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Conceptual Model for the Assessment of Academic Productivity in Research Seedbeds From a Systematic Review

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Abstract: Higher education institutions have focused their efforts on promoting research seedbeds as a strategy for formative research. In this regard, the impact of such a strategy remains unknown due to the lack of models that enable its evaluation. Therefore, this study aimed to design an evaluation model for the academic productivity of research seedbeds based on the available evidence in the literature. To achieve this, a systematic review was conducted following the PRISMA model, analyzing 53 documents including articles, book chapters, and conference proceedings from the SCOPUS, ProQuest, JSTOR, SciELO, and ScienceDirect databases. The results identified indicators that allowed for the design of a model based on six constructs: research training, institutional capabilities, bibliographic production, innovation and development, social appropriation of knowledge, and human resource training. It was concluded that the indicators evaluating research seedbeds seek greater scientific development involving students and improving the quality of research products, which directly impacts the institutional research mission.

Keywords: *Formative research, higher education, measurement, productivity, research seedbeds.*

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Introduction

The main aim of this research was to develop an assessment model for the academic productivity of research seedbeds, based on the evidence available in the literature. Through this model, it is intended that Higher Education Institutions (HEIs) can effectively evaluate the real impact of the research seedbeds pedagogical strategy on their academic productivity. Accordingly, this study is structured into four main sections: the first provides theoretical background on formative research, research seedbeds, and academic productivity; the second describes the methodology followed to achieve the study's objective; the third presents the results and main findings; and finally, the fourth discusses and concludes the study.

In this context, HEIs are keen to implement strategies that facilitate formal research by teachers, but more crucially, they strive to foster formative research within the student-teacher dynamic. As Cerda Gutiérrez (2007) notes, formative research is seen as "part of a theoretical, methodological, and technical preparation process for research, i.e., training human resources for research" (p.61). Consequently, HEIs have introduced multiple strategies aimed at influencing the curriculum and pedagogical management to cultivate students' research abilities and encourage scientific output by both students and teachers. The aspiration is for formative research strategies implemented by HEIs to be integral across all levels of higher education, from undergraduate to doctoral programs (Irving & Sayre, 2014; Kamali Arslantas et al., 2020).

Within the learning environment, it is essential for teachers to play a guiding role in the research process, where both educators and students can collaboratively acquire knowledge in research methods, procedures, and investigative techniques necessary for problem-solving, ultimately aiming to experiment and document research findings (Espinoza Freire, 2020). In this regard, one of the most prevalent strategies adopted by HEIs to strengthen research competencies is the establishment of research seedbeds. These groups are recognized as collaborative and formative research spaces, fostering the development of critical thinking and the proposition of disciplinary problem solutions (Campos Olazabal,

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2020). Given the above, studies on the significance of research seedbeds in higher education have concentrated on skill and competency development in research processes.

In this sense, Alfaro-Mendives and Estrada-Cuzcano (2019) demonstrated the effectiveness of seedbeds in enhancing university students' research skills, reflected in the quality of works presented at scientific dissemination events. Similarly, Kamali Arslantas et al. (2020) noted that the creation of research groups encouraged collaboration among researchers and improved research skills and the writing abilities of participating students. Additionally, Turpo Gebera et al. (2020) observed that seedbeds were spaces focused on teaching research skills and competencies rather than generating new knowledge. Other studies, such as Flores et al. (2019), have linked research seedbeds with the propulsion of nations' scientific development, particularly highlighting the role of affiliated students as agents of social change, as indicated by Mollenhauer et al. (2020). Furthermore, the relevance of this strategy as a pedagogical innovation is underscored, as mentioned by Quevedo Arnaiz et al. (2020).

Based on this context, the existing literature on research seedbeds has extensively explored their roles in promoting research skills and in creating academic networks (Martínez-Daza & Guzmán, 2023). However, a notable deficiency is identified in the absence of concrete models to assess the productivity and effectiveness of research seedbeds. This gap is particularly concerning in a context where the efficiency and impact of such seedbeds are increasingly scrutinized by academic institutions and funders due to their costs. In this light, the current research not only acknowledges this gap but also aims to fill it by developing a conceptual model that evaluates and optimizes the productivity of research seedbeds.

By addressing this significant gap in the literature, the study not only adds a valuable theoretical resource to the field but also provides a crucial tool for academic program administrators, research seedbed leaders, and educational decision-makers. This model seeks to promote critical reflection and a strategic approach towards enhancing the effectiveness and impact of research seedbeds, a key element in today's academic landscape.

Literature Review

Formative Research and Research Seedbeds

HEIs have adopted formative research with the aim of familiarizing students with the knowledge and use of the methodological structure of research processes and procedures. According to Valero Ancco (2021), formative research is conceived as a teaching approach that positions the student as an active participant in the construction of their own learning. In this context, formative research offers an initial approach to employing research methods for solving disciplinary and social issues (Turpo Gebera et al., 2020). Formative research is also seen as a strategy for developing and enhancing skills in research practice and academic production (Cantú Munguía et al., 2019; Vitón-Castillo, 2021). Its key features include a teacher-student relationship where the teacher's role is as a guide, and the student is actively engaged in investigative tasks that extend beyond the traditional academic setting (García Bedoya et al., 2018; Orellana–Fonseca et al., 2019).

In this context, to successfully implement formative research, HEIs have introduced various strategies such as integrating subjects into the curriculum of professional programs, courses, internships or projects, as well as workshops and research seminars, and finally, research seedbeds. All these are aimed at developing skills and attitudes towards research. Table 1 defines some of the formative research strategies employed by HEIs.

Table 1. Formative Research Strategies

Research strategy	Definitions	Authors
Research Seminars	Students delve deeper into the characteristics and methodologies of in-depth research	García Bedoya et al. (2018); Orellana–Fonseca et al. (2019).
Workshops and Working Sessions	A practical and participatory activity that allows students to acquire new knowledge and investigative skills for application in their work or daily life	Hernández et al. (2021).
Degree Work: Projects such as research proposals, theses, monographs, etc.	That offer solutions to contextual problems and aim to demonstrate the student's ability to apply concepts learned during their professional training	Palacios-Moya et al. (2021).
Investigative Practice	The application of theoretical knowledge acquired in subjects to practical projects, enabling students to develop research skills and competencies	Quevedo Arnaiz et al. (2020).

Research seedbeds are conceived as groups that bring together students and teachers for the purpose of developing research projects and promoting learning, as well as the acquisition of investigative skills. These groups may include students from various levels, from basic education to postgraduate, depending on the educational institution and academic level (Martínez-Daza & Guzmán, 2023). Research seedbeds can be in-person, virtual, or blended, and their main goal is to promote formative research and the development of research competencies, such as collaborative learning and critical thinking skills (Adiansyah et al., 2017). Furthermore, research seedbeds offer students the opportunity to acquire skills such as formulating research projects relevant to the community and contributing to advances in the scientific and technological fields (Palacios-Moya et al., 2021).

Under the strategy of research seedbeds, students play an active role in shaping their profile as emerging researchers. They support teachers' research, provide guidance for thesis projects, manage innovative projects, and act as expert monitors in specific disciplinary topics, among other roles (Garza Puentes et al., 2021; Quintero-Corzo et al., 2008). Additionally, research seedbeds participate in platforms for disseminating their research outcomes and are evaluated by qualified researchers. This evaluation is conducted both qualitatively and quantitatively, assessing the internal coherence in the resolution of the research project (Jojoa, 2021). Thus, HEIs regard research seedbeds as a central element for academic productivity, contributing to the improvement of aspects such as quality, reputation, perceived value, and other criteria and evaluation indicators described in the following section.

Academic Productivity

Academic productivity is characterised as the capability of a HEI or research organisation to generate and disseminate scientific advancements through a series of projects (Maletta, 2016). This form of productivity acts as a criterion for quality assurance in HEIs (Mayer & Rathmann, 2018). Both HEIs and governments have established estimates of academic productivity based on measurable variables (research outputs) such as the number of articles published in SCOPUS and Web of Science (WOS), research outcome books, patents, participation in scientific events, software development, undergraduate works, theses, and others (Barragán Moreno & Guzmán Rincón, 2022; Maletta, 2016; Rørstad & Aksnes, 2015). Decisions regarding public and institutional policies of HEIs are influenced by these productivity estimations, with the goal of enhancing the efficiency of resources (e.g., personnel, software, publication fees, document translation, etc.) allocated to research projects (Rørstad & Aksnes, 2015).

In accordance with the above, academic productivity is considered a latent variable, as it is evaluated using multiple indicators. As García-Cepero explains, "(...) production is not the indicators themselves but rather a phenomenon underlying them" (2010, p.16). It is crucial to note that academic productivity is significantly shaped by the disciplinary field in which the research is conducted. Specific traditions or trends in certain areas often dictate preferences for particular types of research outputs. For instance, the engineering field tends to give precedence to patent development, whereas the social sciences focus more on producing bibliographic materials.

Considering these factors, HEIs and research seedbeds focus their efforts on creating outputs that enable them to establish a reputation within the academic community. Therefore, publications in journals indexed in SCOPUS or WOS are often held in higher esteem than conference proceedings due to elements such as the editorial process and peer-review evaluation (Escobar Córdoba et al., 2016; Mayer & Rathmann, 2018). It is important to recognize that most models developed to measure academic productivity primarily focus on HEIs, as indicated by Kozhakhmet et al. (2022), rather than on the strategies employed within them, like research seedbeds. Consequently, there is a need for reflection on the real impacts of such pedagogical strategies related to formative research.

Methodology

To realise the stipulated objective, a systematic review was executed utilising the adapted PRISMA 2020 method. This approach serves as a mixed-method analysis methodology, facilitating the amalgamation of both quantitative and qualitative data (Page et al., 2021). The process was segmented into two distinct stages. The initial stage was dedicated to the identification and retrieval of pertinent documents. Subsequently, the second stage entailed a thorough analysis, the synthesis of findings, and the formulation of a model. The protocol delineating the development of this methodology can be accessed under the registration number INPLASY202360083.

Stage One: Identification of Documents and Sample Formation

To pinpoint articles exerting a considerable influence on research seedbeds, document searches were carried out in the following academic databases: SCOPUS, ProQuest, JSTOR, SciELO, and ScienceDirect. These repositories house abstracts and citations of scientific documents, including articles, books, and conference proceedings. Such documents are held in high esteem by the academic community, as each one undergoes peer review and is published following stringent editorial standards (Schotten et al., 2017). Table 2 illustrates the distribution of research articles identified in each database consulted.

Table 2. Frequency of Records Found Per Consulted Database

Database consulted	Number of records found
SCOPUS	51
ProQuest	55
JSTOR	30
SciELO	45
ScienceDirect	30

In light of the aforementioned, Table 3 displays the equations utilised for determining the document search. No filters were applied in the information search, such as publication period, geographical area of the study, or journal quartile categorization, with the exception of SCOPUS. This approach was chosen to encompass the widest range of studies and to prevent the loss of information. In this study, the selection of literature was confined to works published in English and Spanish. This decision was influenced by the prevalence of these languages in the academic literature pertinent to the field of study and by the linguistic capabilities of the research team. Concerning the selection of search keywords, references were made to prior studies by Jiménez-García et al. (2019), Dagnino et al. (2020), Denford (2013), Reniz-García and Rojas-Millán (2018), Garzón Méndez and Estrada Villa (2019), Escorcia-Guzmán and Barros-Arrieta (2020), and Beltrán-Ríos et al. (2019).

Table 3. Frequency of Records Found Per Search Equation

Search Equation	Number of records found
TITLE-ABS-KEY (“quality indicators” AND “research group”)	11
TITLE-ABS-KEY (“quality indicators” AND “research seedbeds”)	11
TITLE-ABS-KEY (“research products measurement” AND students)	11
TITLE-ABS-KEY (“evaluation indicators” AND “scientific dissemination students”)	12
TITLE-ABS-KEY (“evaluation indicators” AND “generation of new knowledge students”)	62
TITLE-ABS-KEY (“evaluation indicators” AND “technological development and innovation students”)	51
TITLE-ABS-KEY (“evaluation indicators” AND “human resource training for STI students”)	53

The search yielded a total of 211 documents pertaining to the measurement or evaluation of research productivity conducted by students in research seedbeds. Out of the total identified documents, 59 duplicates were removed. An automated reference management tool (Zotero) was utilised to identify and eliminate these duplicates. The remaining 152 documents were subjected to a screening process based on their titles, abstracts, and keywords, leading to the exclusion of 99 documents. The exclusion criteria were as follows: 1) studies not specifically focused on research seedbeds; and, 2) research not linking academic productivity indicators. Ultimately, a total of 53 documents (comprising 50 articles, two book chapters as research outcomes, and one conference proceeding) were selected for content analysis. These documents were catalogued in a matrix encompassing data such as document type, year, authors, document title, journal name, citation quartile classification, and keywords. Figure 1 illustrates the flow diagram created using the PRISMA 2020 method.

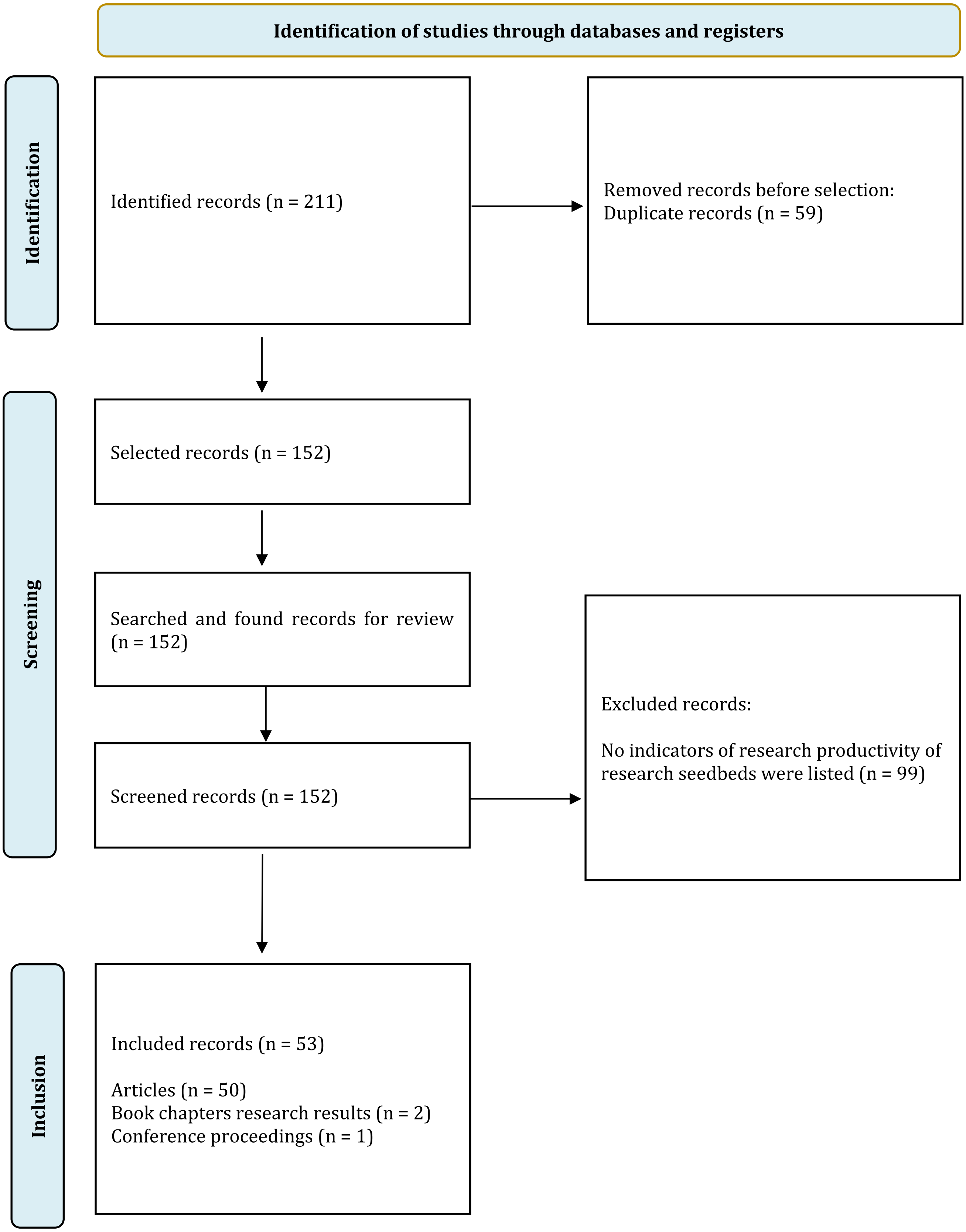

Figure 1. PRISMA 2020 method. Adapted from Page et al. (2021)

Stage Two: Analysis and Synthesis

This stage was divided into three phases. The first phase involved a bibliometric analysis of the included documents, using descriptive statistics in line with the framework established by Nightingale (2009). This analysis encompassed determining the country of origin of the research, the frequency of publication per journal, and the categorization of articles according to the SCOPUS ranking. In the second phase, categories were developed based on the document readings to classify the indicators used to evaluate the academic productivity of research seedbeds. In the final phase, an inductive approach was taken, and based on the results from phase two, a theoretical model was developed to understand academic productivity in research seedbeds as a formative research strategy within higher education institutions. This model was developed through four steps. The first step began with a thorough analysis of the data gathered in the systematic review. This analysis included the identification of patterns, themes, and recurring trends in the selected documents. The second step involved identifying productivity indicators and creating factors. These themes were not predefined but emerged directly from the data, adhering to the principles of the inductive approach. The third step was the development of the conceptual model. Each element of the model was informed and supported by observations derived from the review results, ensuring the model was firmly grounded in the empirical reality of the research seedbeds. Finally, the fourth step was the revision and refinement of the model through an iterative process, where the initial results were continually compared with the outcomes to ensure their validity and applicability.

Results

The review of the 53 research documents revealed 15 countries of origin, with Colombia being the most prominent, contributing 18 publications. This is noteworthy as Colombia's public educational policy incentivizes the formation of research seedbeds, considering it a quality condition for program offerings, renewal of program operating licenses, and achieving institutional accreditation. The ranking includes Spain with seven, Venezuela with six, Peru with four, and Cuba, Chile, and Costa Rica each with three publications. Ecuador contributed two, while Mexico, Portugal, the United Kingdom, Norway, the United States, Canada, and Jordan each had one publication related to the measurement of research seedbeds.

Regarding the distribution of publications in scientific journals, out of the 27 consulted journals, four studies were published in *Signos* Journal, four in the Journal of Social Sciences, three in *Innovar* Journal, and two in Negotium, *Bibliotecas Anales de Investigación*, Inter-American Journal of Library Science, *Propósitos y Representaciones* Journal, Medical Education Journal, Educare Electronic Journal, *Espacios* Journal, and Inventum Journal. The remaining 23 journals had only one publication on the topic. The other three documents consisted of two book chapters and one conference proceeding.

In terms of SCOPUS categorization, of the 50 research articles, only 37 were categorized as follows: 22% in quartile one, 16% in quartile two, 35% in quartile three, and 27% in quartile four. Considering the 53 selected documents, Table 4 presents the frequencies regarding the number of times each indicator appeared in the reviewed studies. The Appendix provides a summary of the selected studies.

Table 4. Indicators to Productivity

Indicator	Number of records found
Executed Projects	4
Publication of Research Documents	12
Quality of Research Products	1
Number of Citations	1
Technological Products	4
Certificates of Copyright	1
Participation in Scientific Events	5
Training of Research Personnel and Development of Content: Teachers and Tutors	9
Development of Specific Competencies in “Seedbed” Students	14
Development of Transversal Competencies in “Seedbed” Students	4
Attitude of Students Towards Research Exercises	1
Institutional and Research Environment	7
Technological Tools	1
Co-authorship	1
Total	66

The academic productivity of research seedbeds focused intensively on the number of projects executed by the student group (Flores et al., 2019; Meneses-Ortegón et al., 2020; Varas Yara et al., 2021) and the number of research documents published as articles, books, or book chapters (Arango Montes & Gómez-Giraldo, 2021; Céspedes Guevara & Zambrano Moreno, 2018; Flores et al., 2019; Flores-E & Ocampo-Rojas, 2021; Garzón Méndez & Estrada Villa, 2019; Jiménez-García et al., 2019; Ocaña Fernández et al., 2020; Prieto-Bustos & Tejedor-Estupiñán, 2020; Vitón-Castillo, 2021; Pineda Ospina, 2019; Turpo Gebera et al., 2020; Wanzer, 2021). Similarly, qualitative measurements were used to assess the quality of the products in terms of methodological coherence and cohesion, providing space for feedback to optimize the development of products and foster creativity and innovation (Alonso-Flores et al., 2020). The purpose of using these indicators is to promote the transfer of knowledge generated in the projects to the professional training processes and the appropriation of knowledge in the country's productive sector. Therefore, the number of citations by both internal and external authors was also measured to establish the degree of dissemination and academic visibility (Aksnes et al., 2019).

Furthermore, research seedbeds aimed to generate products related to innovation and technological development. Therefore, indicators such as the number of patented technological products or products in the process of patent application (Acosta et al., 2020; Cantú Munguía et al., 2019; Garzón Méndez & Estrada Villa, 2019; Romero Betancur & Parra Villamil, 2021) and the number of copyright certificate applications were taken into account (Zermeño-Guerrero et al., 2021). Additionally, evaluation indicators of productivity associated with the social appropriation of knowledge were observed, represented by the number of participations as speakers in scientific events (Alfaro-Mendives & Estrada-Cuzcano, 2019; Arango Montes & Gómez-Giraldo, 2021; Flores et al., 2019; Ocaña Fernández et al., 2020; Turpo Gebera et al., 2020).

Given the purpose of research seedbeds for training research personnel, indicators such as the number of undergraduate theses and dissertations developed, as well as the development of content to strengthen research skills, were highlighted (Arango Montes & Gómez-Giraldo, 2021; González Pérez et al., 2019; Guzmán Duque et al., 2019; Mollenhauer et al., 2020; Numa-Sanjuan & Márquez Delgado, 2019; Palacios-Moya et al., 2021; Pazmiño-Maji et al., 2019; Rojas Arenas et al., 2020; Turpo Gebera et al., 2020;).

Considering the impact of the training process on the productivity of research seedbeds, interest was found in evaluating the development of competencies related to knowledge management (Flores-E & Ocampo-Rojas, 2021; Ocaña Fernández et al., 2020; Vázquez González et al., 2021) and competencies linked to knowledge management, where the execution of works related to explicit knowledge is sought (Beltrán-Ríos et al., 2019; Correa-Díaz et al., 2019; Denford, 2013; Garnica Estrada & Franco Calderón, 2020; Escorcia-Guzmán & Barros-Arrieta, 2020; Enríquez, 2019; Garza Puentes et al., 2021; González Roys, 2022; Guzmán Duque et al., 2019; Mejía Correa et al., 2018; Quevedo Arnaiz et al., 2020; Al-Jedaiah, 2020; Ureña Villamizar et al., 2021).

Additionally, the measurement of cross-cutting competencies specifically related to oral and written communication as skills for knowledge transfer and dissemination was presented (Alfaro-Mendives & Estrada-Cuzcano, 2019; Canto-Farachala & Larrea, 2020; González Roys, 2022; Ureña Villamizar et al., 2021), as well as the achievement of goals, excellence, and quality associated with students' attitude to carry out research exercises (Al-Jedaiah, 2020) and collaborative work (Garzón Méndez & Estrada Villa, 2019).

It is important to mention other indicators of academic productivity developed by students belonging to research seedbeds, such as the institutional and research environment as contexts where the research culture is developed and resources are provided for project development within the group (Arango Montes & Gómez-Giraldo, 2021; Barrantes & Barboza-Arias, 2017; Barrios Hernández et al., 2017; Giraldo Marín et al., 2021; Molina-Molina et al., 2020; Mauricio Nupia & Martínez-Maestre, 2017; Reniz- García & Rojas-Millán, 2018), the evaluation of technological tools used for research, recognizing their impact on research quality (Dagnino et al., 2020), and the intellectual and relational aspects for research development. In this regard, institutions that perceive their intellectual capital as a potential source of knowledge generation facilitate relationships with other members, increasing the quality of academic production through co-authorship, transitioning from individual production to collective production, which can impact the student-teacher relationship (Rojas & Espejo, 2020).

Proposed Model

Based on the indicators identified in the first part of the results, it is evident that assessing the academic productivity of research seedbeds is complex, as formative and institutional aspects affect the production developed within the groups. With that in mind, a model for evaluating academic productivity is proposed, consisting of six constructs: research training, institutional capacities, bibliographic production, innovation and development, social appropriation of knowledge, and human resource development. Figure 2 presents the relationships between these constructs.

The first construct, research training, corresponds to the evaluation of the development and strengthening of students' research competencies throughout their participation in the research group. In this sense, the competencies included in the model are related to knowledge management and communication skills, which are positively related to the process of formative research (Arango Montes & Gómez-Giraldo, 2021; Barrantes & Barboza-Arias, 2017; Mauricio Nupia & Martínez-Maestre, 2017; Turpo Gebera et al., 2020). This construct positively influences bibliographic production, innovation and development, social appropriation of knowledge, and human resource development.

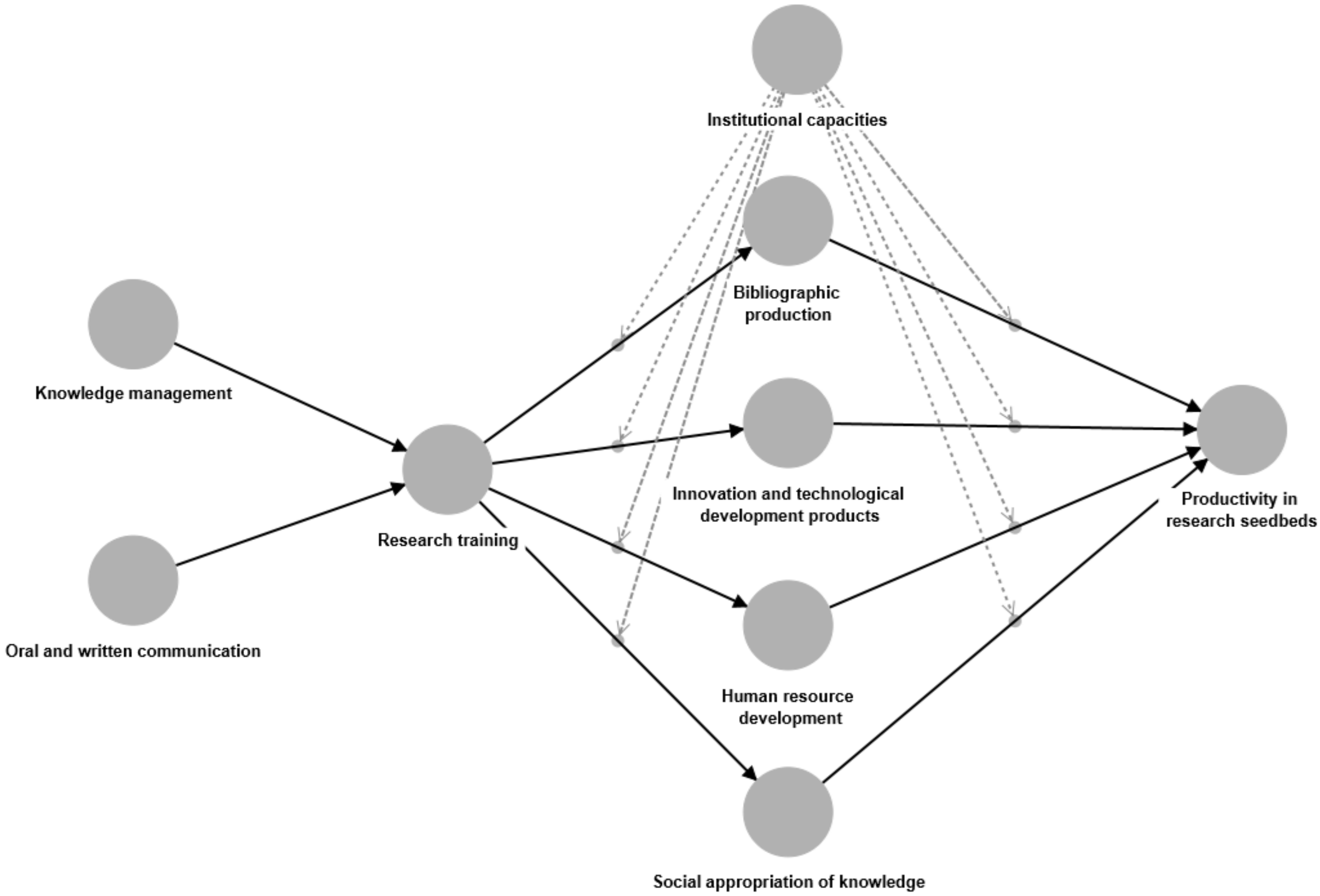

Figure 2. Proposed Model for Evaluating Academic Productivity of Research Seedbeds

The second construct, bibliographic production, involves the creation of intellectual material in written formats, which showcase the results of the group's research projects. Due to the academic nature of these documents, the peer review process, usually external, must be ensured. Indicators to evaluate this construct should be focused on the quantity of published and submitted articles, books, and book chapters resulting from research (Flores et al., 2019; Jiménez-García et al., 2019; Ocaña Fernández et al., 2020; Prieto-Bustos & Tejedor-Estupiñán, 2020).

The third construct pertains to innovation and technological development products, which involve the execution of ideas that create or improve a product. This construct is composed of the quantity of obtained or pending patents, as well as the number of copyright certificates obtained (Cantú Munguía et al., 2019; Romero Betancur & Parra Villamil, 2021; Zermeño-Guerrero et al., 2021).

The fourth construct, social appropriation of knowledge, encompasses all the actions carried out by the research group to disseminate the research results to diverse communities, without necessarily involving the creation of bibliographic material. Regarding the indicators reviewed in the literature, only the number of participations as speakers in scientific events was found (Alfaro-Mendives & Estrada-Cuzcano, 2019; Flores et al., 2019; Ocaña Fernández et al., 2020). However, the quantity of workshops conducted with communities and the production of audiovisual materials within research projects should also be included.

The fifth construct, human resource development, represents the final product developed by students in the research group. This construct should be measured by the quantity of projects executed by students, as well as those currently underway (Garnica Estrada & Franco Calderón, 2020; Meneses-Ortegón et al., 2020). Additionally, the quantity of undergraduate theses and dissertations developed within the group's activities should be considered.

The last construct, institutional capacities, should be understood as a moderator of the five previously described constructs, as it refers to both the institutional environment for research development and the human, technological, and financial resources available to higher education institutions. In terms of the institutional environment, the analysis should focus on the existence of research policies and processes. As for resources, the indicators should include the number.

Discussion

This study identified that the academic productivity of research seedbeds is intensely measured through the number of executed projects and published research documents, a finding that aligns with the observations of Flores et al. (2019) and Meneses-Ortegón et al. (2020). This quantitative approach highlights the importance of tangible outputs as key indicators of success. Additionally, it was evidenced that research seedbeds are effective in developing research skills in students, as reflected in the quality of works presented at scientific events. This observation aligns with the research of Alfaro-Mendives and Estrada-Cuzcano (2019), who also emphasized the correlation between participation in seedbeds and the enhancement of analytical and critical skills necessary for research.

Comparing the results with the study of Kamali Arslantas et al. (2020), it was observed that the creation of research seedbeds not only fosters collaboration and improves research skills but also enhances the scientific writing of students. This observation expands the understanding of how research seedbeds contribute to the academic and professional development of students, emphasizing the value of these groups as incubators of future researchers and academics. This dual function of seedbeds as spaces for learning and scientific production underscores their fundamental role in the academic ecosystem.

Furthermore, productivity in terms of innovation and technological development, reflected in the number of patented technological products or products in the patent application process (Cantú Munguía et al., 2019; Romero Betancur & Parra Villamil, 2021), highlights the relevance of seedbeds in the practical and commercial realm of knowledge. This focus on practical application and knowledge commercialization is an area that deserves more attention in future research, especially considering the growing interest in technology transfer and innovation as drivers of change and economic development.

In relation to the social appropriation of knowledge, the study's findings indicate that activities such as participation in scientific events (Alfaro-Mendives & Estrada-Cuzcano, 2019; Flores et al., 2019) are essential, aligning with Mollenhauer et al. (2020)'s vision of seedbed students as agents of social change. This dimension emphasizes the importance of research seedbeds not only as learning centers but also as platforms for active participation and dissemination of knowledge in broader contexts, thus contributing to societal well-being and advancement.

The study also highlighted the importance of institutional capabilities, corroborating research such as that of Molina-Molina et al. (2020) or Rojas and Espejo (2020), which emphasized the role of an adequate institutional environment and resources in facilitating research development. This finding underscores the need for strong institutional commitment and continuous support to ensure that research seedbeds can thrive and produce meaningful outcomes. Investment in resources, supportive policies, and a robust research culture are therefore crucial for the success of these seedbeds.

Finally, the model proposed in this study represents a significant advancement in the field of research on seedbeds, particularly in a scenario where there is a notable lack of studies that comprehensively address the evaluation of their academic productivity. Against this gap in the existing literature, the model stands out for its holistic and multifaceted approach, integrating aspects such as research training, bibliographic production, innovation and technological development, social appropriation of knowledge, and institutional capabilities. This approach allows not only a more complete and accurate evaluation of the effectiveness of research seedbeds but also identifies areas for improvement and development potential. Thus, the model not only fills a void in existing research but also provides Higher Education Institutions with a valuable tool for strategic decision-making, policy design, and resource allocation, thereby contributing to the advancement and continuous improvement in the training of future researchers.

Conclusion

The analysis conducted in this systematic review facilitated the creation of an evaluation model for the academic productivity of research seedbeds, based on the available evidence in the literature. It was noted that the indicators for evaluating research seedbeds foster greater scientific development involving students and enhance the quality of research products, significantly impacting the research mission.

This study provides a comprehensive assessment of the academic productivity of research seedbeds, through a model that integrates six key constructs. Each of these constructs reflects a crucial aspect of the dynamics and outcomes of research seedbeds, allowing for a deep understanding of their impact and effectiveness.

Firstly, the 'research training' construct reveals that the development and strengthening of research competencies in students are crucial for the success of the seedbeds. This aspect significantly influences bibliographic production and innovation, as well as the social appropriation of knowledge and human resource development. Secondly, the 'Bibliographic Production' construct emphasizes the importance of generating intellectual material. The quantity and quality of publications emerge as a direct reflection of the investigative and academic vigor of the seedbed.

The third construct, 'Innovation and Technological Development', highlights the generation of technological products and patents as a measure of the seedbeds' innovative and practical capacity. This aspect is vital in demonstrating the tangible contribution of seedbeds to technological advancement. The fourth construct, 'Social Appropriation of

Knowledge', illustrates the importance of disseminating research results beyond academic circles. Participation in scientific events and conducting workshops with the community are indicative of the seedbeds' extended impact.

Regarding 'Human Resource Development', it is observed that the projects carried out by students and the theses developed are key indicators of success in training new generations of researchers. Finally, the 'Institutional Capacities' construct acts as a moderator, underscoring that the institutional environment and resources are fundamental in enhancing the other constructs and, thereby, the overall productivity of the seedbed.

Beyond its relevance to the academic community, this proposed model for evaluating the productivity of research seedbeds also has significant implications for other key stakeholders, including policymakers, educational institutions, and potential funders. Policymakers are recommended to consider this model as a tool for developing more effective research-promotion strategies. This could include policies that encourage inter-institutional collaboration, support technological innovation, and foster social appropriation of knowledge. For educational institutions, the model offers a framework to evaluate and enhance their research seedbed programs. They could use it to identify areas of strength and improvement opportunities, as well as to establish strategic objectives aligned with their missions and values. Lastly, for potential funders, such as government organizations, NGOs, and the private sector, the model provides a means to assess the effectiveness and potential impact of the research projects they might fund. This could help guide their investments towards those projects that show greater promise in terms of bibliographic production, innovation, and social relevance.

Collectively, the adoption of this model by these key stakeholders could significantly improve the quality and impact of research conducted in seedbeds, while ensuring that their outcomes are better aligned with the needs and expectations of society at large.

Recommendations

Based on the findings of this study, several specific areas for future research are suggested. Firstly, it is recommended to empirically demonstrate the model proposed here, as it is necessary to confirm which constructs influence academic and scientific productivity. At the same time, a more in-depth analysis of the relationship between institutional capabilities and the productivity of research seedbeds should be developed. Future studies could explore how specific factors, such as financial support, research policies, and technological infrastructure, directly impact the effectiveness of the seedbeds.

Moreover, investigating the transfer of knowledge from seedbeds to industry and the productive sector would be beneficial. This approach would help to better understand how innovations and discoveries made in seedbeds can be practically applied, thus contributing to technological and economic development. Additionally, there is a need for longitudinal studies that examine the long-term impact of participation in research seedbeds on the professional and academic trajectories of students. This could offer valuable insights into the effectiveness of seedbeds in preparing qualified researchers and professionals.

Limitations

In terms of limitations, there are multiple aspects that need to be considered for the interpretation of the results and the model itself. While the databases selected for the systematic review are robust and cover a wide spectrum of relevant literature in education and academic research, it is recognized that excluding other important databases, such as Web of Science, can be seen as a limitation. These platforms might have offered access to additional interdisciplinary studies and varied perspectives, particularly in areas intersecting with medicine, health, and other sciences. The choice of databases was based on a focus on our specific field of study, but it is understood that expanding the sources of data could have further enriched the review. Bearing this in mind, it should be taken into account when interpreting the study's results and conclusions. Additionally, the consideration of these additional databases in future research is proposed to provide a more holistic and diverse understanding of the subject matter.

Moreover, the study only included literature in English and Spanish. This decision, though practical, implies a potential bias, as it does not consider significant works that might be published in other languages. This could result in a partial and possibly non-representative view of global research on research seedbeds. We acknowledge that this approach limits the breadth of our review and might miss valuable perspectives from countries and regions where other languages are spoken. Future research could address this limitation by including a broader range of languages, allowing for a more global and diverse understanding of the topic.

Additionally, while the model has been designed based on a systematic review, it is necessary to conduct empirical studies to evaluate its effectiveness and applicability in different institutional educational contexts. Empirical validation will strengthen the reliability and utility of the proposed model.

Authorship Contribution Statement

Martinez-Daza: Concept and design, data acquisition, data analysis/interpretation, drafting manuscript, technical or material support. Valencia: Concept and design, drafting the manuscript, critical revision of the manuscript, technical or material support. Guzmán: Concept and design, critical revision of the manuscript, technical or material support, supervision, final approval.

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Appendix

Table A1. Methodological Summary of the Studies

Authors	Objectives	Methodology
Acosta et al. (2020)	Analyze patent production in research groups to understand the effect of collaborations and the scientific training of these groups on patent production.	Empirical counting models. Sample of 1,120 research groups from the three main public research institutions in Spain.
Aksnes et al. (2019)	Provide an overview of some of the main issues at play, including citation theories and the interpretation and validity of citations as measures of performance.	Qualitative research, inductive logic and process. Exploration and description to generate theoretical perspectives.
Al-Jedaiah (2020).	Evaluate the effectiveness of knowledge management in higher education at private universities in Jordan.	Quantitative methodology. Technique: questionnaire. Participants: 101 teachers from private universities in the northern area of Jordan.
Alfaro-Mendives and Estrada-Cuzcano (2019).	Demonstrate the significant impact of the "Seedbeds in Classroom" program on developing research skills such as language mastery, basic cognitive operations management, observation, questioning, and social construction of knowledge.	Applied and qualitative research. Pre-experimental research design with a single group and pre-test and post-test. Participants: 32 students from the Research Methodology course.
Alonso-Flores et al. (2020).	Analyze the relationships between public institutional communication of research results and the academic impact and visibility of scientific publications.	Mixed approach, case study, data collection technique from databases, and Mann-Whitney test to compare citations.
Arango Montes and Gómez-Giraldo (2021).	Reflect on the experience of research seedbeds at the University of Antioquia Seccional Oriente (UdeA SO).	Qualitative research, documentary review, interviews with students, teachers, or administrative staff involved in the research seedbeds strategy.
Barrantes et al. (2017).	Describe the institutional processes that led to the establishment of a dialogue for generating Science, Technology, and Innovation (STI) indicators in Costa Rica, as well as their effects on public policy identification.	Qualitative, exploratory and inductive research approach. For case study analysis, the design construction incorporates elements of the analytical-inductive method of social research.
Barrios Hernández et al. (2017).	Characterize the dynamic innovation capacity in Higher Education Institutions (HEIs) through identifying conditions like process, product, and service innovation.	Empirical study. Delphi technique, with a panel of 50 experts, members of HEIs, government, and the productive sector.
Beltrán-Ríos et al. (2019).	Reflect on the importance of knowledge management in higher education institutions and how this innovative strategy can drive development and competitiveness.	Documentary-type methodology.
Canto-Farachala and Larrea (2020).	Explore connectivity in action research practice and participatory communication to improve how action researchers communicate their research findings.	Action Research. Case study on the communication of research results.
Cantú Munguía et al. (2019).	Concretize technological development and innovation projects that allow students to participate in basic and applied research, develop specific skills for autonomous thinking, explore technology transfer, and the potential commercialization of their projects.	Participatory action research. Three categories of analysis: research project design, development, and monitoring. The research is considered qualitative, exploratory, applied, synchronous, and experimental. Data collection involves non-participant observation, a field diary, electronic logs, photographic memories, interviews, and progress reports prepared by the research group members. Participants (67 in total), parents and teachers.

Table A1. Continued

Authors	Objectives	Methodology
Céspedes Guevara and Zambrano Moreno (2018).	Expose findings from the analysis and consultation of the research output of research groups and seedbeds of the Open and Distance University Vice-Rectory (VUAD) of the Universidad Santo Tomás 2010-2014.	Descriptive-interpretive. Quantitative and qualitative analysis of scientific research and research training processes, from the adaptation of indicators of the Colciencias Measurement Model of 2014.
Chavez Mauricio et al. (2021).	Analyze academic contributions to the development of formative assessment in students and teachers of regular basic and higher undergraduate education.	Systematic review with a descriptive level, using the PRISMA Declaration method. Analysis of sixteen scientific articles, 11 with a qualitative focus, 3 quantitative, and 2 mixed.
Correa-Díaz et al. (2019).	Evaluate how knowledge management facilitates solving educational problems in today's global economy.	Qualitative methodology. Documentary analysis of 74 documents of successful educational models and in the development of the research.
Dagnino et al. (2020).	Explore the benefits and limitations of using assistive technologies in educational research in the field of Technology Enhanced Learning.	Mixed methods, combining: systematic literature review, Delphi study, and case study. Uses online questionnaires, videoconferences, word processors, and TEL systems to collect primary information. Data management with tools like Microsoft Excel and MAXQDA. Participants: teachers, researchers, and experts in the TEL field.
Denford (2013),	Synthesize existing research on knowledge-based dynamic capabilities into a unique typology for administrative and academic use.	Theoretical methodology, based on an extensive review of existing literature on dynamic capabilities.
Pineda- Ospina (2019).	Identify the main trends in the production of scientific articles in innovation from the field of administrative sciences.	Bibliometrics. Sample of 680 articles.
Enríquez (2019).	Produce data that enrich and complete the understanding of the role of the university in knowledge management demanded by today's society.	Qualitative methodology. Interview technique. Participants: 5 experts in knowledge management, university, and external sector. Countries of origin: one Brazilian, one Spanish, one Mexican, and two Colombians.
Escorcia-Guzmán and Barros-Arrieta (2020).	Characterize knowledge management in Higher Education Institutions.	Bibliographic review with a qualitative design and the technique of analysis and interpretation of contents applied to scientific documents.
E. Flores et al. (2019).	Conduct a documentary review on the practice of research seedbeds in Latin America as drivers of scientific development in the region.	Documentary and descriptive research. Unit of analysis: 50 articles from the period 2005-2019, various national and international databases and bibliographic indexes. Search criteria: research seedbeds, groups or research networks, among others.
J. Flores and Ocampo (2021).	Evaluate scientific production and its influence on the quality of higher education in the country, as well as identify recommendations to improve students' scientific output.	Search for scientific production of deans in SciELO, Scopus, Science Citation Index (SCI), and Medline/PubMed. Recording article types, number of citations, and h-index up to May 2020.
Garnica Estrada and Franco Calderón (2020).	Analyze general processes (executive, academic, and administrative) that must coexist for innovation to become an organic element in the academic and functional processes of institutions.	Not applicable.

Table A1. Continued

Authors	Objectives	Methodology
Garza Puentes et al. (2021).	Develop a model of knowledge management and development for the university's research seedbeds.	Literature review on the topic, validation of variables through surveys of 33 researchers and leaders of research seedbeds, for the construction of a knowledge management and development model for the university's research seedbeds.
Garzón and Estrada (2020).	Present a lesson learned in a research group and explore knowledge management in the university context.	Methodology: Descriptive - case study. Describes a methodology of ten basic elements to document knowledge management and research in an institution.
Garzón-Puentes and Estrada Villa (2019).	Analyze key aspects of research from the perspective of knowledge management in the university context, particularly in higher education institutions.	Qualitative methodology, case study.
González Roys (2022).	Reflect on research and knowledge management, identify demands and needs, and promote the dissemination and commercialization of research products.	Prospective and interpretive study, theoretical and documentary.
González Pérez e t al. (2019).	Evaluate the quality of theses in the field of Information Sciences at the Central University "Marta Abreu" de Las Villas.	Bibliometrics. Sample of 74 theses. Technique: quantitative content analysis to evaluate the quality of the theses. Thirteen indicators were defined, referring to the methodologies used in the theses.
Guzmán Duque et al. (2019).	Determine students' perceptions of a HEI (Colombia) about the development of their scientific competencies in their educational processes, as mechanisms contributing to the labor world through knowledge management.	Quantitative and descriptive research. Participants: 92 undergraduate students from a higher education institution. Instrument: Hacoin, aimed at measuring the scientific competencies of the students.
Hernández et al. (2021).	Analyze Latin American scientific production in medical education with an emphasis on the need for training editors and reviewers of scientific journals from undergraduate studies.	Participants are undergraduate students.
Jiménez-García et al. (2019).	Present the state of research in Colombia through the review and analysis of the results of research groups and seedbeds.	Quantitative and descriptive research. Focuses on the collection and analysis of research in Colombia. Information obtained from 100 research groups registered on
Marín et al. (2021).	Apply the knowledge flow methodology in scientific research, using models of measurement, quality accreditation, and rankings, to improve institutional visibility and analyze the impact of external factors in this process.	Methodology: KoFI (Knowledge Flow Investigation). Technique: identification of sources, types of knowledge, evaluation of knowledge flow support tools: relationship between types and sources of knowledge and process activities.
Mejía-Correa et al. (2018).	Design a strategy for scientific knowledge management (research activities) for a public university.	Non-probabilistic "voluntary subjects" sampling. Technique: survey. Population: 239 research groups from a public university.
Meneses-Ortegón et al. (2020).	Facilitate the co-creation of educational material by high-ability students, involving teachers and parents.	Design-Based Research methodology used to design experiments and validate the knowledge representation module. Aim: to understand, execute, and evaluate the knowledge management system. Participants: 17 high-ability students (AACC), 12 parents, and 6 teachers in three experiences.

Table A1. Continued

Authors	Objectives	Methodology
Molina-Molina et al. (2020).	Design a measurement system capable of responding effectively and timely to the proliferation of science, technology, and innovation indicators.	Qualitative research and inductive process to identify activities within a system to measure the performance of scientific, technological, and innovation (STI) activities.
Mollenhauer et al. (2020).	Present the Polyhedron Value Proposition model, a methodological framework for formulating advanced design projects in the academic field.	Action Research. Participants: Students of the Applied Research to the Design Project course in the Advanced Design program (MADA). The model was applied on ten occasions, involving multiple student groups.
Numa-Sanjuan and Márquez (2019).	Offer a contribution to the discussion on "Seedbeds" as training spaces for novice researchers in the field of education.	Authors' reflections and discussions with undergraduate and postgraduate students aspiring to become researchers in education. Topics: Research as a systematic process that is learned and taught; Research Competencies for the training of novice researchers; Institutionalization of research seedbeds; Production of Scientific Articles and Integration of Research in the Curriculum.
Nupia et al. (2017).	Analyze the dialogue process that led to the Colombian Model for Measuring the Scientific Production of Research Groups (MCMPCGI).	Documentary and descriptive analysis.
Ocaña Fernández et al. (2020).	Determine the relationship between knowledge management and ICT in mechanical engineering students.	Positivist paradigm. Hypothetical deductive approach. Non-experimental quantitative study design. Data collection technique: survey with 23 closed questions related to the dimensions of respective variables. Questionnaires administered to 256 mechanical engineering students at various stages.
Orellana-Fonseca et al. (2019).	Acknowledge students' assessments of the research methodology training received during their undergraduate education.	Exploratory research involving 15 students. A questionnaire was applied followed by a discussion group to delve deeper into questionnaire responses and construct a collective narrative. Analysis was performed using a categorical reduction analysis model.
Palacios-Moya et al. (2021).	Analyze factors that encourage the intention to undertake research projects by university students.	Quantitative approach, non-experimental and exploratory-descriptive scope. Data collection technique: survey. Research participants: 141 university students from technological and professional level programs. The study population: university students in Medellin (Colombia) meeting certain inclusion and exclusion criteria. The sample used was non-probabilistic convenience sampling.
Prieto-Bustos and Tejedor-Estupiñán (2020).	Present a model for the production of new knowledge on the endogenous relationship between teaching activities and research activities.	Use of a theoretical model. Monte Carlo exercise based on the statistical characteristics of the scientific production records of the Catholic University of Colombia in economic journals from 2007 to 2010.
Quevedo Arnaiz et al. (2020).	Analyze research training at the University from the perspective of epistemology subjects.	Methodology: Quantitative-qualitative, hermeneutic approach for the analysis of results and data obtained. The authors relied on observation and compilation of experiences.
Reniz- García and Rojas-Millán (2018).	Examine the role of the "Living-Lab" concept in promoting innovation and entrepreneurship in a context characterized by technology and knowledge.	Documentary review.

Table A1. Continued

Authors	Objectives	Methodology
Rojas-Arenas et al. (2020).	Characterize the formative research process in the industrial engineering program of I.U Pascual Bravo.	Methodology with a descriptive scope and mixed approach. Instrument: survey. Participants: Members of the research seedbed from the last 4 semesters (31); Coordinators of research seedbeds (4); Teachers (25), and entrepreneurs (16).
Rojas and Espejo (2020).	Identify a technique to measure intellectual capital in a higher education institution, based on the efficiency evaluation of investment in scientific research relative to the components of intellectual capital.	Descriptive and exploratory approach with an ANCOVA regression model of panel data. Sample: 39 records or observations of expenditures and revenues from January 2003 to December 2015 related to scientific research.
Romero Betancur and Parra Villamil (2021).	Analyze the records of patent applications filed by Colombian holders under the Patent Cooperation Treaty (PCT) over the last 20 years, using data from the World Intellectual Property Organization's (WIPO) patent database.	Quantitative and descriptive approach. Technique: analysis of patent applications filed under the Patent Cooperation Treaty (PCT) where at least one of the holders is linked to Colombia. Information source: WIPO database, period from 2000 to 2019.
	Address four important questions in the field of undergraduate research.	Systematic Mapping of Literature and Descriptive and Predictive Analytics. The technique was a bibliographic review of 7310 Graduation Projects from the Escuela Superior Politécnica de Chimborazo. Participants: undergraduate students of the Escuela Superior Politécnica de Chimborazo who carried out Graduation Projects.
Turpo Gebera et al. (2020).	Explore the meanings and significances that teachers assign to the teaching of formative research in an education faculty in Peru.	Qualitative methodology. Interviews conducted with 20 teachers from a faculty of education at a public university in Peru. Textual analysis to elucidate subjective dialogues of the interviewed education faculty teachers.
Ureña Villamizar et al. (2021).	Analyze knowledge management, a cross-cutting axis in the processes of investigative training in universities 2.0, identifying the actors and constructing prospective scenarios.	Mixed approach of quantitative and descriptive analysis, using the MACTOR technique to analyze the play of actors in knowledge management. The data are primary and were collected from argumentative texts published in indexed journals. Independent and reliable sources.
Varas Yara et al. (2021).	Analyze the relationship between concepts, methodology, regulations, and the STI policy in Colombia.	Qualitative methodology. Interview technique. Descriptive and comparative analysis. Measurement of Scientific, Technological, and Innovation Activities (STI) based on concepts and classifications of international references and review of methodologies in the country.
Vázquez González et al. (2021).	Conduct the analysis of construct validity and reliability of the questionnaire "knowledge management for educational innovation in universities."	Classification of activities into categories such as Research and Experimental Development, Other STI, Support for Scientific and Technological Training and Capacity Building, Scientific and Technological Services, Administration and Other Support Activities, Innovation Activities.
Wanzer (2021).	Examine how evaluators and social science researchers define evaluation and, if so, how they distinguish evaluation from research.	Methodology: instrumental, development of tests, apparatus, design and study of the psychometric properties of the questionnaire. Procedure: study of construct validity and reliability of the "knowledge management for educational innovation in universities" questionnaire. Population sample: 250 higher education teachers.

Table A1. Continued

Authors	Objectives	Methodology
Zermeño-Guerrero et al. (2021).	Identify reasons for the protection of scientific works to maintain control, confidentiality, and exclusivity in research within knowledge management.	Mixed methodology. Technique: survey. Participants: 233 members of the American Evaluation Association (AEA) and 499 from the American Educational Research Association (AERA).