that sustained citation pull is limited to a relatively small portion of the literature.

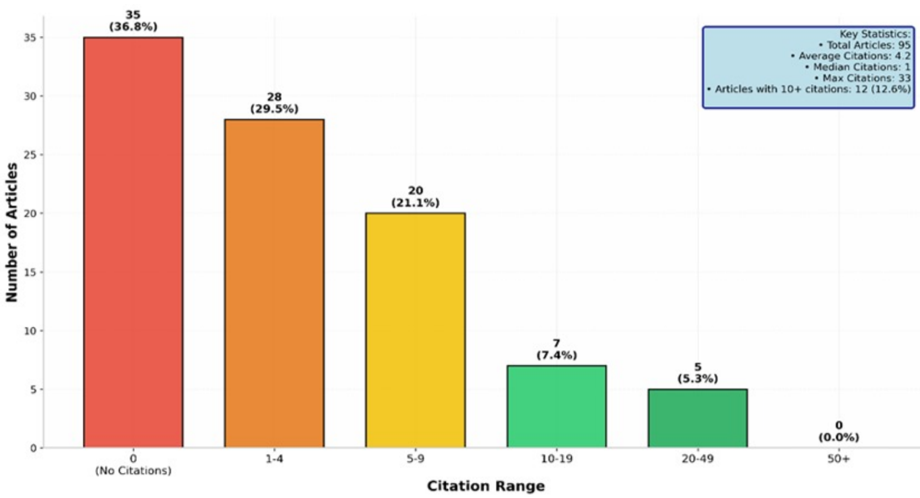

Figure 6: Distribution of Articles by citation count type CG education research

3.5 Most cited publications (top 15)

Figure 7 highlights the 15 most cited papers in the dataset and provides a clearer picture of the studies that have attracted the most scholarly attention. Among these leading papers, the number of citations ranges from 9 to 33, with an average of 16.8 citations in the top group and a maximum impact of 33 citations. The most cited contribution is "Project-Based Learning Approach for Mobile App Training¦" [24] with 33 citations, followed by "Automatic Evaluation of OpenGL Computer Graphics Task..." [18] with 30 citations. The second cluster of influential articles includes "Application of Computer-Aided Instructional Systems..." [14] (23 citations) and two studies with 22 citations: "Technologies and Tools to Support Teaching and Learning..." [27] and "Evaluating Interactive Response Supported by Technologies..." [25]. Additional well-cited works fall into a group of 19 citations [26], including titles focused on improving computer graphics teaching and learning content in introductory computer graphics. The most cited set covers the years 2017“2024, indicating that influential publications are not limited to older articles and that some recent works have begun to accumulate citations quickly. The thematic emphasis of these highly cited studies suggests that the strongest visibility of the field is related to pedagogical approaches (e.g., project-based learning), technology enhancement and assessment (e.g., automated assessment, interactive response systems), and curriculum/instructional improvement, reflecting the applied and instructional nature of computer graphics education research [1, 12, 4, 8].

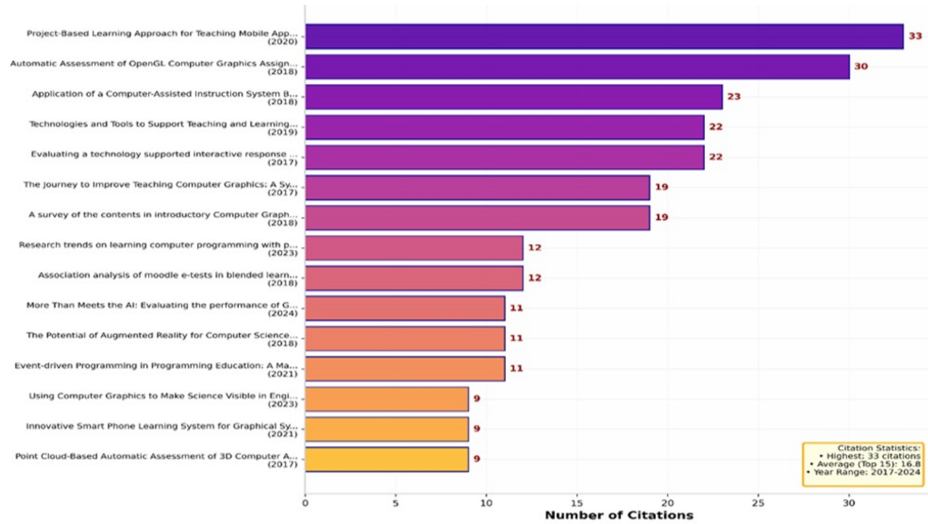

Figure 7: Top 15 most Cited Articles CG education research

3.6 Publications and citation dynamics over time

Figure 8 plots the annual number of publications (columns) against the annual total number of citations (rows) for the period 2016–2025, showing that productivity and citation impact do not change in parallel. The number of publications remains relatively moderate over the period (ranging from 5 to 13 articles per year), while the total number of citations fluctuates much more strongly, suggesting that the impact is not evenly distributed, but rather concentrated in certain years. Citation activity peaks sharply in 2018, with 13 publications and a total of 109 citations, making it the most influential year in terms of total impact. Strong citation performance is also seen in 2017 (66 citations; 13 publications) and 2020 (61 citations; 12 publications). Conversely, despite a very low number of publications for several years, the accumulation of citations is relatively low, for example, in 2022 there are 8 publications but only 14 citations, and in 2024 there are 8 publications with a similar pattern of 29 citations. Since 2021, the total number of citations remains low (26 in 2021, 14 in 2022, 33 in 2023, 29 in 2024), and in 2025, despite 11 publications, the number of citations is very low (1). This is expected, as recently published papers have typically had limited time to accumulate citations. Overall, the figure suggests that the field's impact on citations has been shaped by a small number of high-visibility cohorts (particularly around 2017–2018 and 2020), with the most recent years reflecting a citation lag effect rather than a lack of research activity.

3.7 Country – author – keyword linkages (three-field plot)

Figure 9 presents a three-way (Sankey-style) diagram linking author countries (AU_CO), top authors (AU), and merged author keywords (KW_Merged). Overall, the diagram shows how scientific output is clustered in a small set of countries and how top authors are thematically

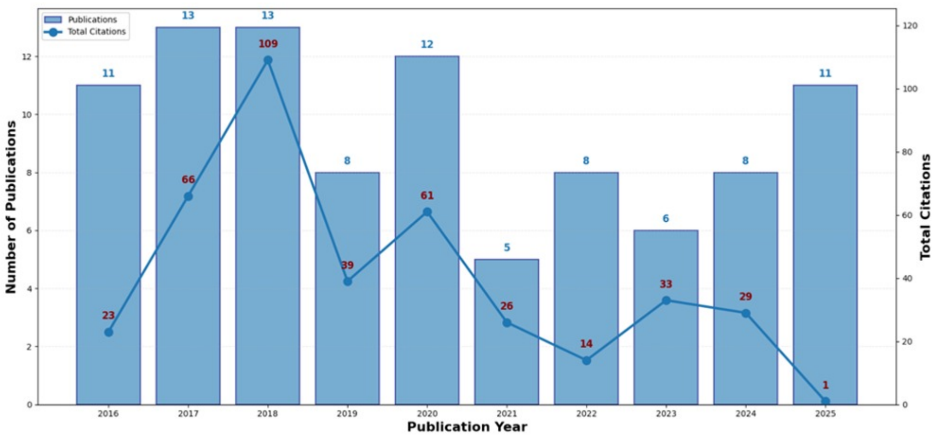

Figure 8: Publications vs Total citation by year

linked to a set of terms related to recurrent education and computer graphics. On the country side, the strongest flows come from Japan and New Zealand, followed by visible contributions from the United States, Brazil, and Kazakhstan. The thickness of these flows suggests that these countries are the main feeders of the set of authors that are frequently found in the dataset. This pattern is consistent with previous country productivity rankings, which reinforce the role of a few countries as major contributors, while others participate selectively. In the area of authorship, several names serve as important links between national contributions and thematic hubs, including Luxton-Reilly A, Wnsche BC, Franco JF, Suselo T, and other recurring authors (e.g. Hooper S, Denny P, Feng TH, Whalley J, and others shown in the 9). The distribution of links suggests that these authors repeatedly publish or are central to collaborative structures that link national outputs to dominant themes.

On the keyword side, the strongest thematic trends are computer graphics and design, followed by assessment and computational education. Additional, narrower but still visible trends relate to animation, teaching, visualization, and learning. Taken together, this suggests that leading authors in the most productive countries tend to focus on core computer graphics education topics (computer graphics/design), alongside pedagogical measurement and curriculum issues (assessment, teaching, learning) and broader computational education contexts. The three-sector diagram shows the relationships that are formed, with a limited group of countries providing the bulk of the authorship, and these authors contributing disproportionately to recurring themes focused on computer graphics education, design-oriented teaching, and assessment/evaluation.

3.8 Corresponding authors' countries and collaboration pattern (SCP vs. MCP)

Figure 10 presents the distribution of corresponding author countries and shows the differences between single country publications (SCP) and multiple country publications (MCP). This figure indicates that corresponding authorship is concentrated in a small group of countries, with most output produced as SCPs, with MCPs accounting for a smaller share in almost all countries. The United States is the leading corresponding author country, showing the highest number of papers and a predominance of single country publications, indicating a strong domestic production capacity and well-established domestic research networks. New Zealand is in second place with a large volume of corresponding authorship, again driven mainly by

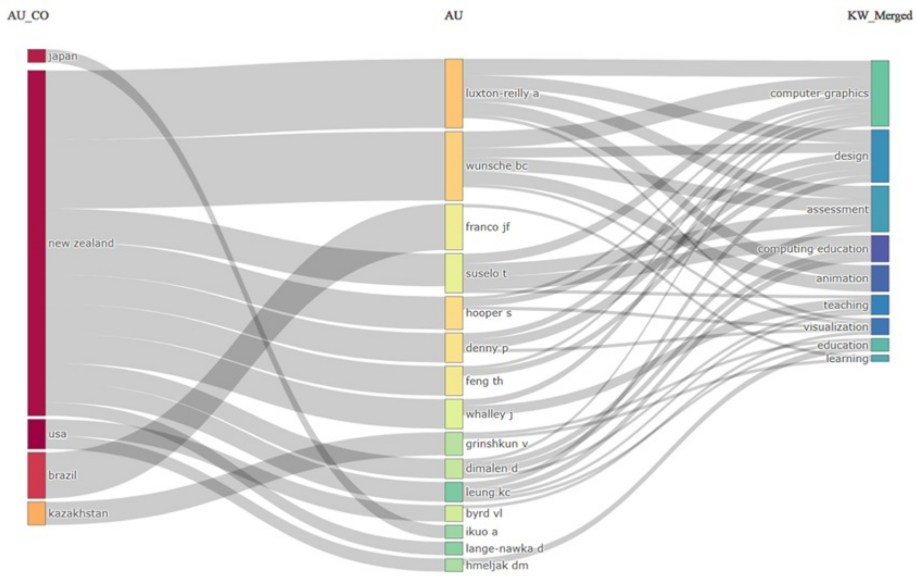

Figure 9: Three-field bibliometric map linking author countries, authors, and keywords

SCPs, although it also shows a visible MCP segment, indicating participation in international collaborations. Middle-group countries such as Brazil, Japan, Portugal, Spain, China and Germany contribute smaller but meaningful corresponding authorship output. Among them, Portugal (and to a lesser extent Brazil and Germany) show a relatively significant MCP component, which means that a larger proportion of their publications are related to international co-authorship compared to countries where SCP is almost entirely dominant. Several additional countries (e.g. Australia, Canada, Finland, India, Italy, Malaysia, Ukraine, etc.) have a small number of authors, usually with more than one paper each, reflecting a long-term structure of participation.

Importantly, the emergence of Kazakhstan among the countries with authorship, although with a small number of papers, indicates the emergence of participation from Central Asia, which is significantly related to collaborative publication in the MCP segment. In summary, the SCP-MCP distribution reinforces two main patterns: (i) authorship is highly concentrated (especially in the US and New Zealand) and (ii) international collaboration is present but remains secondary to single-country production, which is consistent with the overall level of international collaboration in the dataset as shown in the descriptive indicators.

4 Discussion

4.1 Evolution of computer graphics education research

Taken together, the results portray computer graphics (CG) education research as a field with a stable production profile but a shifting intellectual emphasis. While publication output does not show sustained acceleration across the decade, the thematic evidence suggests that research attention has gradually moved from a predominantly "traditional" educational agenda toward a more technology-driven landscape. The discussion-level synthesis (Figure 11) makes this transition visible by contrasting established themes with emerging ones and by showing how technology integration and interdisciplinary reach shape the field's current identity. A defined pedagogical core can be identified in the field. The research stream of computer

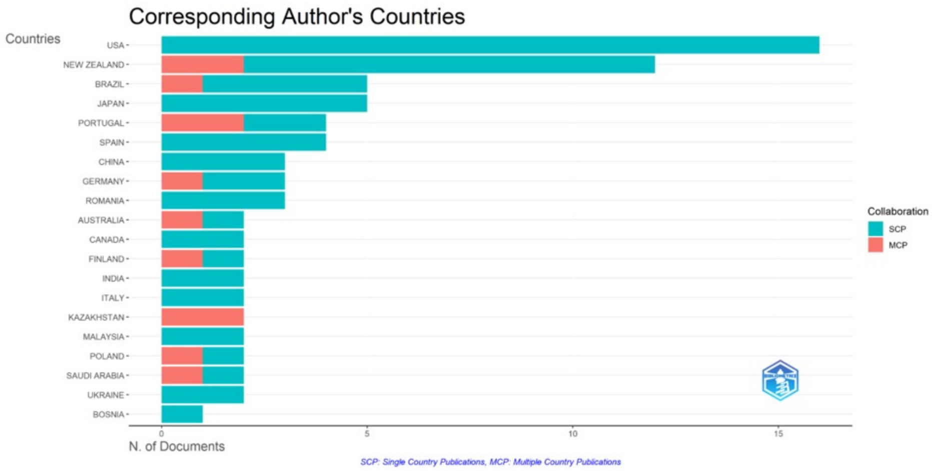

Figure 10: Distribution of corresponding authors by country and collaboration pattern (SCP vs. MCP)

graphics pedagogy and curriculum remains dominant and persistent. It defines instructional design, course architecture, and learning goals. The network of keywords is focused on computer graphics and associated with education-related concepts. The field is organized mainly according to the instruction rather than technical innovations. the figure demonstrates an established theme area as opposed to the emerging one. It shows that existing instructional base will be used in the future. The selectional growth of themes is evident since 2020. The themes such as artificial intelligence, immersive virtual reality and augmented reality training, and games based learning create a new research stream. However, these themes do not substitute the core of pedagogic research. They build up the top layer over the core. New technologies are employed as the means of instruction, assessment, and educational environment. Figure 11 reveals artificial intelligence as the most rapidly developing theme. Only a fraction of papers is classified into multiple categories. The analysis shows fast innovation with limited cross-thematic integration.

The second insight deals with technology integration levels. From Figure 11 it can be seen that high technology interventions like artificial intelligence, virtual reality or augmented reality and automation are a significant part of themes. The medium technology intervention area includes mobile technologies, multimedia and games. Still there is a significant low technology base in pedagogy and curriculum design. This distribution suggests a hybrid technological landscape rather than transition to advanced technologies only. High technology interventions take place within classical instruction research. The development depends on curricular and pedagogical basis. It is driven by the translation of experimental tools into scalable and measurable pedagogic designs. The third insight deals with applied and interdisciplinary nature of the field. The thematic structure demonstrates strong connections to computer science education and STEM education. Further connections are made with educational technology and somewhat restricted domain specific areas like health education. Such structure is consistent with conference dominated publications. This means that the field is characterized by the applied research approach when innovations are rapidly reported and implemented in the classroom. However, the results still remain scattered and need better synthesis and cross contextual verification.

The methodology distribution in Figure 11 supports the view that the field is methodologically diverse but uneven in evidence consolidation. Quantitative empirical studies and

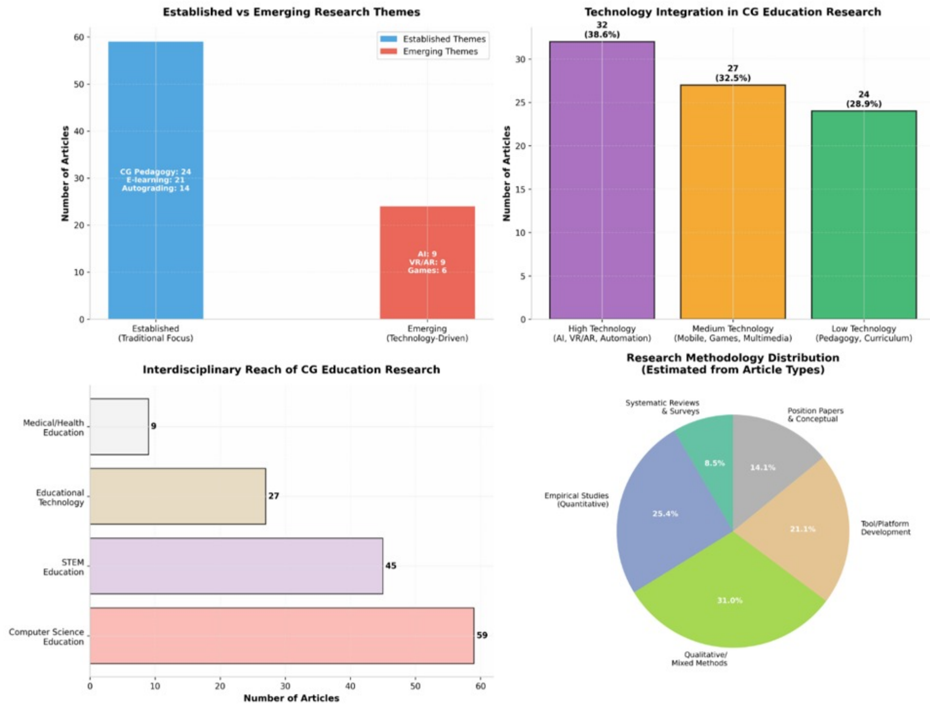

Figure 11: Thematic Trends and Research Evolution in CG Education

qualitative/mixed approaches both occupy large shares, and a noticeable portion of the literature is oriented toward tool or platform development. However, the smaller share of systematic reviews and survey (Figure 12) suggests that synthesis and consolidation are still limited relative to the pace of innovation. This helps interpret the citation structure reported in the Results: when a field produces many context-specific interventions and tools, impact tends to concentrate in a smaller subset of broadly reusable or widely discussed studies.

Figures 11 and 12 allow the results to be read as a coherent narrative: computer graphics education research is anchored by a stable pedagogical tradition, while newer technology-driven directions, particularly AI and immersive learning, are becoming increasingly visible and shaping the field's evolving agenda. At the same time, the interdisciplinary spread and the strong presence of tool- and platform-oriented work reinforce the applied character of this domain, where innovations often emerge quickly but may differ in evaluation depth and transferability across settings. Building on this interpretation, the evidence suggests that the field is not constrained by a lack of ideas, but by how well these ideas are connected, validated, and translated into cumulative instructional knowledge. In particular, emerging themes frequently appear alongside, rather than fully integrated with, established pedagogical and assessment practices, and methodological diversity is not always accompanied by comparable metrics or replication across contexts. These patterns point to several structural research gaps related to cross-category integration, rigorous validation, contextual diversity, theoretical grounding, and classroom-level empirical evidence for AI, which are discussed in the next subsection.

4.2 Research gaps and future directions in computer graphics education research

While the field has expanded in scope and now encompasses topics as diverse as e-learning, automated assessment, immersive environments, and AI-enabled learning, the evidence in this

Bibliometric Indicator	Value
Main Categories Identified	6 (+1 overlap)
Dominant Theme	CG Pedagogy & Curriculum
Fastest Growing Theme	AI in Graphics/Computing Education
Most Interdisciplinary	E-learning & Mobile Multimedia
Highest Technology Integration	Autograding & Feedback Tools
Established Themes (2016–2019)	59 articles (62.1%)
Emerging Themes (2020–2025)	24 articles (25.3%)
Overlap/Uncertain Categories	12 articles (12.6%)
VR/AR Medical Applications	9 articles (dominant sub-theme)
Systematic Reviews	6 articles (6.3%)
Tool Development Focus	15 articles (15.8%)

Figure 12: Bibliometric analysis summary CG Education Research (2016-2025)

review suggests that its development remains uneven. The underlying pattern is thematic fragmentation. Most research is grouped within relatively distinct streams (e.g., CG pedagogy, e-learning, automated assessment, VR/AR, games, and AI), with only a small portion of the dataset falling into overlapping categories. This suggests that in practice, many innovations are still being developed and evaluated separately. For example, immersive learning environments, automated feedback systems, and AI-based support tools are often discussed as separate interventions rather than as components of a single integrated learning workflow. As a result, the field may miss opportunities to build richer, end-to-end learning ecosystems for computer graphics education.

A second and closely related issue concerns the strength of validation. The vast majority of the studies reviewed seem to focus on tool development, platform implementation, or classroom use to demonstrate proof of concept, but fewer studies demonstrate robust validation across multiple institutions, teachers, or student populations. This does not diminish the value of implementation-oriented work, indeed, it is often necessary in a technology-rich field, but it does limit the generalizability of findings. In other words, many studies demonstrate that a tool can be used, but few demonstrate that it remains effective across contexts, over time, or under comparable evaluation criteria. For computer graphics education to mature as an evidence-based field, future research needs to go beyond local capacity and include stronger comparative and replication designs. The review also points to a contextual imbalance in the literature. While the data set is in principle international, only a limited number of studies explicitly address national, regional, or population-specific educational contexts. Many articles present their interventions in a relatively context-neutral manner, which can make it difficult to understand how infrastructure, curriculum standards, teacher preparedness, or resource constraints affect implementation outcomes. This is particularly important for underrepresented regions, where the practical conditions for implementing CG educational technologies may differ significantly from those in highly resourced institutions. In this regard, more context-sensitive studies in regions such as Central Asia, Africa, and parts of South Asia would not only improve representativeness, but also strengthen the external validity and practical relevance of the field.

Another point regards integration levels. Figure 11 demonstrates that high technology interventions such as AI, VR/AR and automation constitute a considerable portion of the theme areas. Medium technology includes mobile technologies, multimedia, and gaming. Another area with a noticeable base relates to pedagogy and curriculum development in terms of low technology. There is no indication of pure adoption of advanced technology but rather its mixed nature along with classical instructional approaches and research. Development relies on curricular and pedagogical basics. It depends on how new and experimental technology could be turned into scalable and measurable solutions for instruction. A limitation concerns theoretical underpinning. CG and e-learning research is centered on instructional practices, software applications and delivery approaches. Relations between constructivism, cognitive load theory, multimedia learning, self-directed learning and other theories is not strong enough. Practice-oriented approach dominates which makes systematic comparison of methods difficult and prevents explaining the effects of certain tools and practices. More theoretically based and designed innovations are necessary to accumulate pedagogical knowledge. The other evident gap regards empirical data about AI applications. Only a small portion of the studies evaluates generative AI or large language model application in the course of a semester. Sustainable learning outcomes remain under examined. This gap is critical due to rapid AI adoption in education. Future studies are required to use classroom based comparative designs with shared evaluation criteria. Criteria include conceptual understanding, coding quality, visual reasoning, and feedback quality. The field shows limited integration rather than lack of activity. Further work is required on validation, contextual transfer, and theoretical justification. Stronger AI based classroom evidence is also required. Future designs should integrate VR or AR, automated assessment, and AI feedback within unified course models. Cross institutional testing is required across student groups. This direction supports a more coherent and transferable research base.

4.3 Theoretical and contextual limitations of current CG education research

While the CG education literature is increasingly expansive and technology-focused, this review highlights two issues that still limit the extent to which the field can advance: theory is often poorly articulated, and many educational contexts are underrepresented. These are not minor details. They strongly impact the ability of research findings to be compared across studies, replicated in other settings, and used to generate cumulative knowledge, especially as the field moves from "how do we teach CG" to "how do we teach CG with new technologies". On the theoretical side, much of the educational work is still practice-first. Many studies describe course structures, learning activities, software platforms, or delivery formats in a clear and useful way, but they are less clear about the intervention in terms of learning theory (e.g., constructivism, cognitive load, multimedia learning, or self-directed learning). This does not mean that researchers are ignoring theory; on the contrary, theory often takes a back seat. The problem is that when the theoretical rationale is hidden, it becomes harder to understand why an approach works and it becomes even harder to compare it to other approaches. This limitation becomes even more apparent as new technologies enter the field. For example, AI tutors, VR/AR learning environments, and automated feedback systems can easily be hailed as "performance-enhancing tools", but without a stronger theoretical foundation, we know less about the mechanisms of actual learning, for example, whether gains are due to better scaffolding, reduced cognitive load, improved feedback time, or increased student self-regulation. Contextual representation is identified as a second limitation. Although many countries are included, contributions remain concentrated in a few leading nations. The United States and New Zealand dominate the output. The MCP and SCP model indicates collaboration exists but is not dominant. This weakens cross context learning and slows shared evaluation standards. Evidence is mainly produced in well resourced higher education systems. These conditions include stable internet, licensed software, and technical infrastructure. Such assumptions reduce transferability to under resourced institutions. Adaptation needs remain unclear for many contexts. The limitation becomes more critical with rising technology integration. AI and VR or AR form rapidly growing research areas. The literature is increasingly interdisciplinary across STEM and healthcare education. Intervention effects vary strongly by context and pedagogy. However, contextual and pedagogical details are often insufficient for comparison. Without stronger theoretical grounding and contextual reporting, results remain locally bound. Many studies provide innovative demonstrations with limited generalizability. A broader limitation concerns lack of synthesis across settings. Stronger theory driven and context sensitive designs are required. This is especially important in underrepresented and resource constrained regions. Improved design can support comparability and transferability.

5 Conclusions

This review focuses on computer graphics education research between 2016 and 2025. A bibliometric study of 95 papers is carried out. Output level stays consistent over the decade. Collaborations are common. International collaborations are rare. Productivity has fluctuations with a reduction in 2021 and rise in 2025. The trend depicts that the development in the field follows cycles and not a linear path. There are citation impact delays with the recent publications. Conference papers account for the majority in the sample. Journals papers have lower representation. This research area is application oriented and knowledge diffuses quickly. Geographic output is spread worldwide and highly concentrated. Most countries produce very little output and make up a long-tail pattern. Studies are mostly single-country studies. Benchmarking across nations is uncommon. There is citation concentration. Only a few papers receive higher number of citations. Majority of papers get low number of citations. Papers which receive high citations discuss scalable teaching and assessment. Computer Graphics is the central theme. AI, VR/AR, OpenGL, and Evaluation are some emerging themes. Newly emerging themes are not well connected to pedagogical core of computer graphics education. Many studies prioritize implementation over theory or validation. Context reporting is weak for transferability. Future work is required on integrated systems combining VR or AR, AI tutoring, and automated feedback. Multi institutional studies and shared metrics are required. This supports stronger and transferable knowledge development.

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