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ORIGINAL

Bridging the Gap to Success: A 50-Year Bibliometric Analysis of Preparatory Education and Academic Performance in Engineering and STEM Fields

Reduciendo la Brecha hacia el Éxito: Análisis Bibliométrico de 50 Años sobre Educación Preparatoria y Rendimiento Académico en Ingeniería y Áreas STEM

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ABSTRACT

The transition from secondary to higher education presents significant challenges for students in engineering and STEM fields, where academic preparedness is crucial for success. This study presents a comprehensive bibliometric analysis of global scientific production on preparatory education and its impact on academic performance, with a particular focus on engineering and STEM students. Using a dataset of 210 documents retrieved from the Scopus database (1974-2025), the analysis explores publication trends, influential sources, leading authors, thematic evolution, and citation patterns. The methodological framework integrates Biblioshiny (R-based Bibliometrix) and VOSviewer to perform descriptive, relational, and conceptual analyses. Results indicate a steady growth in publications, with a significant increase after 2010, and a moderate annual growth rate of 4,03 %. The United States leads in productivity, followed by Australia and the United Kingdom, though contributions from emerging regions such as Latin America and the Middle East are gaining visibility. Keyword co-occurrence and thematic mapping reveal four major clusters: academic performance and educational measurement, engineering education and curricula, student transition and retention strategies, and emerging technologies such as machine learning and predictive analytics. Despite a rich thematic landscape, the field shows low international collaboration (4,76 %) and a fragmented author network. This study contributes to the understanding of the intellectual structure and global dynamics of preparatory education research and offers insights for policymakers, educators, and researchers aiming to enhance student success in engineering and higher education. Future research should strengthen interdisciplinary collaborations and explore data-driven strategies for personalized academic support.

Keywords: Preparatory Education; Academic Performance; Engineering Education; Transition to University; Higher Education; Academic Gap; Network Analysis; International Collaboration.

RESUMEN

La transición de la educación secundaria a la superior presenta desafíos significativos para los estudiantes de ingeniería y áreas STEM, donde la preparación académica es crucial para el éxito. Este estudio presenta un análisis bibliométrico integral de la producción científica global sobre la educación preparatoria y su impacto en el rendimiento académico, con un enfoque particular en estudiantes de ingeniería y áreas STEM. A partir de un conjunto de 210 documentos recuperados de la base de datos Scopus (1974-2025), se analizan las tendencias de publicación, las fuentes más influyentes, los autores líderes, la evolución temática y los patrones de citación. El marco metodológico integra el uso de Biblioshiny (Bibliometrix en R) y VOSviewer

para realizar análisis descriptivos, relacionales y conceptuales. Los resultados indican un crecimiento sostenido en las publicaciones, con un aumento significativo a partir de 2010, y una tasa de crecimiento anual moderada del 4,03 %. Estados Unidos lidera en productividad, seguido de Australia y el Reino Unido, aunque las contribuciones de regiones emergentes como América Latina y Medio Oriente están ganando visibilidad. El análisis de co-ocurrencia de palabras clave y el mapeo temático revelan cuatro grandes clústeres: rendimiento académico y medición educativa, educación en ingeniería y currículo, estrategias de transición y retención estudiantil, y tecnologías emergentes como el aprendizaje automático y la analítica predictiva. A pesar de la riqueza temática, el campo muestra una baja colaboración internacional (4,76 %) y una red de autores fragmentada. Este estudio contribuye a comprender la estructura intelectual y la dinámica global de la investigación sobre educación preparatoria, y ofrece aportes para responsables de políticas, docentes e investigadores interesados en mejorar el éxito académico en la educación superior. Se recomienda que futuras investigaciones fortalezcan las colaboraciones interdisciplinarias y exploren estrategias personalizadas basadas en datos para el apoyo académico.

Palabras clave: Educación Preparatoria; Rendimiento Académico; Educación en Ingeniería; Transición a la Universidad; Educación Superior; Brecha Académica; Análisis de Redes; Colaboración Internacional.

INTRODUCTION

The transition from secondary to higher education remains one of the most critical and complex phases in the academic journey of students, particularly in disciplines such as engineering and STEM fields, where foundational knowledge and academic preparedness play an important role in student success.[1] In recent decades, institutions around the world have implemented remedial, bridging, and preparatory courses to support underprepared students, improve academic performance[2], and reduce dropout rates during the early years of university education.[3]

The effectiveness of these pre-university interventions has become an increasingly relevant topic in the global educational landscape, especially given the growing diversity of student populations,[4] the widening access to higher education, and the mounting pressure to increase retention and graduation rates in engineering programs.[5] Initiatives such as college readiness frameworks, transition programs, and academic leveling courses have been adopted with the aim of ensuring equitable access and success for students from diverse academic backgrounds.[6,7]

Although a significant body of literature has explored the impact of these interventions on student performance, the research remains fragmented across disciplines, regions, and educational systems. Furthermore, the evolution and intellectual structure of this field have not yet been systematically mapped through bibliometric techniques. Existing reviews tend to focus on specific interventions or populations but often overlook broader trends, influential works, and emerging themes that shape the discourse on preparatory education in engineering. To address this gap, this study conducts a comprehensive bibliometric analysis of scientific production over the past five decades (1974–2025) related to preparatory courses and their impact on academic performance in engineering and university education. By analyzing 210 articles retrieved from the Scopus database, this research aims to:

1. Identify the most influential sources, authors, countries, and documents in the field.
2. Reveal thematic clusters and conceptual trends through co-occurrence and thematic mapping.
3. Highlight emerging and declining areas of research.
4. Provide a foundation for future studies and policy development in engineering education.

This article applies robust bibliometric methods using Biblioshiny (R-based Bibliometrix) and VOSviewer, offering a panoramic and data-driven view of the academic dialogue on preparatory education. The findings not only contribute to the academic understanding of student success strategies but also provide actionable insights for educational policymakers, program designers, and institutional leaders in STEM education.

METHOD

This study employed a bibliometric analysis to explore the scientific production related to preparatory or bridging courses and their impact on the academic performance of students in engineering and STEM education. The analysis aims to identify the evolution, intellectual structure, and thematic trends of the field over the last five decades.

The search strategy was designed to balance exhaustiveness with thematic relevance, focusing specifically on preparatory education interventions and their measurable impact on academic performance within engineering and higher education contexts. The search terms (e.g., “remedial course”, “bridging course”, “foundation

program*") were selected based on a preliminary literature review and widely recognized educational taxonomies to capture the conceptual core of academic leveling programs. While this approach may have excluded less frequent synonyms or terminological variants, conceptual precision and search replicability were prioritized. It is noteworthy that for future replications or expansions of this study, incorporating additional terms such as "academic support," "first-year experience," or "learning support" could enrich thematic coverage without compromising the specificity of the documentary corpus.

The dataset was extracted from the Scopus database due to its broad multidisciplinary coverage and high indexing standards. The following search query was applied to the Title, Abstract, and Keywords (TITLE-ABS-KEY) fields:

("remedial course*" OR "bridging course*" OR "foundation program*" OR "preuniversity program*" OR "college readiness" OR "transition program*" OR "academic leveling" OR "preparatory course*" OR "propedeutic course*") AND ("academic performance" OR "academic achievement" OR "student performance" OR "academic success" OR "retention" OR "dropout" OR "GPA") AND ("engineering student*" OR "engineering education" OR "STEM education" OR "Universit*")

The search included documents published between 1974 and 2025, yielding a total of 210 articles from 157 different sources. The dataset was downloaded in BibTeX format, including metadata such as authors, institutions, keywords, citations, and references. Two primary tools were used to perform the bibliometric analysis:

- Bibliometrix R package (version 4.2) and its web-based interface Biblioshiny were used for descriptive statistics, thematic mapping, co-authorship, co-citation, and keyword co-occurrence analysis (Aria & Cuccurullo, 2017).
- VOSviewer (version 1.6.19), a free software tool developed by the Centre for Science and Technology Studies at Leiden University, was employed to visualize bibliometric networks, including keyword clusters, citation networks, and coauthorship maps.

These tools enabled the construction of comprehensive visualizations and statistical summaries of the bibliographic data.

Inclusion and Exclusion Criteria

Inclusion Criteria

Peer-reviewed journal articles and conference proceedings written in English or Spanish, published between 1974 and 2025, and directly related to preparatory education, academic performance, and engineering/STEM students.

Exclusion Criteria

Editorials, book chapters, dissertations, articles not focused on postsecondary education, or those unrelated to student preparation and performance. Bibliometric indicators used are shown in Figure 1.

Figure 1. Key bibliometric indicators used in the analysis

RESULTS

Annual Scientific Production

The analysis of annual scientific production provides insight into the historical development and growing academic interest in the relationship between preparatory courses and the academic performance of engineering students. Tracking the volume of publications over the last five decades allows for the identification of thematic maturity, emerging trends, and key turning points in the research field.

As shown in figure 2, the annual number of publications on this topic remained consistently low from the

1970s through the early 2000s, with an average of fewer than two articles per year. A notable upward shift begins around 2008, with a clear acceleration in research activity after 2010. This is evidenced by a marked increase in the number of articles published annually, peaking in multiple years between 2015 and 2023 with values exceeding 10 articles per year. The linear regression model fitted to the trend yields an R^2 value of 0,6839, indicating a moderate to strong correlation between time and publication volume.

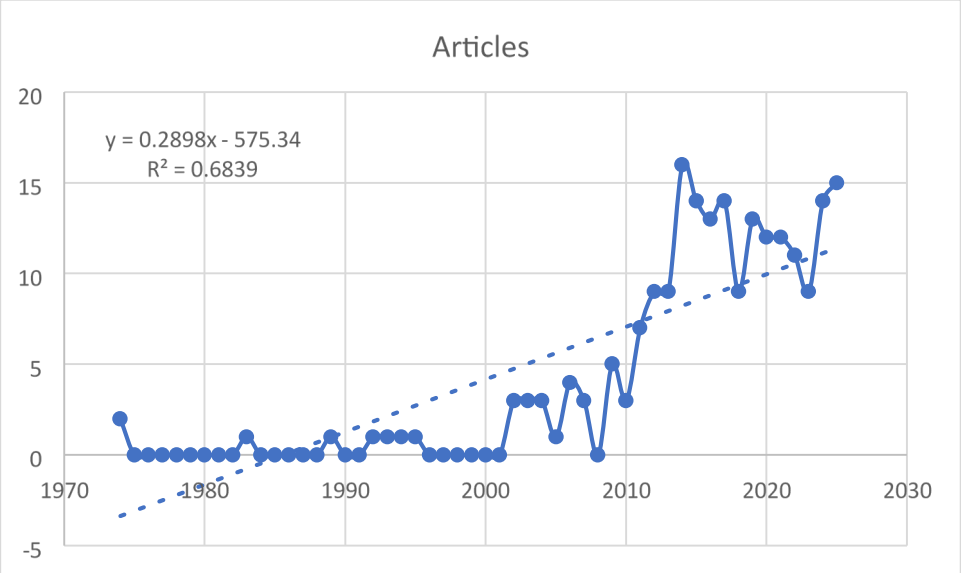

Figure 2. Annual scientific production of articles on preparatory programs and academic performance in engineering students (1973-2024)

This pattern may be attributed to several global academic and educational developments. First, the expansion of STEM education initiatives globally—particularly after the launch of programs such as the U.S. "Educate to Innovate" campaign[8] and UNESCO's Science Education frameworks[9]—has driven increased interest in preparing underprepared students for rigorous university curricula. Additionally, growing concerns about retention and dropout rates in engineering programs,[10] which are among the highest in higher education globally,[11] have led institutions to invest in research on bridging strategies, including preparatory or remedial courses.[12] Another catalyst may be the increasing globalization of higher education and the massification of university access since the early 2000s,[13] which exposed disparities in academic preparedness among incoming students. As institutions faced more heterogeneous student populations, the demand for evidence-based interventions to ensure academic success gained visibility in scholarly discussions.[14] Moreover, the post-2010 surge in publications coincides with a broader rise in data-driven educational research and open-access publishing, facilitating the dissemination of pedagogical innovations across regions and institutions.

Average Citations Per Year

The average number of citations received by articles per year is a key indicator of the scientific influence and visibility of a research field. In bibliometric studies, citation metrics help identify not only the volume but also the impact of scholarly contributions over time. Evaluating citation trends allows for the detection of highly cited periods and the relative attention garnered by research on preparatory programs in engineering education.

As observed in figure 3, the average citations per article (MeanTCperArt) show a fluctuating pattern, with notable peaks after 2005 and especially between 2010 and 2017. A particularly high spike is recorded around 2011, reaching more than 30 citations per article in that year, suggesting the presence of highly influential publications. This trend is modeled with a linear regression equation y=0,1843x−361,79, though the low coefficient of determination (R^2 = 0,1081) indicates high volatility and that the overall increase in citations is driven by a few standout years.

In contrast, the average citations per year (MeanTCperYear) display a more stable but slower growth pattern, with a regression model of y=0,0418x−83,024 and a slightly higher R^2 value of 0,431. This indicates a gradual increase in yearly attention but also suggests that the field is still consolidating in terms of influence.

These patterns reflect a typical emerging research domain, where early foundational works receive consistent recognition over time, and bursts of attention correspond to pivotal studies or reviews. According to the Leiden Manifesto for research metrics,[15] citation peaks often reflect landmark contributions that either

introduce new frameworks or respond to global educational priorities—such as addressing retention challenges in STEM or scaling equitable access to engineering education. Moreover, the 2010s saw a rise in educational reforms and international comparative assessments (e.g., OECD's Education at a Glance, 2015–2022), which may have elevated the relevance of studies on academic preparedness and performance, aligning with global policy interest. However, the irregularity in citation frequency also suggests that more longitudinal studies or meta-analyses are needed to unify and standardize the findings in this field, enhancing its long-term scientific impact.

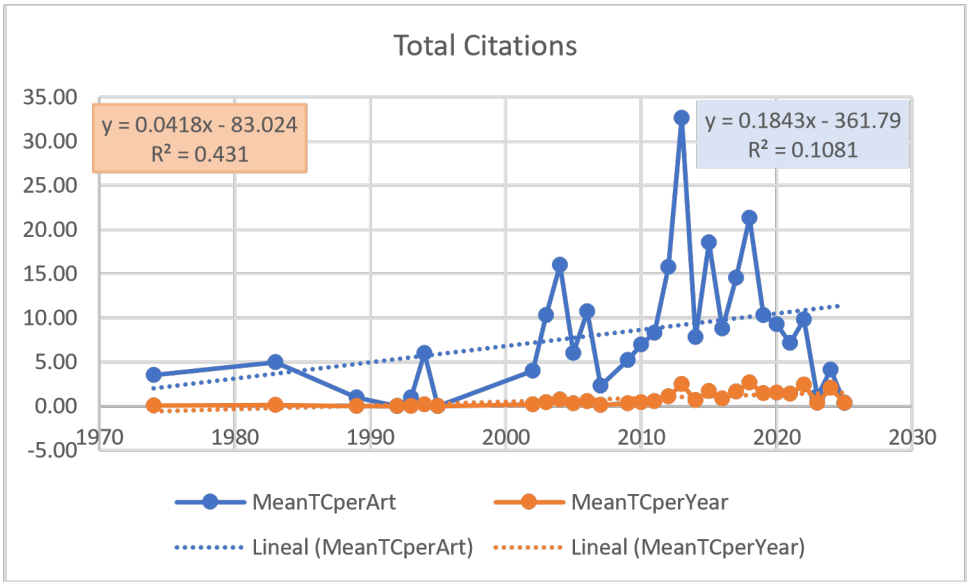

Figure 3. Average citations per article and per year for studies on preparatory programs and academic performance in engineering education (1973–2024)

Intellectual Contributions by Country, Keyword Themes, and Institutional Affiliation

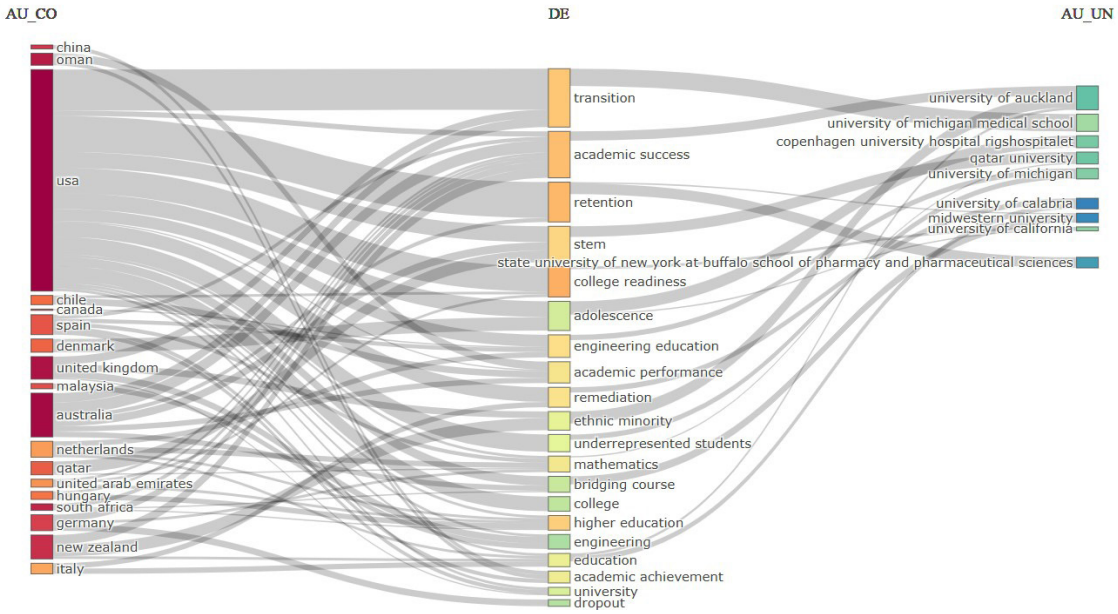

Figure 4. Three-field plot linking Countries, Keywords, and Institutional Affiliations in the research domain (1973–2024)

Understanding the geographical and institutional landscape of research, along with the thematic focus, is fundamental in bibliometric studies.[16] A three-field plot provides a visual representation of the interplay between countries of origin, the main keywords used in the publications, and the affiliations of the contributing authors. This offers insights into the global distribution of research efforts, the dominant thematic areas, and the leading institutions shaping the academic discourse on preparatory education and academic performance in engineering.

As shown in figure 4, the United States (USA) stands out as the most prolific contributor, linked with a wide range of thematic descriptors such as transition, retention, academic success, college readiness, and STEM. These themes reflect a mature and policy-driven research agenda in the U.S., likely influenced by longstanding national concerns over student dropout rates in STEM fields and efforts to broaden participation among underrepresented groups.[17]

Following the USA, countries such as China, Oman, Canada, Spain, and Chile show active participation, although with more specialized thematic alignments. For instance, China's contributions are strongly associated with academic success and remediation, indicating a growing internal focus on educational quality and access. Meanwhile, European nations like Denmark, United Kingdom, and Netherlands connect with keywords like college, bridging course, and higher education, suggesting a systemic approach to transitions between secondary and tertiary education. In terms of affiliations, leading institutions include:

- University of Michigan and University of Michigan Medical School, both associated with academic success and transition.
- University of Auckland (New Zealand), connected with themes of transition and STEM.
- University of California, Midwestern University, and University of Calabria also appear with distinct but focused thematic lines.

This three-field mapping reveals a research ecosystem that is both globally dispersed and thematically diverse, with strong institutional concentrations in North America and Europe. It also highlights the importance of cross-border and cross-institutional collaborations, especially in tackling the multifaceted challenges of university readiness and engineering education outcomes.

Most Relevant Sources

As illustrated in figure 5, the ASEE Annual Conference and Exposition emerges as the dominant source, with 26 documents, clearly highlighting the pivotal role of engineering education conferences in shaping scholarly discussions around academic preparedness. The prominence of this source aligns with the fact that the American Society for Engineering Education (ASEE) has long been at the forefront of educational innovation and student success research in engineering programs (ASEE, 2023).

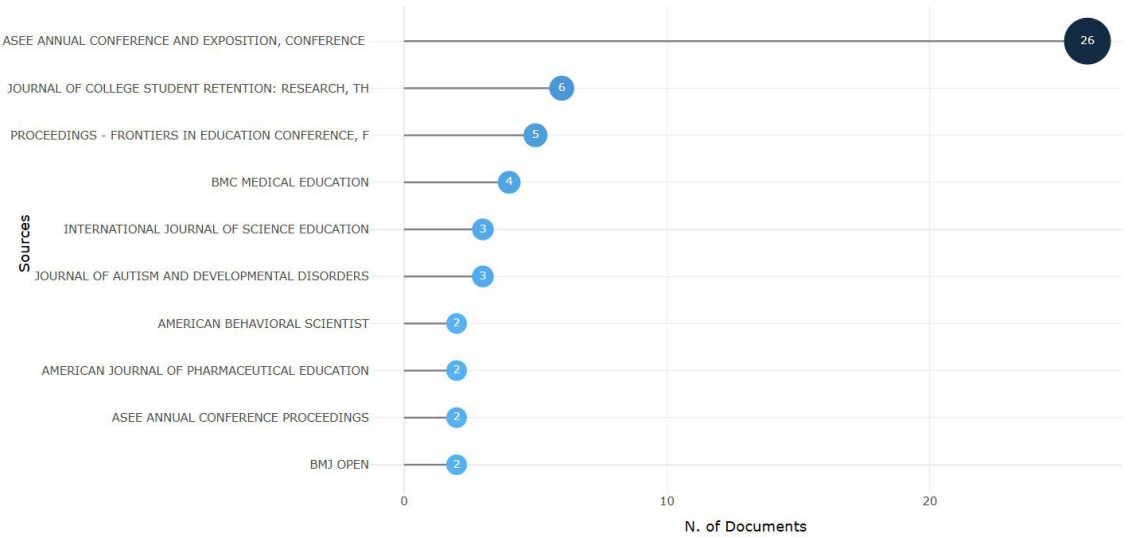

Figure 5. Top sources publishing research on preparatory programs and academic performance in engineering education (1973–2024)

The Journal of College Student Retention: Research, Theory & Practice, with 6 articles, ranks second. This journal's focus on retention theory and intervention strategies supports the relevance of preparatory courses as a factor influencing university completion rates. Close behind is the Frontiers in Education Conference Proceedings, with 5 documents, reinforcing the role of academic conferences in disseminating timely research related to student transitions, curriculum reform, and learning support services.

The presence of BMC Medical Education (4 documents) and BMJ Open (2 documents) reflects a cross-disciplinary interest, particularly in fields like medical and health education, where foundational knowledge and preparatory training are also critical. This suggests that while the main focus is engineering education, there is thematic overlap with other areas where academic readiness significantly impacts student outcomes.

Additionally, sources such as the International Journal of Science Education and American Behavioral

Scientist demonstrate that the topic is also addressed from science education and social science perspectives, respectively. These journals typically engage with broader educational equity, student motivation, and systemic barriers—themes highly relevant to bridging programs and access policies.

Most Relevant Authors

As shown in figure 6, three authors stand out with the highest number of documents: De Paola M, Molontay R, and Scoppa V, each contributing three publications to the domain. Their relatively high productivity, in the context of a specialized topic, suggests a focused research trajectory likely dealing with performance metrics, education policy, and student readiness

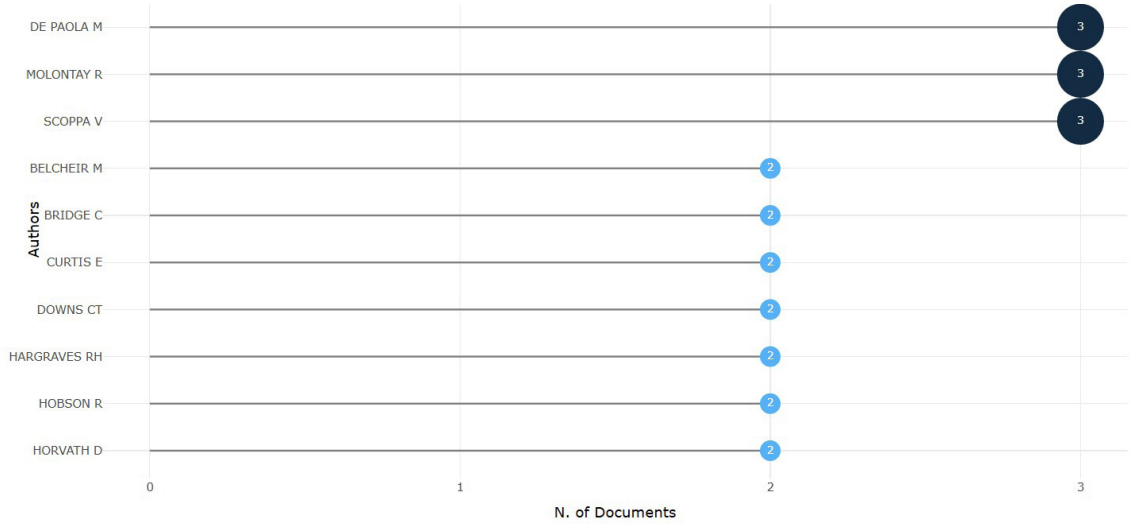

Figure 6. Most relevant authors in the field of preparatory education and academic performance in engineering students (1973–2024)

For instance, De Paola M and Scoppa V have previously published extensively on the economics of education and student assessment, indicating a quantitative approach to evaluating academic outcomes. Molontay R, on the other hand, has contributed to the intersection of data science and educational analytics, suggesting a methodological diversification in the field.

Several other researchers—Belcher M, Bridge C, Curtis E, Downs CT, Hargraves RH, Hobson R, and Horvath D—follow closely with two articles each, reinforcing the observation that while the field has multiple contributors, no single dominant author has yet emerged. This is consistent with a developing research area, where many scholars contribute in parallel, often from multidisciplinary perspectives.

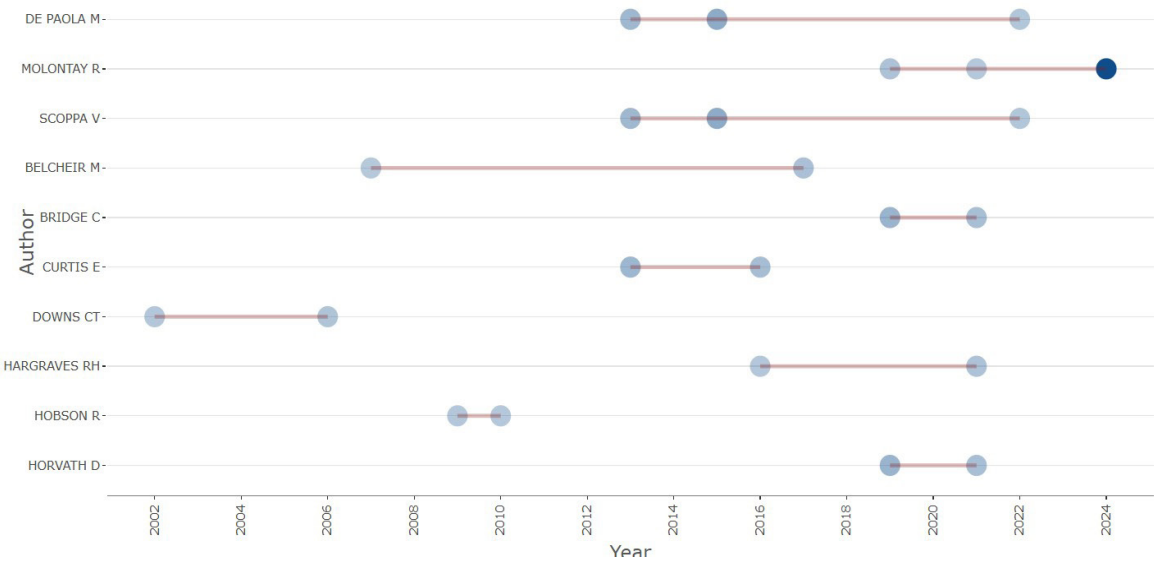

Figure 7. Authors' production over time in the research domain of preparatory education and academic performance in engineering students (2002–2024)

As illustrated in figure 7, De Paola M, Molontay R, and Scoppa V have maintained consistent research activity over multiple years, reflecting a sustained interest in the field. Notably, Molontay R has produced work spanning from 2016 to 2024, with a clear continuation into the most recent years. This trajectory suggests both ongoing engagement and possibly increasing influence, aligning with the rising relevance of data analytics and educational performance metrics in higher education research.

Early and continued productivity from 2006 to 2015, indicating a foundational contribution during the formative years of the field's growth. Similarly, Curtis E and Bridge C contributed steadily between 2014 and 2020, highlighting a period of intensified focus on academic transitions and retention strategies.

Meanwhile, authors such as Downs CT, Hargraves RH, and Hobson R display episodic publication activity, concentrated around specific years. This pattern may reflect targeted research projects or institutional interventions rather than long-term thematic dedication.

Interestingly, the timeline demonstrates a growing cluster of publications post-2010, confirming the acceleration in scholarly interest already observed in the annual publication trends (**Figure2**). The fact that several key contributors have remained active into the 2020s signals that the topic continues to evolve, potentially influenced by post-pandemic challenges, such as educational recovery, digital readiness, and widened access gaps in engineering programs.

Geographic Distribution of Scientific Production and Corresponding Authors

Geographic analysis of scientific production provides critical insight into the global spread of research and the geopolitical leadership in a given academic domain. By examining both the countries of corresponding authors and the overall scientific output by nation, it is possible to identify regional hubs of expertise, patterns of collaboration, and potential gaps in contribution.

As shown in figure 8, the United States dominates the field with the highest number of corresponding authors and a total of over 50 documents authored independently, confirming its leadership in shaping this area of research. Interestingly, most U.S. contributions are Single Country Publications (SCP), suggesting a strong national infrastructure and localized research initiatives rather than broad international collaboration.

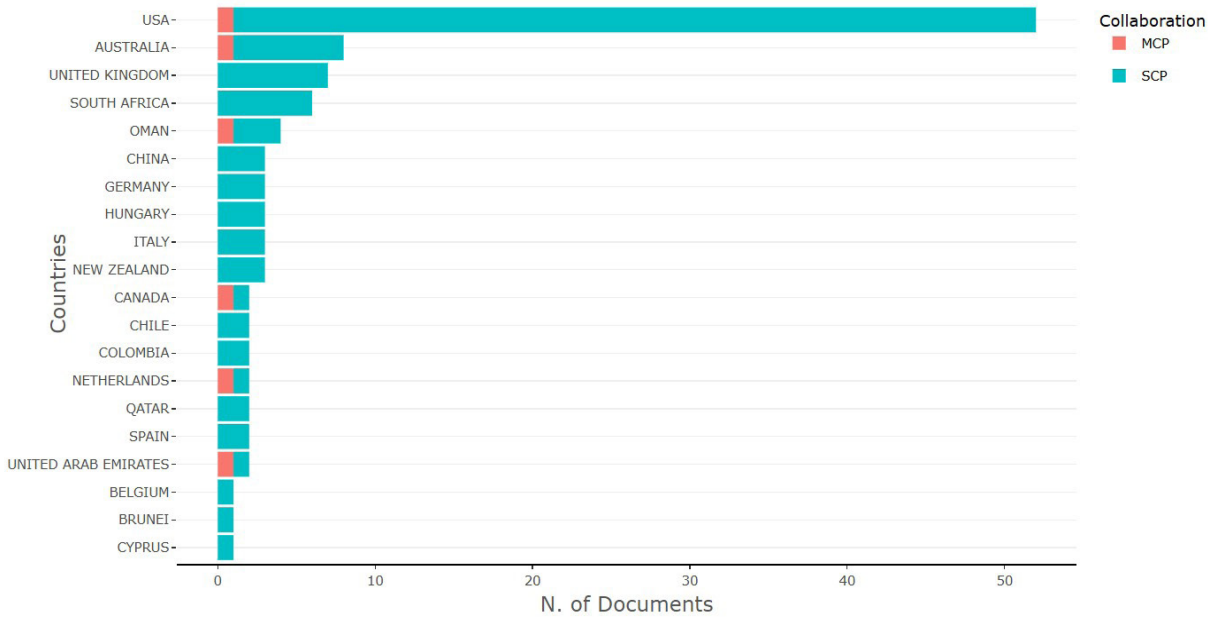

Figure 8. Scientific production by corresponding authors' countries and international collaboration (Single Country Publications vs. Multiple Country Publications)

Other top contributors include Australia, United Kingdom, South Africa, Oman, and China, with each country exhibiting a mix of SCP and Multiple Country Publications (MCP), indicating varying degrees of international engagement. For example, Australia and the UK demonstrate a higher proportion of collaborative outputs, aligning with global research policy incentives that promote transnational projects in education and engineering.

The geographical diversity expands further when analyzing total scientific production by country (Figure 9). The USA leads overwhelmingly with 317 articles, followed by Australia (50), UK (36), and Oman (22). The presence of nations such as New Zealand, South Africa, Chile, Malaysia, Qatar, and the United Arab Emirates highlights a broad engagement across continents, especially among countries with well-established or rapidly developing higher education systems.

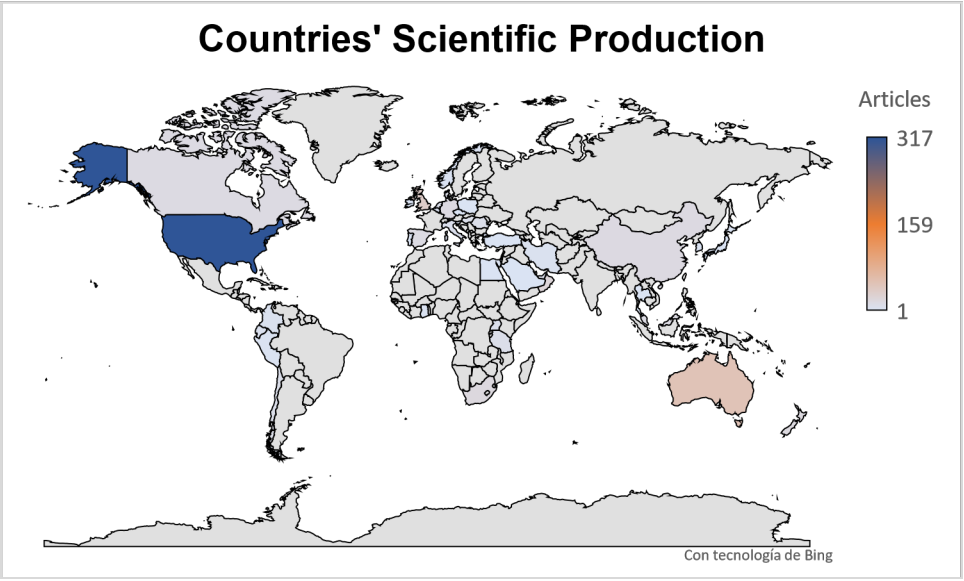

Figure 9. World map of total scientific production related to preparatory education and academic performance in engineering education (1973–2024)

Notably, countries from the Global South, including Ecuador (5 articles), Colombia (4), Peru (3), Uganda (6), and Ghana (3), are also represented. Although their overall output remains modest, their participation reflects growing interest in addressing educational inequality, dropout rates, and engineering pipeline development—key themes in developing regions. The limited output from other Latin American nations (e.g., Brazil and Argentina are absent from the top ranks) and large Asian research powers (e.g., India, South Korea, Japan) suggests an opportunity for expansion and inclusion in future research agendas.

Most Global Cited Documents

Citation analysis enables the identification of the most influential studies within a given research field. Highly cited documents typically reflect either foundational theoretical contributions, methodological innovations, or policy-relevant findings that have resonated widely across academic and professional communities. In this study, we ranked documents not only by their total citation count (TC), but also by their citations per year (TC/year) and normalized citations, to account for differences in publication date and citation opportunity as shown in table 1.

Table 1. Most globally cited documents in the domain of preparatory education and academic performance in engineering and STEM education

	DOI	Total Citations	TC per Year	Normalized TC
From middle school to college: developing aspirations, promoting engagement, and indirect pathways from parenting to post high school enrollment[18]	10.1037/a0038367	138	12,55	7,43
Student Supports: Developmental Education and Other Academic Programs[19]	10.1353/foc.2013.0003	104	8,00	3,18
Transitions from high school to college[20]	10.1353/foc.2013.0004	98	7,54	3,00
Self-affirmation facilitates minority middle schoolers' progress along college trajectories[21]	10.1073/pnas.1617923114	88	9,78	6,04
Peer-Led Team Learning in General Chemistry I: Interactions with Identity, Academic Preparation, and a Course-Based Intervention[22]	10.1021/acs.jchemed.8b00375	58	7,25	2,72
Procrastination, academic success and the effectiveness of a remedial program[23]	10.1016/j.jebo.2014.12.007	47	4,27	2,53
Strengthening the Bridge to Higher Education for Academically Promising Underrepresented Students[24]	10.1177/1932202X1102200306	36	2,40	4,34
Interpretable Dropout Prediction: Towards XAI-Based Personalized Intervention[25]	10.1007/s40593-023-00331-8	34	17,00	8,21

Improving the Success of First Term General Chemistry Students at a Liberal Arts Institution[26]	10.3390/educsci 8010005	33	4,13	1,55
Class size effects on student achievement: heterogeneity across abilities and fields[27]	10.1080/096452 92.2010.511811	32	2,46	0,98
Is there a link between Preparatory Course Attendance and Academic Success? A Case Study of Degree Programmes in Electrical Engineering and Computer Science[28]	10.1007/s40753-016-0047-9	28	3,11	1,92
Effectiveness of a Short, Intense Bridging Course for Scaffolding Students Commencing Universitylevel Study of Chemistry[29]	10.1080/095006 93.2012.663116	26	1,86	1,65
Peer mentors as a transition strategy at University: why mentoring needs to have boundaries[30]	10.1177/000494 4115604697	24	2,18	1,29

The most cited document is “From middle school to college: developing aspirations, promoting engagement...”, with 138 citations and an average of 12,55 citations per year, highlighting its long-term impact. This study is frequently referenced in research on college readiness and student transitions, particularly in relation to underrepresented groups and parental influence.

Other top-ranked publications include “Student Supports: Developmental Education...” and “Transitions from high school to college”, both from the same issue of The Future of Children journal, indicating that special issues can serve as influential platforms for consolidation of research themes.

More recent studies also stand out due to their high normalized citation scores, such as “Interpretable Dropout Prediction...” which reflects growing attention to AI-driven interventions and explainable machine learning models in the context of student success prediction. Despite its recent publication, it achieves 17 citations per year, with the highest normalized impact score of 8,21, signaling the rising influence of data-driven educational research.

Thematic Map of the Field

Thematic mapping is a strategic tool in bibliometric analysis that allows researchers to identify and categorize the conceptual structure of a field. By plotting themes according to their centrality (relevance to the field) and density (degree of development), it becomes possible to evaluate the maturity, influence, and potential of different research areas.

Thematic clusters are distributed across four quadrants (figure 10), each representing a different strategic position:

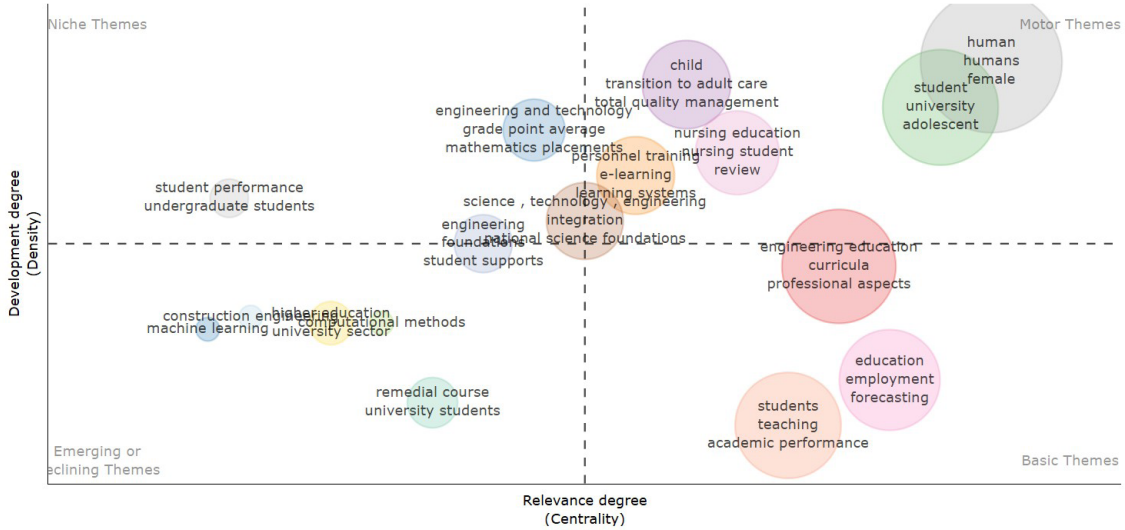

Figure 10. Thematic map based on co-word analysis of keywords in studies on preparatory education and academic performance in engineering education (1973–2024)

Motor Themes (High centrality, high density – top-right quadrant)

Themes in this quadrant are both well-developed and highly relevant, indicating that they form the intellectual and applied core of the field. Here, we observe terms such as: Student, university, adolescent, female, human, humans.

These terms reflect a broad and active research domain, strongly connected with studentcentered learning, demographic factors, and human development. The inclusion of female and adolescent suggests that equity

and developmental psychology are gaining central importance within preparatory and transitional education studies, possibly linked to global concerns about diversity and inclusion in STEM fields.

Basic Themes (High centrality, low density – bottom-right quadrant)

These are fundamental topics that are central to the field but may not yet be deeply developed. They represent broad entry points or recurring subjects in the literature, including: Engineering education, curricula, professional aspects, education, employment, forecasting, academic performance, students, teaching.

This indicates a strong focus on curriculum design, pedagogical strategies, and the link between education and labor market outcomes, particularly within engineering and technical education. These areas are foundational but could benefit from more empirical depth or theoretical refinement, suggesting opportunities for future research expansion.

Niche Themes (Low centrality, high density – top-left quadrant)

Niche themes are highly specialized and internally cohesive, but not yet widely connected to the broader field. This quadrant includes: Student performance, undergraduate students, mathematics placements, science, technology, engineering, integration, grade point average, learning systems.

These themes suggest research on performance metrics and placement policies, often dealt with in isolated or technical contexts. While mature within their subdomains, these topics may benefit from better integration with broader educational or policy frameworks.

Emerging or Declining Themes (Low centrality, low density – bottom-left quadrant)

Themes in this quadrant are either emerging, underexplored, or declining in relevance. Among them: Remedial course, university students, higher education, computational methods, machine learning, construction engineering.

The presence of remedial course in this space suggests that although central to this study's topic, the concept may be under-theorized or fragmented across disciplines. Interestingly, computational methods and machine learning—relatively new entrants—signal a potential emergent trend of data-driven analysis in academic success prediction.

Keyword Co-occurrence Network

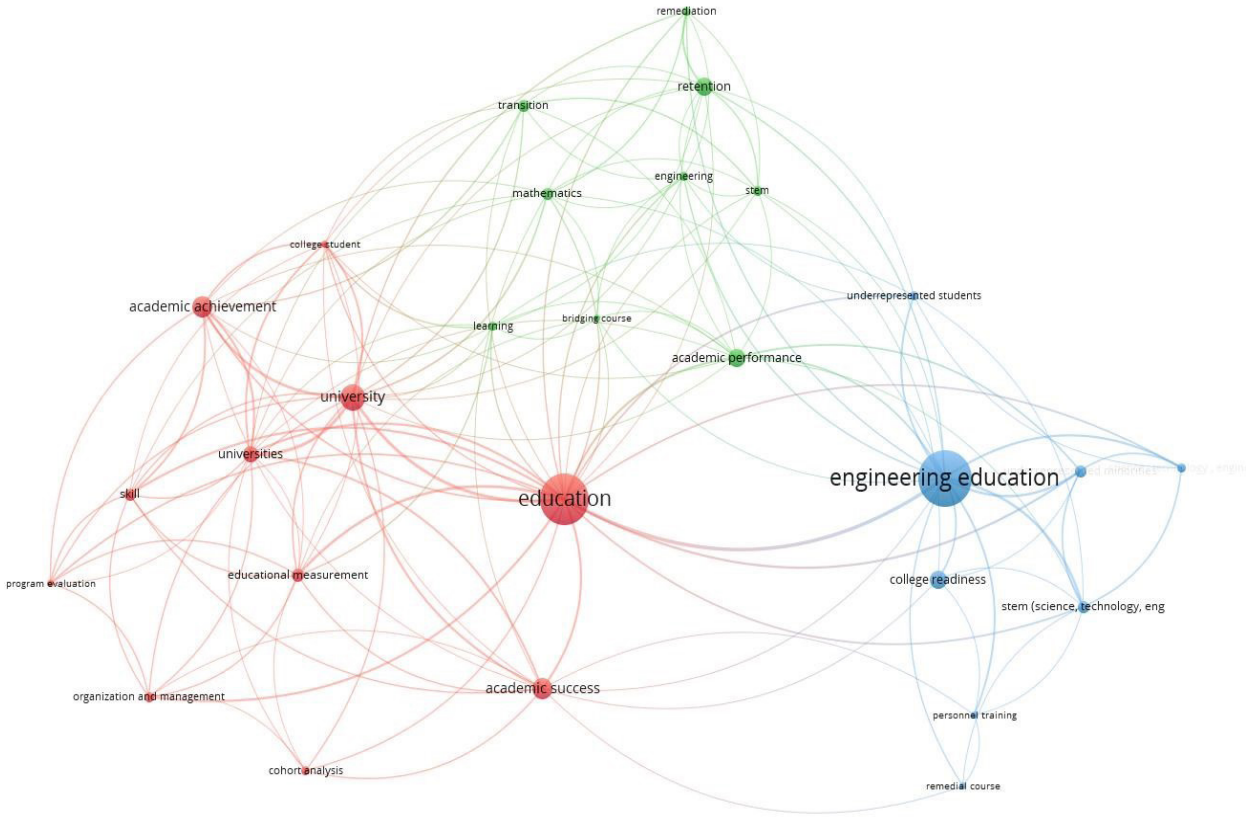

Figure 11. Co-occurrence network of keywords related to preparatory education and academic performance in engineering students (1973–2024)

A keyword co-occurrence network reveals the intellectual structure and thematic interconnections within a research domain. By examining the frequency and co-presence of keywords across documents, this analysis identifies conceptual clusters that represent dominant and emerging lines of inquiry. The color-coded clusters in the network map correspond to thematically related research foci (figure 11).
The network displays four major thematic clusters, each represented by a central keyword and its closely associated terms:

Cluster 1: Educational Core and Institutional Assessment

Centered around the keyword education, this red cluster includes terms such as: Academic achievement, academic success, university, educational measurement, program evaluation, cohort analysis, organization and management.

This cluster reflects a systemic focus on academic outcomes and institutional performance, indicating that much of the research is rooted in assessing how preparatory or bridging interventions affect university-level learning and success metrics. It suggests a strong foundation in educational evaluation, often tied to program-level effectiveness or policy reform.

Cluster 2: Transition, Retention, and Mathematical Preparedness

This green cluster is built around academic performance, mathematics, learning, and transition, with terms like: Retention, remediation, STEM, engineering, bridge course, underrepresented students. Here, the emphasis is on student trajectories, especially in the first-year experience of engineering or science students. The presence of underrepresented students highlights an equity-oriented approach, while remediation and bridging courses suggest interventions aimed at improving preparedness in critical areas such as mathematics.

Cluster 3: Engineering Education and Readiness

Dominated by the term engineering education, this blue cluster includes: College readiness, STEM (science, technology, engineering), personnel training, remedial course. This grouping underscores a more practice-driven, disciplinary lens, focusing specifically on the needs of students entering engineering and technical fields. Themes of college readiness and training connect directly to institutional efforts to close skill gaps before or during the initial academic terms.

Cluster 4: Institutional Role and Success Metrics (subcluster overlapping with Cluster 1)

With recurring nodes like university, academic success, and educational measurement, this overlapping area between red and green clusters highlights that institutional environments and academic metrics are deeply interconnected, especially when evaluating the success of preparatory programs.

CONCLUSIONS

This study provides a comprehensive bibliometric mapping of global research on preparatory education and academic performance in engineering and university contexts, covering five decades of scientific production. The key conclusions are as follows:

- Scientific growth in the field has been steady, with a notable acceleration after 2010, indicating increasing global concern for academic preparedness and success in higher education.
- The research is dominated by contributions from the USA, UK, and Australia, but emerging participation from countries such as Chile, Oman, Ecuador, and Qatar points toward a more inclusive future landscape.
- Thematic analysis revealed four main clusters: academic performance and measurement, engineering education and readiness, transition and retention, and emerging technologies such as AI in education.

Despite the interdisciplinary richness, the field exhibits low international collaboration, calling for greater integration of global research efforts and more inclusive policy dialogue. Highly cited documents show that student-centered approaches, bridging interventions, and data-informed strategies are gaining traction and influence.

The findings of this study offer concrete implications for educators, policymakers, and higher education institutions. For educators, the identified thematic clusters, especially those related to transition strategies and predictive analytics, underscore the need to implement leveling programs that integrate personalized monitoring and early academic support, using data to identify at-risk students. For policymakers, the dominance of Anglophone countries coupled with low international collaboration highlights the urgency of fostering consortia and funding projects that include emerging regions, promoting the transfer of successful academic preparedness strategies. Finally, institutions can use these results to redesign their entry-level curricula,

establish early warning systems based on the performance factors detected in the literature, and create liaison offices to facilitate the transition from secondary school to university, ensuring a more equitable and robust foundation for success in engineering and STEM.

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