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Bibliometric Approach to Cooperative Learning Trends in Experimental Engineering Teaching

Amen Loor Hugo Enrique[1], Reyes Alejandro Andrea Cristina[2] And Coppiano Cortez Katherine Aracely[3]

[1] Universidad Estatal de Milagro, Milagro, Guayas (Ecuador), Ciudadela universitaria Km. 1.5 vía al Km. 26, hamenl@unemi.edu.ec

[2] Universidad Estatal de Milagro, Milagro, Guayas (Ecuador), Ciudadela universitaria Km. 1.5 vía al Km. 26, areyesa@unemi.edu.ec

[3] Universidad Estatal de Milagro, Milagro, Guayas (Ecuador), Ciudadela universitaria Km. 1.5 vía al Km. 26, kcoppianoc@unemi.edu.ec

Abstract

Cooperative learning constitutes an active pedagogical methodology that encourages interaction and collaborative work among students to achieve common academic goals. From a constructivist perspective, it has proven to be especially effective in addressing complex problems in different fields of science and education. In the current context, marked by the need to guarantee quality education, it is essential to identify current trends in this methodology in specific areas, such as experimental teaching in engineering, and to establish the pertinent adaptations to both the discipline and the methodology. In this sense, the present study poses the following research question: What are the current trends in cooperative learning applied to experimental teaching in engineering? To answer this question, bibliometrics was used as an analysis tool, processing a total of 483 articles obtained from the two main scientific databases: Scopus and Web of Science. Science , prioritizing those publications with the greatest impact. The analysis identified two main thematic clusters. The first brings together studies that demonstrate a greater use of cooperative learning in primary education, with an emphasis on developing basic competencies and initial experimental skills. The second cluster focuses on research on collaborative and cooperative learning applied to secondary and university education, where there is growing interest in its implementation in experimental engineering environments. These findings offer an updated overview of the most relevant lines of research, as well as opportunities to enhance this methodology in the field of engineering.

Keywords: collaborative learning, science areas, bibliometrics , bibliometrix , R language

Introduction

Science careers are characterized by the need for their students to acquire specific skills in the field of experimental practice [1] . This challenge involves multiple dimensions where

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knowledge from different fields such as biology, chemistry, engineering and social sciences are fused. For [2,3] , it requires innovative teaching techniques that achieve competencies in professionals, making them capable of facing complex problems. Within these techniques, collaborative learning has emerged as an effective pedagogical tactic, promoting both the management of content and the strengthening of interpersonal and problem-solving skills [1,4–6] . However, the effectiveness of this methodology in the field of experimental activities requires a meticulous and systematic study to establish its influence on the learning process.

Cooperative learning, based on constructivist theories, maintains that students actively build their own knowledge through social interaction. This view is consistent with the complexity of experimental activities, in which cooperation and communication are essential to solve real problems [7] . However, despite its potential, the application of cooperative learning in areas of science presents challenges such as the development of experimental practices that foster positive interdependence among students, in discoveries and understanding of scientific phenomena, in addition to the assessment of learning processes and outcomes in collaborative environments [4,8–10] .

The demand for introducing collaborative learning has grown in recent years, one of the routes that has been uncovered in the application of STEM/STEAM education (Science, Technology, Engineering and Mathematics + Art), due to the demands of the labor market and the need to train professionals capable of performing in multidisciplinary and collaborative contexts [1,1,2,10–13] . For science careers, which are distinguished by their applied and experimental nature, cooperative learning seems to be perfectly in tune with educational needs, enabling students to use theoretical knowledge in practical contexts through dynamic collaboration within the course or laboratory [14–17] .

An important point to consider is that cooperative learning is based on the active participation of students in small diverse groups, in which each member works together to achieve shared goals while enhancing their own learning and that of their peers [5,6,8] . Unlike conventional methods focused on one-way instruction, cooperative learning integrates principles of social constructivism, emphasizing the relevance of dialogue and co-creation [4,6,18] . Furthermore, current studies have indicated that this methodology not only enhances academic performance, but also promotes fundamental soft skills, such as communication, leadership, and team collaboration [19–21] .

Although the advantages mentioned above exist, there are still challenges in the application of cooperative learning in the experimental field. For example, several investigations have indicated that the effectiveness of this method may be conditioned by contextual elements, such as task design, group dynamics and students' prior skills [11,2,22]. In addition, there are gaps in the literature about how these variables affect learning outcomes in highly technical areas,

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such as experimental areas, which suggests the need for a rigorous analysis that collects and studies the available evidence [22–24] . In addition, quality education is one of the greatest concerns of our society; Sustainable Development Goal number 4 mentions that the deficiencies in knowledge in areas of science by 2030 exceed 300 million children and young people. [25] . Therefore, this work seeks to answer the question: What are the current trends in cooperative learning applied to the teaching of experimental sciences? For that, we carried out a bibliometric analysis to determine the trends in the field of cooperative learning and the teaching of experimental sciences, were extracted from the 2 main databases of scientific publications Scopus and Web Of Science a total of 483 articles see Table 1, of which the publications of the high quartile journals Q1 were addressed, for the processing we used our own code developed in Python version 3.30.0, R Language version 4.3.2 and the Bibliometrix package version 4.3.0

Table 1. Search equations

Type of documents	Articles	
Databases	**Scopus**	**Web Of Science**
Downloaded documents	128	355
Search equation	TITLE-ABS-KEY (" cooperative learning " AND science AND experimental) AND (LIMIT-TO (DOCTYPE , " ar "))	("cooperative learning " AND science AND experimental) All Fields And refined (Document types: Article)
Total documents	416	

Methodology

For the selection of documents we applied the PRISMA methodology [26] see Image 1. For the processing of the set of documents we developed the following workflow:

1. Extraction and integration of documents through the execution of own codes in Python version 3.30.0, which performed the integration and classification of the journal 's publication quartiles. from the Q1 to Q4 quartile. For this study, we will only consider documents from high- impact Q1 publications.
2. bibliometric measures through the bibliometrix 4.3.0 package
3. Analysis of cooperative methodology trends in experimental sciences through the use of co -occurrence networks

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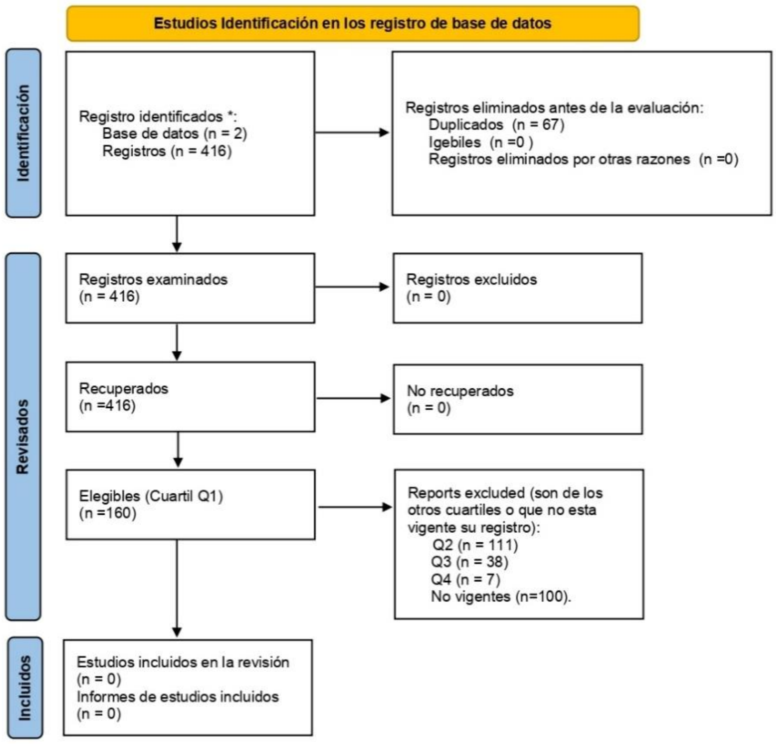
Imagen 1. Document selection flowchart



Results

bibliometric measures through the bibliometrix 4.3.0 package

In image 2, the main bibliometric measures corresponding to the 160 publications are shown, which are addressed in the period from 1993 to 2024, where its annual publication rate is 9.57%, being a very good production and indicating that the cooperative methodology in areas of science is of interest both for publication and reference since its citation rate is 16.58% of a total of 5,670 citations among 349 authors.

Imagen 2. bibliometric measures

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Analysis of cooperative methodology trends in experimental sciences through the use of co -occurrence networks

Based on the relationship between documents defined by the concentration of relationship with the conceptual terms defined by the authors. The Degree graph plot See Image 3, 2 clusters are defined that concentrate the largest number of conceptual terms defined by the authors, in Image 3 the network of relationships between the terms is graphed. Table 2 lists the terms associated with cooperative learning and the experimental sciences of the first cluster , these terms are related to studies carried out in elementary and primary education, within the relevant techniques we find problem-based and Jigsaw . In Table 3 the listed term corresponds to the application of 2 methodologies or a combination of them, these are collaborative and cooperative learning, these are applied at the secondary and university levels, in this context we find techniques such as: laboratory instructions and discovery learning.

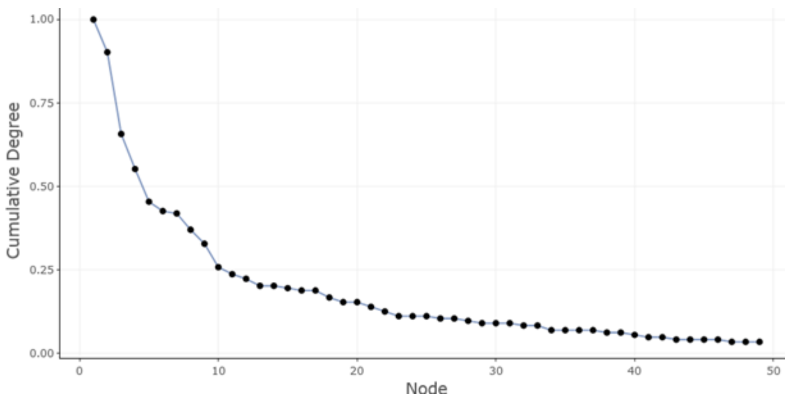

Imagen 3. Degree chart Plot

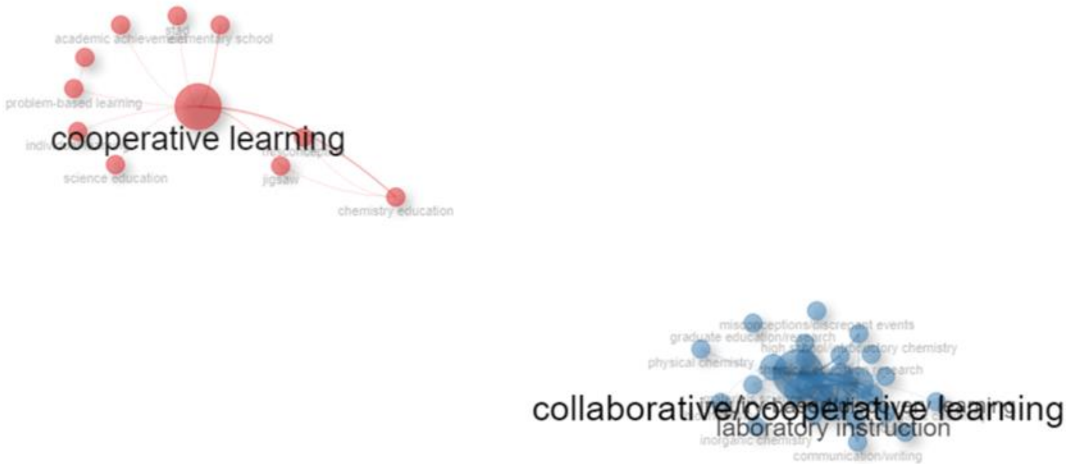

Imagen 4. Co-occurrence Network Chart

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Table 2. Trends in cooperative learning methodology and experimental sciences Cluster 1

Conceptual term	Description	Quotes
Cooperative Learning	Cooperative learning creates an inclusive learning environment that fosters student competencies such as collaboration, achieving common goals, positive interdependence, and individual responsibility. Among the results achieved are: they promote cognitive and emotional development, making them effective for use in experimental science subjects.	[1,4–6,9,9–12,14,18,27–37]
Problem-Based Learning (PBL)	Problem-based learning (PBL) is an active methodology. Students work in teams to solve specific , open-ended problems . This approach encourages the practical application of theoretical concepts, increasing motivation and deep learning.	[38–42]
Jigsaw	*jigsaw* model is a cooperative strategy that divides content. Students are grouped together, and each student is assigned the responsibility of learning and teaching their part to the group. Its results allow for improved conceptual understanding and group cohesion in educational contexts, especially in science.	
Misconception	The basis of the subject of experimental sciences are their solid theoretical concepts, in this process if there is a disconnection between the theoretical and the experimental practice, erroneous concepts can be formed	[43–48]
STAD (Student Teams-Achievement Divisions)	The STAD method is a cooperative learning methodology with individual and group assessment. This approach balances friendly competition between teams with the development of individual skills, highlighting the improvement of academic performance in science.	[49–51]

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Table 3. Trends in cooperative learning methodology and experimental sciences Cluster 2

Collaborative /Cooperative Learning	Collaborative and cooperative learning fosters interaction among students, promoting the joint construction of knowledge. It is also appropriate for experimental science subjects. It facilitates the resolution of complex problems and improves the retention of scientific concepts, two key pillars of quality training in these areas.	[2,8,20,21,32,35,37–39,52–56]
Laboratory Instruction	Laboratory instruction is essential for consolidating theoretical concepts through practical experience. This method develops experimental skills, fosters critical thinking, and promotes problem-solving in real-world contexts.	[40,57]
Inquiry-Based /Discovery Learning	Inquiry-based or discovery-based learning empowers students to explore phenomena and formulate hypotheses. In chemistry, this approach promotes scientific thinking and self-directed learning.	[27,49,58–60]
Problem Solving / Decision Making	Problem-solving and decision-making are key skills in experimental science education. These competencies are developed through practical tasks and case studies, improving students' analytical skills.	[6,11,13,29,36,61–66]
Hands-On Learning / Manipulatives	Hands-on learning through manipulatives allows students to interact with materials and tools, reinforcing abstract concepts through concrete experiences.	[6.67]

Conclusions and recommendations

The application of cooperative methodology in experimental sciences has a current application, two trends are discovered, cluster, the first cluster of cooperative learning, which is most evident in primary education studies. The second trend corresponds to the collaborative/cooperative learning cluster, which is reported with greater occurrence in secondary and university level studies. Of the techniques found, such as problem-based, Jigsaw

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, laboratory instruction, and discovery learning, they fit into experimental practices that are group-based and generate knowledge. It is recommended to extend this study through a meta-analysis and to understand how the application and effect of the techniques reported in this work are measured.

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